AN INTEGRATED PERFORMANCE MEASUREMENT SYSTEM FOR PRODUCT DEVELOPMENT

by

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The author retains responsibility for errors and omissions.

An Integrated Performance Measurement System for Product Development

By
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Submitted to the Alfred P. Sloan School of Management and the School of Engineering on May 04, 1992 in partial fulfillment of the requirements for the degree of Masters of Science in the Management of Technology

Abstract: In response to competitive pressures for faster development cycles, higher quality, and cost competitive products, major manufacturing firms such as Boeing, General Electric, Kodak, and Motorola have attempted to streamline their operations and adopt new development practices. Two processes most commonly adopted in industry are "Design Process Orientation" and Concurrent Engineering. Both processes constitute fundamental shifts in the day to day behavior of product development personnel and management strategies. As a result of these shifts, many conventional performance metrics and measurement systems have become obsolete. The current research will attempt to develop the basis of a performance measurement system for new product development. This basis will serve either as the foundation for a performance measurement system or as a template to evaluate an existing performance measurement system. Nominal Group techniques and the KJ Method will be identified as methodologies which support both the new product development process and the development of a performance measurement system.

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Introduction

This work focuses on the early phase of the New Product Development (NPD) Process, more specifically, concept formulation, definition, and system design. Given that the NPD Process is a significant factor in overall firm profitability (see Griffin & Hauser, 1991), the effective management of its early phases is critical to a successful and profitable outcome. However, the current literature fails to rigorously address how to manage the early phase of the NPD process, beyond providing some rules of thumb regarding size of the development team, representative membership from all disciplines (engineering, manufacturing, finance, marketing) and so on. Management of the development process is also complicated because the design process is both ambiguous and dynamic. The design process is ambiguous because multiple design strategies exist and identification of a best strategy is difficult. The design process is dynamic because design factors constantly shift in importance. Management of the early phases of NPD is further confounded by the frequent need to rely on increasing technical sophistication, which reinforces the use specialists who may conceptualize the "problem" from a narrow or fragmented viewpoint. This strong reliance on technical specialists can sometimes result in a process or product outcome which is less sensitive to the end customer/user.

Given that the NPD Process is typically ambiguous, dynamic, and includes a diverse cast of players, how does the organization manage and direct the individual towards successful product development? Some have argued that the goals of the organization and the individual can be aligned if promotion and salary systems are tied to the product's success. The flaws in that reasoning are two-fold. First, the success of a product is not established for a significant period of time (relative to the design decisions). Therefore, the uncertain nature of the product's success and the delay in the potential reward system reduce the efficacy of the reward. Second, in large products / organizations, the perceived impact of the individual on the success of the product may be very small relative to the overall number of contributors. Consequently, product success fails as a strong device in motivating or reinforcing individual behavior(s) in the early phases of the NPD process.

Monetary and promotion systems provide, at best, weak linkage between the organization's goals and those of the individual in the product development cycle. It is the premise of this work that clear articulation and communication of organizational goals, agreements between all concerned (functional) parties to these goals, and a measurement/management system to monitor the early process are the key ingredients to successful product development.

The approach used to address the problem of management of the early development process was three fold: First, the current product development literature was reviewed. Second, a number of companies who are involved in process mapping and concurrent engineering were interviewed. Third, the author became involved with the Center for Quality Management (CQM), a research group developing metrics for product development. A primary assumption in this approach is that product development is a multi-disciplined problem and thus requires an integrated strategy for managing the development process. The goal of management strategy is to optimize the "overall product development process" and thus optimize organizational performance. The constructs for creating a performance measurement system rest heavily in the area of organizational and group dynamics.

This three-fold approach, particularly the work with the CQM, revealed that all successful product development groups used mechanisms to communicate unambiguously about the task at hand. Further, these communication mechanisms were successful in overcoming functional barriers within the organization, through shared goals and an internal customer-supplier orientation. For example, data from one world-class electronics manufacturing firm strongly reinforced the importance of these communication mechanisms to the point where the firm's anticipated capabilities in manufacturing and anticipated needs in design were being communicated, established, and accepted as integrated goals for the respective groups.

Overview of the Research Strategy to Improve NPD Management

Chapter One will present a detailed argument for the need to improve NPD management. The chapter will identify shortcomings in the current literature, using Smith and Reinersten (1991) as a representative example, reinforce the argument that the early phase of NPD is critical to overall success, and provide evidence from behavioral psychology to support the development of a detailed measurement system.

Chapter Two will identify and define applicable group dynamic processes for integrating activities across functional boundaries. The literature in group dynamics reveals that all the investigated cases employed different aspects of Nominal Group Techniques (NGT) as integrative mechanisms between functional work groups in order to overcome language barriers (technical jargon) and individual biases based on personal experiences and bounded thinking. The chapter will also show how CAD/CAE systems may function as integrating mechanisms to aid communication in the NPD process, and identify the limitations of this approach. Chapter Two will then summarize the pertinent parts of the research with the Center for Quality Management, and the application of the KJ Method which support these observations on integrative strategies Finally, the chapter will present an example from a world class manufacturing firm. This example will demonstrate how this firm used integrative mechanisms from NGT and performance metrics to achieve goal congruence between marketing, design engineering, and manufacturing.

Chapter Three develops and presents the basis of a performance measurement system It combines integrative processes and the physical tasks necessary to support NPD, and integrates them into a performance measurement system. The chapter will define the dimensions of the measurement system and discuss the impact of the dimensions on NPD processes. The attributes of an effective management control system will be operationalized into a framework that permits a corporation to self-evaluate their performance measurement system. Finally, some key problems and potential solutions to implementing a performance management system for NPD will be discussed.

Chapter 1 - The Need for Improved NPD Process Management

This chapter will present a set of arguments identifying deficiencies in the current product development literature. The presentation will then make the case that the identification of the early phase of NPD represents the greatest point of leverage for success, and is therefore the appropriate area for management attention and control. Lastly, this chapter will briefly examine principles from behavioral psychology and present the argument for explicit identification of desired individual behaviors in the NPD process, in order to promote goal congruence between the individual and the organization.

Deficiencies in the Current Approach

A significant amount of the current literature on product development calls for improved productivity and cycle time reduction through successive incremental product improvements. Smith and Reinersten (1991) support this point of view and are representative of Clark (1991) and Clausing (1991). However, they go beyond much of the current literature in identifying that incremental product improvements in industrial products typically result in added customer costs (inventories, maintenance training, compatibility, etc.) and are likely to be poorly received. A second area where incremental product enhancements are poorly received is in commercial industries, where third party vendors provide complementary and competing assets. One example of a poorly received product enhancement is from the Personal Computer (PC) industry. One PC manufacturer, after rapidly introducing an enhanced model to the market, recognized the ability to improve the design and manufacturability of its Mouse. The redesign was implemented, tested for commonality against the older mouse, and introduced to the market as the same model. Immediately upon introduction to the market, customer complaints indicated that the mouse was inoperative. On investigation, it was found that the mice in question were from a favored third party vendor which manufactured its own clone of the mouse. The upgrade proved incompatible with vendor's version of the device. This incompatibility reflects the difficulty in removing tacit design details from a product. The PC manufacturer was forced to replace the improved product with older units to ensure a satisfied customer base.

The current lack of concurrent product and process development is highlighted in the work of Nevins and Whitney (1989), who contend that shorter new product cycles have reduced the amount of time available to correct design and production system errors. As a consequence of this, manufacturers are being denied the out-year production which constitute the bulk of the firm's profits. "To overcome time compression, manufacturers must be able to use lessons from previous design activities to aid the current one. That is, the learning may still take longer than th time available to design one new product or system, but it can be systematized." Stated differently, the production learning / experience curve is typically lost or suffers some inefficiency with the introduction of a new product. Nevins and Whitney contend that the learning curve can and should be transferred with little or no discontinuity between products. The authors use Japanese ship building, a high complexity/low volume industry, as an example of "group technology" which permits ships to be designed for efficient production with decreasing unit costs, even as designs change. The shipbuilding example illustrates that by systemized learning significant production efficiencies can be achieved, even with a relatively small production volume.

Other deficiencies in the current systems extend to financial and management accounting as reported by Kaplan (1987). In "Relevance Lost - The Rise and Fall of Management Accounting," Kaplan identifies the evolution of the existing financial and management accounting systems in the 1940s and 50's. His study identified that production and management control systems were superseded by financial based systems on the basis of convenience. The Securities and Exchange Commissions requirements for financial data and the lack of information processing technology caused American firms to discard the non-financial measurement systems. One flaw in the use of financial management tools, specifically discounted cash flows, in NPD is explained as follows:

"Traditional manufacturers use economic analysis to decide on a case by case basis whether replacing a person with a piece of machinery, such as a robot, will save money. The replacement calculation is based on the assumption that the candidate substitute is equivalent to the current method in every way except cost.

However each candidate is different in its ability to deliver quality, its reliability, its tolerance to noise and vibration, its speed of change-over, and so on. We must reflect these factors in the analysis. Failure rates, repair costs, and testing methods, for example, must be considered. These in turn are affected by product design...."

A second inadequacy in the existing financial & management accounting systems as they apply to NPD is the incongruity of product development cycles/time with quarterly and semiannual financial accounting. Product development cycle times in industrial electronics, for example, range from 18 to 36 months. During this phase of development, the cash flows are obviously negative. However, since financial measurements, reports, and subsequent stock fluctuations occur on a three month cycle (or less), the temptation exists to alter development outlays and pull in development milestones (which cannot be re-addressed later without some distress) for finance-based reasons. As demonstrated and discussed later in Figure-1 and Table-1, early concept and design decisions impact downstream costs after several years, illustrating a short sighted view resulting in longer term costs.

In summary, Smith and Reintersten's identification of the incompatibility of incremental product innovation in industrial markets, the PC example, Nevins and Whitney's systemized learning, the financial accounting deficiencies identified by Kaplan, and a growing body of literature (see also Utterback ICRMOT, 1991) support the position that a more robust understanding of the product development process is required in order to support "getting it right the first time" on larger scale projects. Again, the current literature presents an incomplete strategy for managing the early phases of NPD. The next section will present the results of three independent studies which evaluated the relative importance of the different stages of the development process and begin to address the need for more effective management strategies.

The Importance of the Development Phase

The early development phase of NPD is critical to successful completion because all subsequent design phases are simply refinements on the early concept. Therefore, only incremental improvements and gains can be achieved in the down stream phases. One study from General Electric is presented below in Table-1. The study, a worldwide benchmarking activity, evaluated the relative contribution of dollar costs by four variables: concept design, material, labor, and overhead costs associated with the development of the product and total life cycle costs. The four variables constitute standard management accounting control points. The data suggest that while concept design accounts for only 5% of the development cost of the product, concept design accounts for 70% of the total life cycle costs. More specifically, overhead rates, labor rates, and material costs reflect marginal impact points on life cycle costs. It is ironic that these latter measures typically receive a high degree of scrutiny in management review processes.

Table-1: GE Benchmarking
Effects of Product Design on Total Cost

	Development Cost	Committed Total Life Cycle Costs
Concept Design	5%	70%
Material	50%	20%
Labor	15%	5%
Overhead	30%	5%

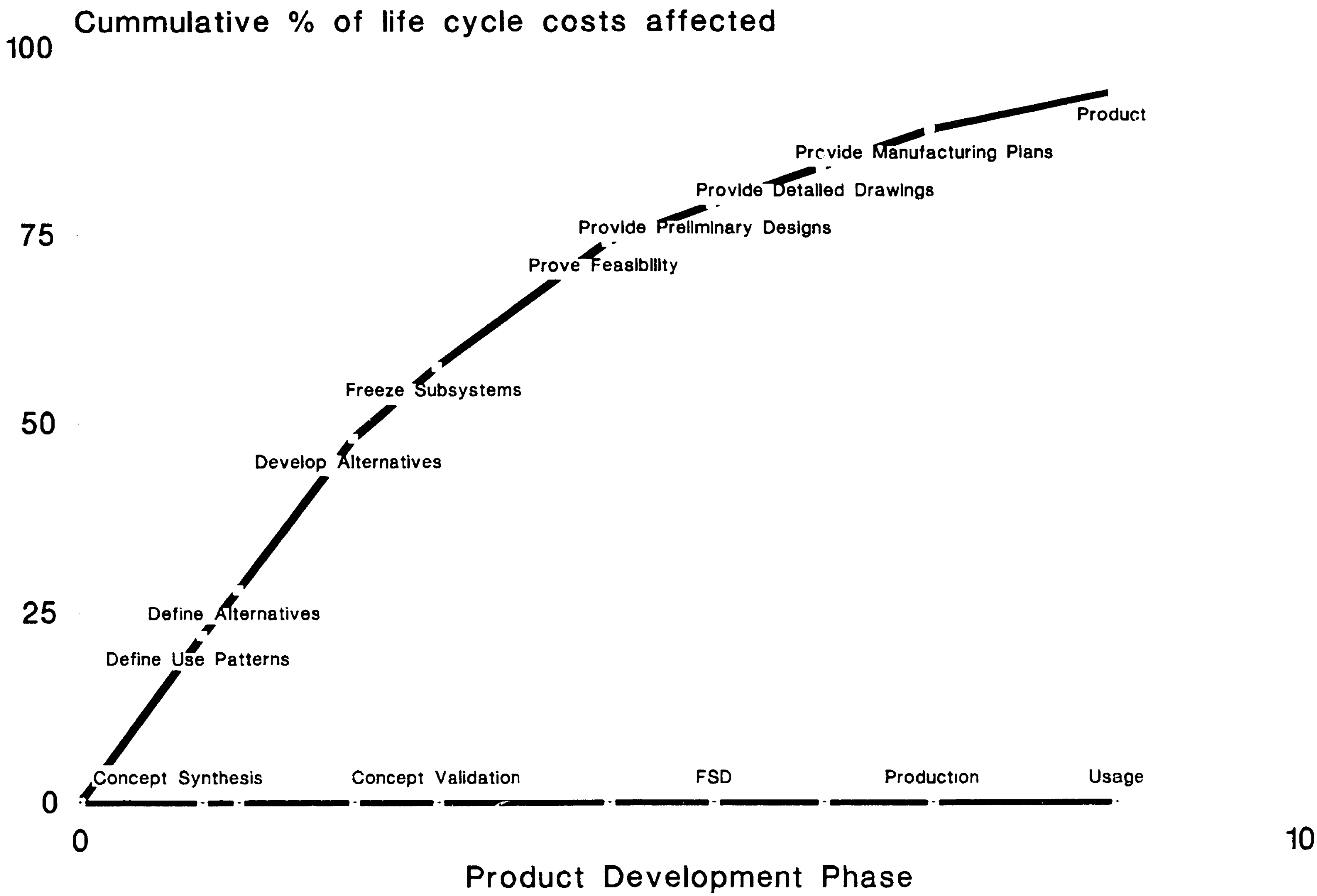
Adapted from:
GE Benchmarking Activities
Productivity Best Practices Workshop Aug 1991.

A second example demonstrating the importance of the early phase of NPD is a NASA Historical Cost Study (1991). The study identified that the probability of a cost overrun was significantly reduced if the Definition Investment (Concept Definition) phase of the project was increased to 25%. The statistical correlation between higher investment in concept definition and increased likelihood of staying within budget in this study was calculated at $R^2 = 0.933$. These data again reinforce the notion that the early concept definition and validation phases are critical to achieving business success, where business success is defined as developing the product within the allocated budget. Further, these data indicate that for the projects evaluated (typically $10 - 20M), confidence in the required budget was not achieved until 25% of the resources were expended.

A third example illustrating the importance of early NPD phases is a study by the National Research Council (NRC). The results of this study are presented in Figure-1. The data in Figure-1 indicate that efforts/activities expended from the concept synthesis phase through concept validation phase affect upwards of 60% of total life cycle costs. Again, the importance of these activities are frequently overlooked in management accounting reviews.

All three studies cited above independently support the conclusion that concept formulation, validation, and initial design phases typically occupy only 5 - 25% of product development costs, yet impact 60 - 80% of the product's total life cycle cost. It can therefore be concluded that the early design and development phase constitutes an area of significant leverage deserving more rigorous scrutiny and control.

NRC - LIFE CYCLE COST COMMITMENT vs DEVELOPMENT PHASE



Development Phase as a Key Leverage Point

Merchant's work (1982) highlights the importance of identifying and managing key leverage points in an organization:

> "The need for controls over any particular behavior or operation within an organization depends very simply on the impact of that area on overall organizational performance. Thus, more control should be exercised over a strategically important behavior rather than over a minor one, regardless of how easy it is to control eacn. For example, controlling the new product development activity is far more important in many companies than making sure that the production of existing products is accomplished as efficiently as possible. Consequently, more resources should be devoted to controlling the new product activity, even though it is a far more difficult area to control."

Merchant's point is not one regarding design versus production efficiency, but an argument for identifying the point of greatest leverage at the system level. Merchant's argument, together with the GE, NASA, and NRC data, make the case that management attention would be better focused and more cost effective in the early design phases than in the later design and production phases. Further, effective leveraging of the early phases requires the development and implementation of low level metrics to support the management control function.

If NPD requires additional management attention, the next issue to be explored becomes, "How does one 'leverage' or more effectively manage the NPD process?" Effective performance by individuals comprising NPD teams is a critical focal point for improved management control. Management's ability to influence and direct individuals behavior will be discussed next.

Influencing Individual Behavior

The arguments for explicitly identifying the desired individual behaviors in order to promote goal congruence between the individual and the organization will now be presented. The issue of individual behavior is addressed by Daniels' (1989) work in performance management, derived from B.F. Skinner's work in behavioral psychology. Daniels specifically identifies a three-phase model: the Antecedent-Behavior-Consequence (ABC) model. The premise is that specific behaviors are sustainable only if they are supported by anticipated consequences; that antecedents are effective only because they have been associated with past consequences. We are all familiar with the premise that people (and employees) will respond to what is done versus what is said. Of particular interest to the current work is the recognition that immediacy and certainty have stronger effects as behavioral reinforcers than do uncertain responses which are delayed in time. This is significant in that the completion or achievement of organizational goals are typically non-immediate and uncertain. They therefore constitute the weakest inducement for individuals. Therefore the identification of organizational goals is a necessary but insufficient condition to achieve alignment of the individual's goals to the organization's goals. Rather, the organization is required to take additional proactive steps in establishing the appropriate antecedents and consequences to support individual behaviors which align with the organization's goals. The identification and implementation of low level metrics applied to the NPD process function as the antecedent conditions necessary to guide individual behavior, which the organization can later recognize and reward.

Sterman's work (1989) in the field of Systems Dynamics provides one explanation for the inability of individuals to respond to delayed effects. Sterman identified that even under conditions where complete knowledge of the system is provided and no uncertainty regarding the value of variables exists, individuals still perform poorly. This finding contradicts more colloquial theories which contend that individuals are simply short sighted, since in Sterman's studies the individual theoretically could calculate the exact consequences of each action. The suboptimal performance of individuals in the studies can be explained as follows. The studies employed a simple simulation model with a single input variable and a nonlinear feedback loop. The model is representative of a production function with a single input and nonlinear feedback. Subjects were asked to match the output level of the model to another variable. In general, subjects were unable to match the outputs to the variable target without incurring "costly" overshoots. The suboptimal performance was explained because the solution to a single variable model with nonlinear feedback (a simple model) is a third-order nonlinear differential equation . a problem which does not lend itself to an intuitive solution.

In summary, the fields of Behavioral Psychology and Systems Dynamics both support the position that in a complex setting with temporal delays, feedback, and side effects, there is a high probability for local optimizations but suboptimal system performance. Stated differently, the individual is likely to lack goal congruence with the overall organization. Further, this supports the argument for the development of low level metrics to provide behavioral expectations to successfully manage or influence employee behavior.

Influencing Organizational Behavior

Our discussion turns to the field of organizational behavior and change. Again, the focus is on the individual and how strongly he/she is influenced by their organizational environment. In many organizations concurrent engineering, process orientations, and cycle time reduction programs are new and constitute attempted changes in organizational norms. How are these changing expectations and organizational goals being communicated to individuals? These issues are addressed by reviewing the work of Nadler (1988,1990), Schein (1989), and Tushman (1988,1990). All three authors refer to the change process in terms of an initial state, a managed transition state, and a final future state. Their approach expands the view of single antecedents and consequences affecting individual behavior (Daniels) and introduces multidimensional organizational influences on the individual to achieve desired organizational change. Of particular significance is that organization change goals can be translated into desired behaviors expressed at the level of the individual employee.

Receptiveness to change, e.g. introduction of concurrent engineering, can be a potential stumbling block as an organization attempts to integrate new tools or processes. Schein identified the three (3) prescriptive agents necessary to overcome the initial inertia to change:

[1] Disconfirmation of the current state. The reasons for the dissatisfaction with the current state must be identified and communicated. This dissatisfaction may be the result of a more efficient external competitor or a series of internal goals. Information (management accounting for example) can therefore be used to generate "pain" which causes the organization to recognize that it must change its current practices.

[2] Guilt and anxiety aroused because goals and/or standards will not be met. The key to this stage is that the change targets, i.e. the employees, view the proposed changes as tangible and related to actions they can take. This view is consistent with both Nadler and Beer, who identify the need to "build participation" in the change.

[3] Psychological Safety. The degree of disconfirmation and guilt generated in the first two items must not exceed a threshold where the change targets become defensive and political. The factors associated with the change process suggest that change must be motivated through the communication of information and intention. That having established this tension and uncertainty, the change process must then be directed toward a clearly articulated and tangible end state.

Schein's third point regarding psychological safety is particularly relevant to the need to develop low level metrics applied to early phases in the NPD process. Schein's point is that the employees must feel that they can individually impact the organization in a measurable way. Since firms or departments are often comprised of hundred's of employees, individuals often feel that their contribution is of little value. Applying this psychological concept more directly to the NPD process suggests that cross-functional NPD teams need to understand that their efforts impact both development and implementation processes, e.g. short and long term effects, in specific and measurable ways. The use of integrated metrics which map into business goals is one mechanism to achieve the necessary communication, intent, and motivation with NPD teams.

This work has developed the argument regarding the need for metrics in managing the early phases of the NPD process, based on Merchant's call for the identification and control of key leverage points, and the behavioral need to have expectations clearly articulated. Nadler and Schein further reinforce the argument with their focus on effectively managing the three phases within any change process. Thus, the introduction of new NPD processes into a workplace needs to include the articulation of desired individual behavior as these change processes are occurring. The discussion will now turn to the specific issues of product development cycles and productivity improvement.

Chapter 2 - Integrative Mechanisms in the NPD Process

The product development process is dynamic and ambiguous, and the current literature fails to provide a roadmap for navigating it. This author contends that the role of management in effectively guiding the NPD process is to design and articulate a navigational system which is both clear and motivating to the individual. There are four key concepts in management's role. 1) to appropriately blend creativity and structure in the development process. 2) to maintain the development group's focus on the end product. 3) to facilitate communication between functional groups to ensure goal congruence. 4) to mediate disagreements between functions through facilitation. The results of the literature search, company interviews, and pro-active research with the Center for Quality Management (CQM) revealed that all the investigated groups employed some aspects of Nominal Group Technique (NGT) in order to implement these four concepts. The application of NGT strategies helped overcome the functional organizational boundaries, produced an unambiguous vocabulary to support the product design process, and exploited the benefits of group solutions and individual creativity concurrently. Therefore, we will use NGT as the primary model for developing an analog to manage the early product development process.

First, this chapter will review the need for integrative mechanisms to support concurrent product and process design, and identify preconditions to facilitate concurrency. NGT processes will then be described in some detail, to illustrate how these processes can be utilized as integrative mechanisms to develop and articulate common goals and objectives across cross-functional NPD teams. The chapter will then review Robertson and Allen's (1991) and Murotake and Allen's (1990) work on Computer Aided Design and Computer Aided Manufacturing (CAD/CAM) and identify the parallels with NGT. Third, we will review the methodology and product being generated by the CQM, again drawing parallels to NGT. Lastly, we will briefly review the product development methodology being conducted at a world class manufacturing organization. The example will demonstrate how NGT has been adapted to establish shared goals between the organization and the individuals.

The Need for Integrative Mechanisms

The need to adopt concurrent product and process design strategies in the NPD process is critical to a successful outcome. Integrative mechanisms are especially necessary between design functions and manufacturing to achieve the seamless introduction of new products down the manufacturing learning curve. Nevins and Whitney (1989) identify five key elements to achieve this integration. They specifically caution, through anecdotal detail, that "design rules" such as minimizing part count or using the most inexpensive part may not be the most effective choice, when the decision is made independent of inputs from manufacturing. The key elements to integrate product and process design are:

1 Careful analysis and understanding of fabrication and assembly process to permit their operation with consistency and quality.
2 Strategic product design, conceived to support a specific strategy for making and selling the product.
3 Rationalized manufacturing system design coordinated with product design.
4 Economic analysis of design and manufacturing alternatives to permit rational choices.
5 Product and system design that are characterized by robustness and structure.

Three necessary preconditions to achieving concurrent product and process design can be generalized from the five points above: 1) The manufacturing process should be stable, well characterized, and information should be widely understood by the organization (an example of this will be provided from the Telecommunications Industry); 2) the product strategy must be integrated with all business functions and reflect external customer needs, 3) the product development group needs to apply systems thinking in the decision process to achieve common goals.

Nevins and Whitney are helpful in identifying the specific "tasks" or mechanisms which function as integrative mechanisms between design and manufacturing. But what process(es) are available to develop and articulate those tasks? More specifically, how is manufacturing information disseminated? How is product strategy integrated into all business functions? How is "systems thinking" applied?

NGT provides the framework to open communication and planning such that integrative mechanisms can be developed across functional groups involved in NPD processes. NGT will be fully described in the next section.

Nominal Group Technique

NGT was developed by Andre L. Delbecq and H. Van de Ven in 1968. The process was designed to take advantage of the benefits of group evaluation process without the accompanying inhibition on individual creativity. To quote Delbecq (1975) directly:

> "Researchers have concluded that when the group task is to generate information on a problem, interacting groups inhibit creative thinking. (This is not a generic statement of superiority. For other purposes, such as attitude change, team building, and consensus generation, interacting groups are superior. The emphasis here is on idea generation.) Individual inhibitions and premature evaluation in interacting groups result in a decrease in quality of group ideas in terms of creativity, originality, and practicality. ... A focus effect is also characteristic of interacting groups, that is, the group tends to pursue a single train of thought for long periods."

NGT is a structured group process designed to exploit different processes for idea generation and evaluation. The process begins with the identification of goals and intent. The participants silently generate ideas and write them down on 3 x 5 inch note cards. The output of the group is nominally 18 to 25 propositional statements. The silent writing achieves five results:

1) Individual creativity is enhanced by preventing group conforming behaviors.

2) Social pressure is generated by the silence and observation of others working.

3) Balanced participation is achieved through an equal number of ideas being generated by every individual.

4) A greater breadth of ideas is achieved by virtue of a larger group of individuals working on the problem.

5) Problem focus is maintained by virtue of the anticipated review.

The second step in the process is a round robin collection of each idea. The leader requests one idea from one individual at a time. The idea is verbally repeated and placed on the flip chart. This structured process achieves seven results:

1) Balanced participation is maintained.

2) Problem mindedness is increased.

3) Ideas are depersonalized. Separation of the person and idea is accomplished through two mechanisms: a) Written statements are more objective and less personal than verbal statements, b) As the list lengthens, it becomes increasingly difficult to associate one idea with one individual. The list becomes a depersonalized group product.

4) An increased number of ideas can be dealt with. (The rule of thumb being used is that individuals retain 40% of what is heard but 70% of what is seen and heard.)

5) Tolerance of conflicting ideas is increased.

6) Ideas verbally stated by one individual may spontaneously generate a new idea in another individual.

7) Development of a written record and guide is achieved.

The third step in the process is Structured Serial Clarification. The leader proceeds in a round robin to request clarification of each individual's listed idea. This structured feedback process achieves four objectives:

1) It avoids spending an undue amount of time on any one or group/subset of ideas.

2) It provides an opportunity for clarification and elimination of misunderstandings. Ideally the propositional phrase is presented in a report-like manner, i.e. who, what, where, when, and how. This report style presentation minimizes misunderstandings due to vagaries in language usage.

3) It provides an opportunity to provide supporting logic and voice disagreements. The limited time span assists in minimizing influence based on verbal prominence or status.

4) It records differences of opinion without undue argumentation. The purpose is to air and record differences, not resolve them.

The fourth and final step is silent voting on preferences. In this process each individual anonymously ranks the top 5 to 9 items on the list (the exact number is selected based on the length of the list). The rankings are collected and pooled via an arithmetic mean. This process has three objectives:

1) The silent voting process is designed to minimize social pressures and political maneuvering due to status, personality, and group conformity.

2) The rank ordering process is designed to provide greater fidelity when the values are aggregated among members.

3) Group voting tends to result in more robust decision making. Many examples of this exist, such as the Canadian Arctic Survival Test. These tests continuously demonstrate that group decision making is generally more robust than individual decision making.

Earlier it was noted that two of four key concepts in management's role in guiding and structuring the NPD process was to appropriately blend creativity and structure through facilitation and leadership, and mediate disagreements between functions. These management objectives can be accomplished when NGT processes such as silent idea generation, depersonalization of ideas, etc., are applied by NPD Teams. The next segment of this work will summarize relevant literature and specific companies to highlight processes which achieve the objectives of unambiguous vocabulary and the blending of individual creativity with group judgement.

Computer Aided Design (CAD) System Use as a Communication Tool

In a series of studies Robertson and Allen (1990, 1991) examined the use of CAD systems and their wide range of successes and failures at different firms. Their studies focused on the effective application of CAD to improving overall product development effectiveness. They highlight that the application of CAD does not always produce ostensible gains which are translated into product development effectiveness. Robertson and Allen concluded that organizations, independent of success, view CAD systems as one of three types of capital:

> "**CAD systems as physical capital:** Some see CAD systems as electronic drafting boards and use them as they would a drafting board. At this level they are merely automating the drafting process.
>
> **CAD systems as supporting human capital:** CAD can be used to extend the capabilities of the designer in at least two ways. Three-dimensional CAD is a significantly different medium of design than are two-dimensional CAD systems or drafting boards. Design in two dimensions can lead to what some term "wire-frame fog:" confusion caused by too many lines on a drawing. Three-dimensional designs can be rotated and surfaces can be shaded or lines removed to improve visualization of the design. The result is a fundamentally different process requiring greater skill and concentration (Majchrzak and Salzman, 1989), but with a potential for greater creativity.
>
> The analysis capabilities that are often available in CAD systems also support human capital. Commercially available packages allow the evaluation of a design's thermal and mechanical stress characteristics, vibration characteristics, or kinematic behavior. Such packages can improve the engineer's understanding of the capabilities and limitations of a particular design.
>
> **CAD systems as enabling improvements in social capital:** CAD systems can be used to improve the communication of design information within and between companies. CAD Systems can act as a medium of communication in two ways: through CAD file transfer or as an aid to conversations. CAD file transfer can be used by an engineer to access other engineer's designs to understand the nature of other designs or to check the fit between parts. This access lets the engineer quickly get answers to design-related questions without having to track down or interrupt other engineers.
>
> CAD systems can also be a valuable aid to conversations, as they provide a flexible and unambiguous design representation. Conversations in front of a CAD terminal often differ significantly and have different effects on the design than do conversations in front of white-board or engineering drawing. The CAD representation of the design can be altered during the conversation, details can be added or removed, and the appearance of the design can be changed to focus on specific design details. Given this common reference, fewer misunderstandings occur and conversations are more effective."

Robertson and Allen's research supported the conclusion that organizations which view CAD systems as enabling improvements in social capital demonstrated improved overall product development effectiveness.

A less rigorous example of CAD system use in concurrent engineering was derived from a videotape from the Convair Division of General Dynamics which describes recent successes obtained through the use of concurrent engineering. The tape depicts the interaction between various engineering functions involved in the development of an advanced cruise missile. The participating engineering functions included structural analysis, human factors, maintenance, and flight dynamics. The primary communication mechanism between these functions was a Mechanical Engineering CAD system. Proposed designs were file transferred from one engineering group to another. Analysis was conducted and the results returned with commentary. The commentaries in this case identified structure over-designs. By using this information early on, a redesigned bulkhead was generated with a significant weight savings. Additional commentary identified a maintenance issue which required the removal of another bulkhead in order to service one of the electronics packages. This removal process would have required two men and a special support dolly. Use of the CAD system helped to incorporate a hinged supporting member, thus eliminating the need for the special dolly and one of the two support personnel. The General Dynamics example is illustrative of the use of a CAD system as a communications enabler which supported information flow and problem identification by overcoming distance and language barriers which typically arise between functional engineering disciplines.

Use of CAD systems as a communication tool is consistent with NGT processes which support cross-functional group interaction and communications. The parallel to NGT processes in this example can be conceptualized from four perspectives: The CAD tool supported an unambiguous vocabulary for communication through use of a physical model. Feedback on the design was depersonalized and provided early in the process before it became finalized in the designer's mind, hence preventing it from becoming a source of argumentation. Similar to NGT, the use of CAD systems supports non-argumentative feedback because communication can be directed towards the written/drawn object. Group judgement is facilitated by virtue of the communication and interactive analysis capability of the CAD tool, which is also an objective of NGT. Lastly, individual creativity is enhanced in CAD system application in that an individual may work alone as well as communicate easily across his/her group.

Creativity in NPD processes is a critical issue and worth noting here. The enhancement of creativity with CAD systems is not a panacea. Murotake (1990) studied conditions where the use of Computer Aided Engineering (CAE) tools were negatively correlated to productivity. Typically, CAE tools are "single-function" tools aimed at leveraging personal productivity. These tools evolve to increasing sophistication through adherence to a single structured design methodology. Murotake found that engineers were more likely to use a CAE tool if it were sophisticated ($r = 0.55$). In addition, productivity and creativity increased with highly structured development tasks ($r = +0.35$). However, for <u>unstructured</u> tasks, which typify the early phases of NPD, use of CAE tools is negatively correlated ($r = -0.33$) with innovative engineering work. One explanation for this negative correlation is that sophisticated single function tools tend to promote "cloning" of tasks. Cloning of tasks and designs may be inappropriate for the task at hand where greater "bandwidth" of thought is desired. We therefore conclude that CAD/CAM and CAE tools are supportive mechanisms, once the product development process is in the subsystem design phase. The current tools may not support the very earliest phases of NPD.

Use of CAD/CAE systems provide strategies to enhance NPD functions in ways that are highly similar to NGT processes. These similarities are: use of written and drawn data; mixture of individual and group work, and a process which establishes an unambiguous vocabulary. In the next section another integrative methodology, the KJ Method, will be reviewed as it was applied at the CQM in the development of metrics for product development.

The Center for Quality Management (CQM): Research Committee on Metrics.

The CQM is a joint industry and university association modeled after the Japanese Joint Union of Scientists and Engineers (JUSE). Its expressed purpose is to facilitate cross-company and university learning in the field of management science. One of the projects the CQM undertook is a research project to develop and evaluate a series of metrics for product development. The metrics were designed to monitor an ongoing program and to quantitatively evaluate one product development process against another. The metrics were developed using a structured methodology called the KJ Method. Each step in the KJ method is outlined in Table-2. Validation of the process models and metrics occurred through reviews and experimentation in member companies. The method was developed to its current form by Jiro Kawakita of the Kawakita Research Institute and is currently being applied by Prof. Shoji Shiba of the University of Tsukuba in Japan.

Table-2: Expanded KJ Method
Metric Development Methodology

Procedure	Key Characteristic
1. Research Team Selection	Cross functional representation
2. Research	Readings/interviews
3. Synthesis of a conceptual model	Best Practices Product Development Process.
4. Brainstorming	
5. Validation	Alpha testing, potential users evaluate
6. Develop a tree diagram Bottom Up Top Down	To develop and evaluate solutions to explicit problems
7. Labeling and Semantic Scrubbing Word (denotation/connotation) Level of Abstraction	To develop an unambiguous vocabulary
8. Tree Diagram evaluation and ranking Link bottom leaf to nodes above	Ranking of metrics based on effectiveness and feasibility. How important is it? How easily can you measure it?
9. Develop Operational Definitions (OPDEFs) for selected variables	Document the measurement procedure
10. Field Test	Validation of the solutions in controlled experiments.

CQM Experimental Methodology

A cross functional and industry team was selected from BBN, BOSE, DEC, GE, MIT, Polaroid, and the US Navy. In order to develop and evaluate a series of metrics for product development, the research team represented various engineering disciplines, manufacturing, technical training, and marketing functions. Consistent with the Expanded KJ method (Table-2), cross functional representation was an explicit goal in order to identify the earliest point of useful contribution of all functional disciplines into the NPD Process. Information from the literature searches and field interview data were reported back to the research group on a continual basis, the second step in the KJ methodology. The next step included the generation of The Generic Product Development Process (GPDP) map, presented in Figure-2.

The GPDP map identified the "loop back points", which reflect financial commitment points and "opportunities" to reevaluate the current product trajectory. Therefore these points constitute natural "tollgates" and were identified as the logical points to implement benchmarks. For example, referring to Figure-2, the point between Customer Requirement and Concept Analysis was a natural point to evaluate how well customer requirements matched market needs.

A tree diagram approach was then employed to identify appropriate benchmarks. Returning to Figure-2 and the point between Customer Requirement and Concept Analysis, we identify the problem of interest as, "Do the identified customer requirements support market needs?" This problem statement was written down on a large sheet of paper where all participants could view it. It should be noted that the first step in the tree diagram process is very similar to the NGT process in which a defined a problem statement is defined, and written down in full view of all participants in order to maintain group focus.

GENERIC PRODUCT DEVELOPMENT PROCESS

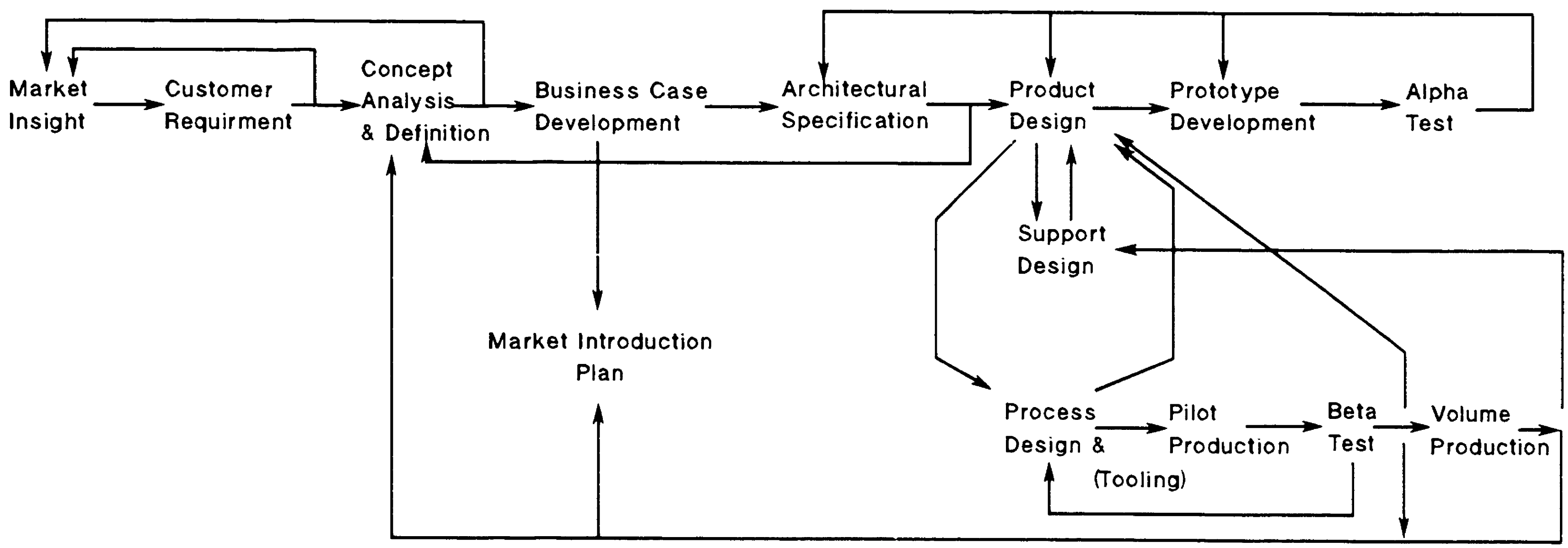


Figure - 2

The tree diagram process was conducted in Seven major steps. They were:

1. Bottom-up Enumeration: All participants silently wrote down 5 - 9 potential solutions on 3x5 inch P st-it™ cards. After all members completed this task, the cards were placed on the right side of a large sheet of paper or flip chart in the front of the room.
2. Semantic Scrubbing: The group leader took each card in turn and read the card out-loud twice. The card was then scrubbed for meaning. That is to say the vocabulary of the card was reworked until no abstract concepts were present. The card then reflected a report style statement in the form of who, what, where, when, why and how statements. This step was critical in overcoming ambiguities in language use and developing a shared vocabulary between the participants.
3. Grouping and Forming of Hierarchy: Cards with similar ideas were physically grouped together. The hierarchy was formed by identifying or establishing the underlying purpose of the individual ideas within one group. This underlying purpose became the heading for this node in the tree. The second, third, and fourth levels of hierarchy were developed by identifying the purpose of the lower level nodes in the tree as they related to the problem theme.
4. Top Down Checking: This was a check for completeness of the solution space. Concepts not captured during the bottom up enumeration were recognized now, on the basis of the new perspective. Having identified a missing branch, the group executed the Bottom-up Enumeration process of step 1.
5. Iteration: Steps 1 through 4 were repeated until a complete tree was completed. The process of bottoms up generation and top down checking was very deliberate. We began with a bottoms up approach in order not to bound the problem space. If for example, a top down methodology were utilized, we might have neglected a possible solution space.

In each subsequent decision process the group's attention was focused on refining the defined areas. Therefore, the probability of recognizing the omission was reduced

6. Solution Evaluation: Potential solutions were mathematically evaluated on the basis of two criteria: 1) the effectiveness of the particular metric in measuring the desired purpose, and 2) the feasibility of carrying out the measurement. The effectiveness criteria will be discussed first by returning to the initial problem of interest based on the tree diagram. "Do the identified customer requirements support a market need?" example. One element/node in the tree was "To assess the relative stability of a customer requirement over the product life cycle". Two supporting metrics were identified and proposed: The first metric was to assess the strength of the relationship between the customer requirement and current market needs. The second metric was to assess the strength of the relationship between the customer requirement and future market needs. It was clear that if we could measure future needs, then a high correlation to customer requirement stability could be achieved. Therefore, this metric received a score of 5 (5 - strong - 1 - weak) indicating a strong relationship. The measurement of current requirements was a "good" measure, but less so than the measurement of future needs. Therefore it received a score of 4 for effectiveness.

The second criteria was the feasibility of carrying out the measurement. Against this criteria, measuring the relationship between a customer requirement and a future need received a score of 2, indicating the difficulty in successfully measuring this parameter. Conversely, measuring the relationship between a customer requirement and a current need received a score of 4, indicating high confidence in successfully measuring this value. The scores received on these criteria (5&2 and 4&4, respectively) were then evaluated against the ranking matrix presented in Table-3, to generate a rank.

Table-3
Ranking Matrix

CUSTOMER REQUIREMENT	A	B	C	D	E	F	G	H	I	J	K	L
EFFECTIVENESS	5	5	4	5	**4**	**5**	3	4	3	4	2	3
FEASIBILITY	5	4	5	3	**4**	**2**	5	3	4	2	5	3
RANK	1	2	3	4	**5**	**6**	7	8	9	10	11	12

Legend: Higher value indicates a stronger (better) relationship on effectiveness and feasibility
Lower values indicate a stronger (better) rank.
Highlighted numbers refer to example
Customer Requirement E = relationship of customer requirement to current needs.
Customer Requirement F = relationship of customer requirement to future needs.

7. Operational Definition (OPDEF) Generation: The operational definitions were the protocol for measuring the particular metric. The OPDEF restated the purpose and intent of the measurement, in this case, to gauge the relative stability of Customer Requirements (CR) over the product life cycle. Second, it identified the means/activity to accomplish the measurement, for example, relationship of CR to current needs. Third, a step by step sequence to document the measurement was provided. The protocol for measuring the stability of a customer requirement is outlined below:

Step 1. Write current needs down the left hand column.

Step 2. Write CR number across the top.

Step 3. Write future needs down right hand column.

Step 3.1 If a current need will still be valid in the future, annotate that in the future need column.

Step 3.2 If a current need will not be valid in the future, leave future column blank.

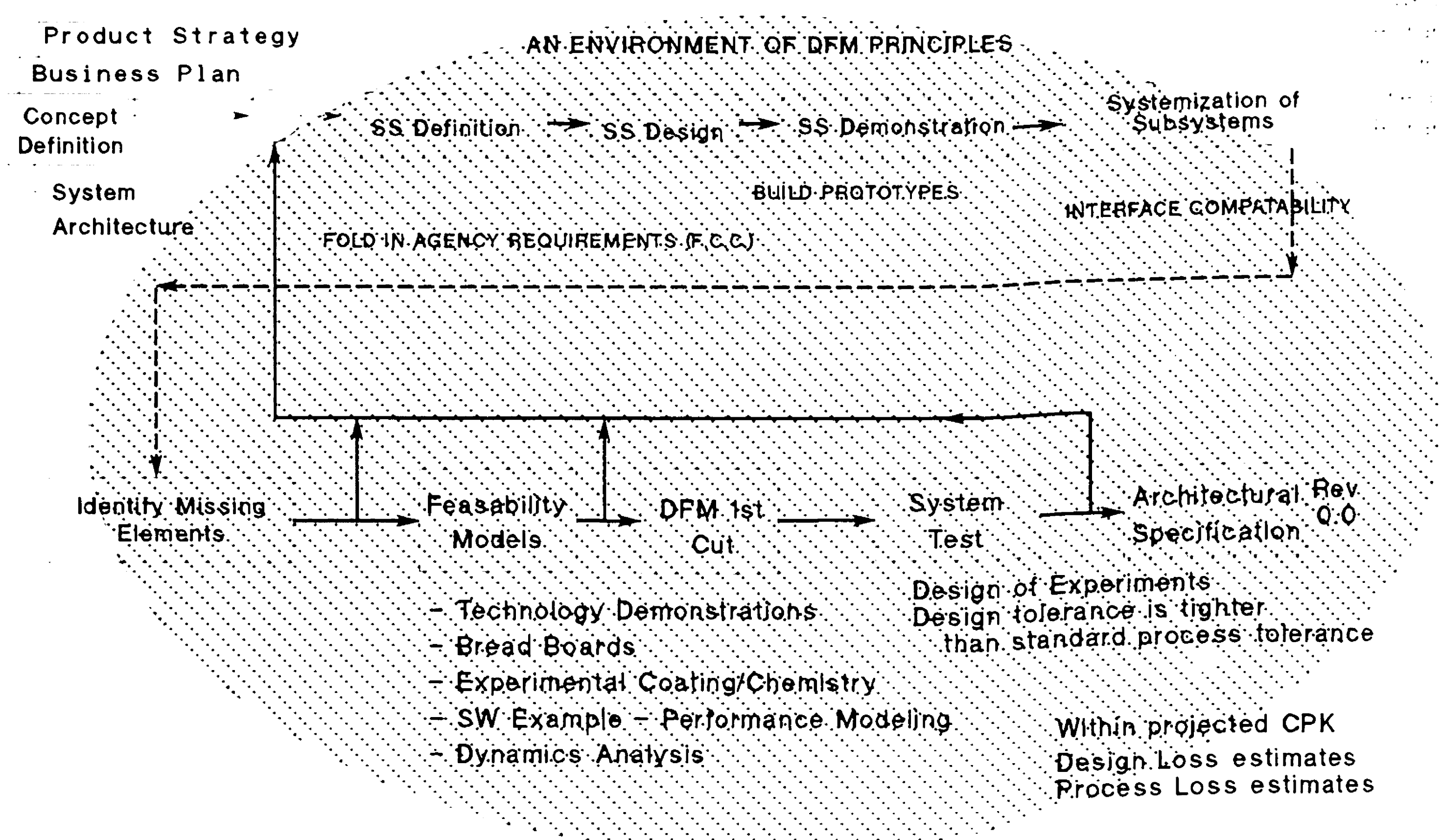
Step 3.3	If there is a future need not reflected in the current need column, write in the future column.
Step 4.	Use a scale of 1-5 to reflect the strength or degree of association between CRs and needs.
Step 5.	Note relationships such as one CR which has a high value against one or more needs, or a cluster or relationships, etc.

CQM Results.

The KJ methodology has been applied to the Customer Requirement and Concept Analysis & Definition phases of the product development process (refer to Figure-2). The resulting tree diagrams and performance metrics have been incorporated into the performance measurement system presented in Chapter Three. The process is currently being applied on the Architectural Specification, Product Design, and Process Design phases of product development. The conceptual models for specification and design phases are presented in Figure-3 and Figure-4.

The product design conceptual model deserves additional comment. The top level break-out has been adapted from Garvin's work (1987) in quality dimensions. We consciously avoided a first order break-out by standard engineering disciplines (electrical, mechanical, software, systems) for two reasons. First, the internal engineering disciplines are irrelevant to the external customer. They are a reflection of the internal language associated with task accomplishment. By starting with a conceptual model based on the perceptions of the external customer, we hope to achieve a higher degree of goal congruence with the external customer and therefore with the organization. Second, by starting with the eight dimensions of quality and identifying how each discipline fulfills its role within that context, we provide an explicit mechanism for the business plan and product strategies to be reflected into the design process.

Architectural Specification



Goals: Customer Integrity in both directions
Check lists and efficiency rating
Metrics for how well we have captured the VOC in breadboard & documentation
What it communicates – How it communicates

Figure–3

PRODUCT DESIGN

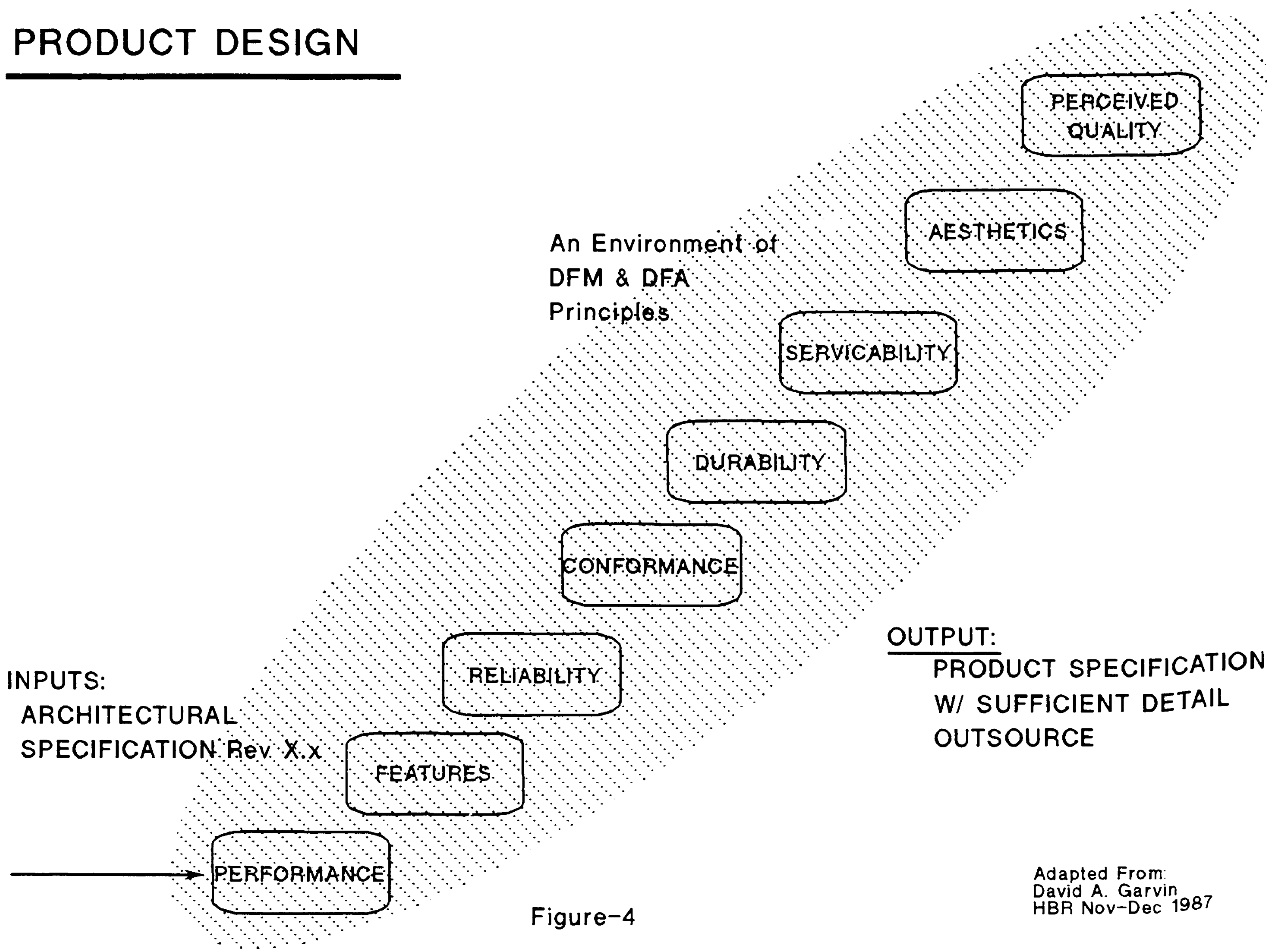


Figure-4

CQM Discussion and Lessons Learned

The benchmarks for customer requirements are now being evaluated in controlled trials. Two companies have provided a total of 12 development groups for the trials. One half of each company's groups function as a control group and develop products using current in-house practices. The balance of the development groups are using the CQM benchmarks as control points. One key characteristic of the metrics is that customer (both internal and external) integrity in both directions is identified and secured. Preliminary results indicate that the groups using the CQM metrics are reducing their total development cycle. Although early, it appears that the process has generated a sound product.

While the product of this research, the metrics, is viewed positively, the greater significance is in the process itself. The research methodology, presented in Table-2, paralleled the product development process and NGT in several key areas. First, cross-functional representation was a feature of both the research group and a product development team. Second, both groups were focused on the delivery of a product. Third, individual creativity and insights were required to accomplish the task. Four, structured processes were required to support efficient execution of the overall task. These parallels and the apparent early success in the trials prompted us to identify the critical success factor(s).

Semantic scrubbing was identified as a critical success factor. This conclusion was drawn from the following experiences. First, when semantic scrubbing was not rigorously performed, the group typically failed to complete the down stream tasks of grouping and hierarchy formation. Second, semantic scrubbing required the greatest time and discipline. Third, as the group gained experience interacting with one another, this task was executed with greater and greater ease. These effects were attributed to the establishment of a common vocabulary, and a shared set of expectations regarding the structure of the work. To summarize, the process provided an integrative mechanism which overcame functional boundaries, generated an unambiguous vocabulary, and exploited the benefits of group solutions and individual creativity concurrently.

The next section of this work provides an example from the telecommunications industry. The example demonstrates the use of NGT to facilitate cross-functional communication and achieve goal congruence between Marketing, Engineering, and Manufacturing.

Contract Books to Integrate and Measure Performance

This telecommunications firm is involved in the design, manufacture, and distribution of land mobile communication products. (The information presented here was obtained through personal interviews.) Their product design methodology provides an example of how their processes and tasks are developed and communicated to achieve a high degree of manufacturing and engineering integration.

The product design process is broken into five phases: 1) market needs assessment, 2) a product definition phase, 3) a concept selection phase, 4) a system design, and 5) a detailed design phase. The system design phase is of particular interest because of its use of NGT elements in developing common understanding and goals across functional groups. The system design phase is discussed below:

System Design. The system design activity marks the start of "structured integrated engineering and manufacturing." The activity results in the publication of a "Contract Book." This book articulates items such as:

Physical Design	Design Approach	Factory Cycle Time
Size	- Electrical	Product Assembly Efficiency
Styling	- Mechanical	Automatability (TBD)
Material Costs	Reliability	Factory Costs (w/ P&L)
Number of parts		

The contract book parallels NGT in that it provides a common and unambiguous understanding of the product features, manufacturing processes, and technologies used to develop the end product. Therefore the contract book is a communication and integration vehicle which supports unambiguous communication across functional boundaries and explicitly establishes shared goals. The contract book expands the concept of shared goals, beyond product definition and organizational goals, by including performance metrics for each functional discipline: manufacturing, electrical engineering, mechanical, etc. The mechanisms used to identify, set, and update these metrics are of primary interest: interconnections and technology drivers. The drivers are identified through a process which historically plots technical performance and identifies trends. For example, market forces will demand a continuous increase in the number of product features while reducing the product's physical size. This drives circuit density up. In turn, the increased circuit density requirement drives chip placement and bonding capabilities. From this we develop a metric on how closely parts can be placed and bonded onto the circuit board. An illustrative example is presented below.

The goal:	Develop a metric for a reflow solder line. The attribution must relate to what the designer (upstream customer) wants.
Metric:	How closely can you place parts? What is the defect rate [in ppm]?
Underlying Question:	Has manufacturing (as compared to another world class facility) characterized their process well enough to reliably predict placement and yield?

This example also demonstrated two of the three tasks identified by Nevins and Whitney. The first task is manufacturing process stability, characterization, and information dissemination. Process stability and characterization are explicitly addressed in the chip placement metric. The ability to reliably predict yields requires a statistically stable process and a sufficient understanding of the underlying science to predict future performance. Information is disseminated through the contract book, since the contract book is widely distributed and configuration controlled. The second task is an integrated product strategy with all business functions. This task is covered implicitly with the above process. Marketing and Engineering had a responsibility to project where their requirements would be in the future, while Manufacturing had a responsibility to predict its future capabilities. These data, when communicated to the relevant organizations, support a coherent product migration strategy based on increased technical sophistication. Further, each organization accepted the other's requirements as their internal goal, which promoted mutual trust, reliance, and a set of shared goals.

The telecommunications firm provided an example of shared goals, vocabulary, and mutual trust. These phenomenon were achieved through the use of metrics which were designed to expose dependencies between marketing, engineering, and manufacturing. The ability to support these metrics required the firm to emphasize careful analysis and understanding of fabrication and assembly processes. Lastly, the use of trend analysis identified key technologies and processes which support a strategic product design, conceived to support a specific strategy for making and selling the product.

This work has presented the case for the development of an integrated performance measurement system specific to NPD. This case has been based on organizational behavior, individual behavioral psychology, and identified shortfalls in the current NPD processes and management accounting systems. Chapter Three will present the basis of the NPD performance measurement system. This basis will serve either as the foundation for a performance measurement system or as a template to evaluate an existing performance measurement system. Lastly, key aspects of an intervention plan to implement concurrent engineering and/or a performance measurement system will be presented.

Chapter 3 - Framework & Intervention Plan

Chapter One of this paper identified the importance of the early phases of NPD processes for overall product and firm success. Chapter Two presented the case that it necessary to take an active role, through integrative mechanisms, to influence individual behavior in NPD processes in order to ensure overall goal congruence. Further, NGT and The KJ Method were identified as integrative processes which can be used to identify and establish common organizational and individual goals, in addition to supporting cross-functional communication through unambiguous vocabulary. Lastly, the telecommunications example demonstrated that low level metrics can function as an integrating mechanism which aligns organizational, functional, and individual goals.

Chapter Three will present both the basis of the NPD performance measurement system and the intervention plan for implementing a performance measurement system. The chapter is broken into three sections: 1) the attributes of the framework; 2) the performance measurement system checklist; and 3) the intervention plan outline. In the first section we will identify and discuss the dimensions of the measurement system. This discussion is based on the organization behavior principles discussed in Chapter One and Chapter Two. Through this discussion we will identify the important attributes of each dimension. In the second section we will operationalize the attributes to generate the evaluation checklists. The checklists were developed using the integrative methodologies discussed in Chapter Two, namely the KJ Method. The checklists are intended to support an organization's self-evaluation of its performance measurement and management control systems, as they apply to the NPD process. Lastly, we will briefly discuss the key issues in an intervention plan to implement a performance measurement system.

Framework Attributes

Chapter One highlights the need to leverage and better control the NPD process, "even though it is a far more difficult area to control" (Merchant, 1982). The challenge is to create an

NPD performance measurement system which incorporates the basic attributes of the management control function yet maintains the vitality of NPD as a dynamic process. Merchant articulates four attributes of good control systems:

1 - Future oriented: The goal is that an informed person [emphasis on informed] should be confident that no major unpleasant surprises will occur.

2 - Multi-dimensional: Good control can not be established over an activity with multiple objectives unless performance on all significant dimensions is considered.

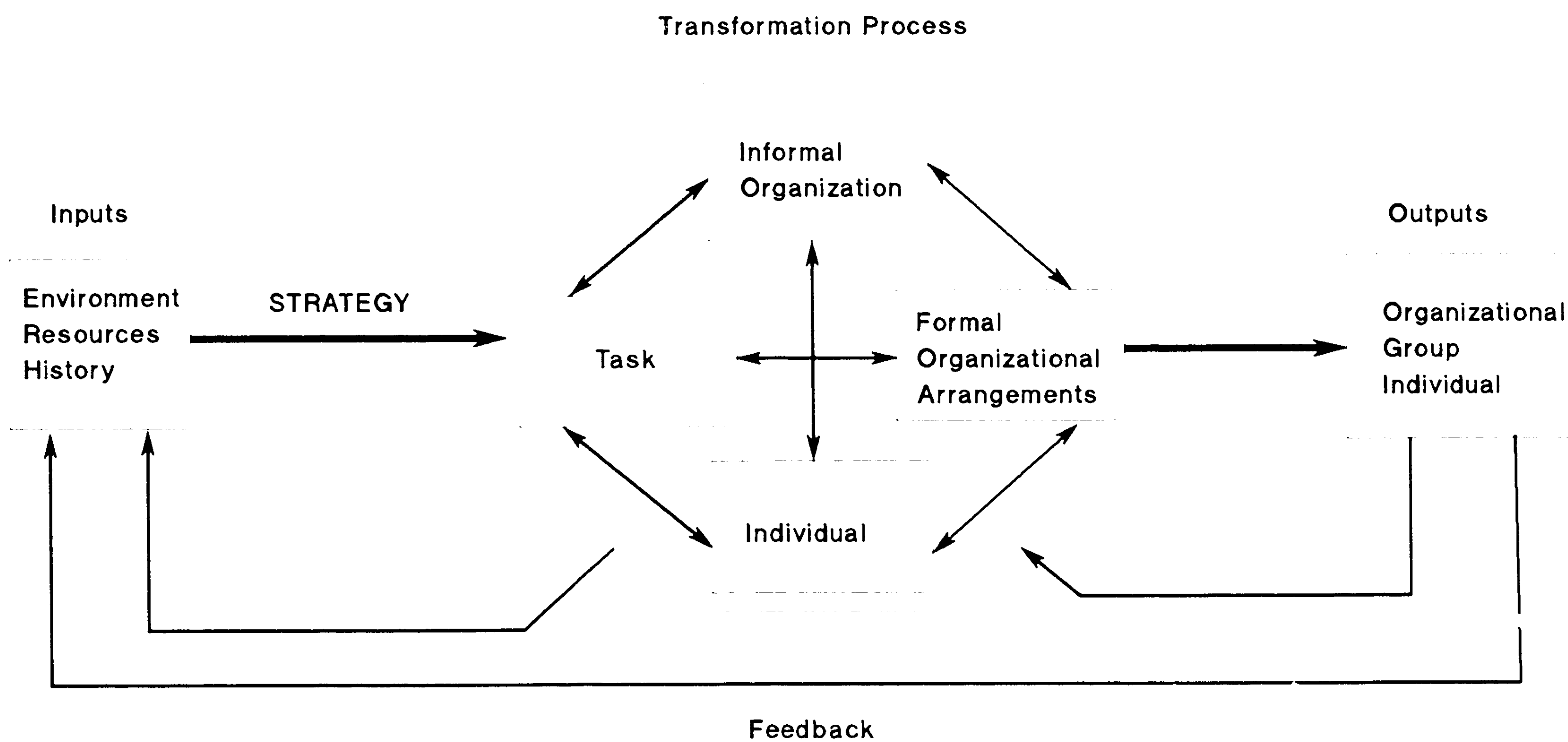
3 - Subjective: The assessment of whether good performance assurance has been achieved is subjective, and good control signals are multi-valued or continuous vs. binary in nature.

4 - Value added: Better control is not always economically desirable.

Therefore the proposed NPD performance measurement system will be future oriented, in identifying how behavior affects upstream and downstream decision making. The performance measurement system will emphasize multi-dimensionality in an attempt to integrate divisive organizational elements with potentially disparate goals. Performance goals will be created and defined as continuous variables to provide for both qualitative and quantitative dimensions. Finally, the performance measurement system is assumed to be value-added, because the early phases of NPD are key contributors to overall product and firm success.

Important Elements to a Performance Measurement System

The attributes of an effective management control function described above provide the basic foundation for a comprehensive performance measurement system. Nadler's "Congruence Model of Organizational Behavior" (refer to figure-5) provides the key elements at both the organization and individual level. This author contends that the organizational forces which resist change are the same forces which prevent organizational and individual goal congruence in the NPD process. Therefore, these forces need to be included in and impacted by a performance



Adapted from:
Nadler & Tushman
Organizational Psychology
Prentice Hall 1979

FIGURE-5

A CONGRUENCE MODEL OF ORGANIZATIONAL BEHAVIOR measurement system. Nadler identified the specific behavioral inputs and outputs of four basic organizational sub-systems; 1) formal organizational arrangements; 2) the individual; 3) the task, and 4) the informal organization. We have adapted Nadler's behavioral dimensions to describe and elaborate an integrated performance measurement system. Nadler's four elements can be used to characterize and define the critical subsystems in the NPD process. Defining the subsystems supports identifying a performance measurement strategy which articulates the specific behavioral inputs and outputs, to ensure effective congruence in the goals and behaviors of the individual and the organization.

The Business Organization (Formal Organizational Arrangements). Articulation of the organization's goals is a necessary precondition to developing an integrated performance measurement system. The case supporting the exposition of organizational goals and expectations as a necessary precondition to individual goal alignment was established in Chapter One. Therefore, the organization's goals must be clearly communicated. Behavioral inputs and outputs to the business organization include management expectations relative to financial and market share success factors, as a function of time.

At the Business Organization Level, the second type of input to be shared is anticipated market and competitive responses, and the firm's counter response(s). These analysis are a standard part of strategic marketing and new product introduction (Urban and Star, 1991). The explicit communication of these issues to the NPD team is two-fold. First, this information is complementary to the information discussed above. Therefore, this information augments and provides a clearer picture of the organization's goals and expectations. Second, the early involvement of top management, particularly in larger corporations, in the early phase of NPD is a new phenomenon. Line managers, group leaders, and individual contributors have typically executed the early phase of NPD without attention from top management. The new-found attention from top management will likely be viewed as interference by group leaders and line managers, unless it appears that top management: 1) is in fact bringing additional skills to the process; and 2) has expended a thoughtful amount of time on the process.

The third area of business level input on NPD processes is resource allocation. The appropriate allocation of resources is implicit in successful NPD processes. What is not implicit is that as firms reduce their NPD development cycles, the number of product lines is proliferated. The increased numbers of products pull more simultaneous products into the NPD pipeline. The increased number of products in the NPD pipeline increases the likelihood of critical resource shortages which threaten the NPD success. Strategies which deal with optimal resource allocation for NPD are beyond the scope of this paper. However, it is incumbent on the performance measurement system to identify that inadequate and/or inappropriate resources have been applied to a specific NPD activity if it threatens the successful outcome of the activity.

The fourth kind of input by the business organization to the NPD process is consistent system support, specifically, the implementation and adherence to processes such as the NPD process and performance measurement systems. The organizational challenge is to adhere to stable processes even when confronted with crises which tempt process circumvention.

To summarize, we have identified four behavioral inputs and outputs from the Business Organization as it applies to the NPD process. First, the organization must articulate its expectations with respect to the new product. Second, the organization must share its expectations with respect to competitive and market responses. Third, the organization must commit the resources to support an effective NPD process. These resources include: personnel, tools, training, and information support mechanisms. Fourth, the organization must be proactive in the early stages of the process. The organization needs to implement, monitor, and consistently respond to the signals being sent by the performance measurement system.

The Individual. The expressed position at the start of this paper was the need to align the individual's goals with the organization's goals. Chapter One argued that behavioral conditioning provides for greater immediacy and causes the employees (in the mid-and long-term) to adopt the underlying values which support the desired behavior. Further, the individual dimension of the performance measurement system needs to be presented as an integrative or win-win proposition to the employees. Each of these conditions will be discussed below.

The organization must first explicitly identify the desired behaviors and skill sets. These behaviors and skills sets must be relevant to the individual's task/assignment and mapped to the cross-functional players on his/her team. If the individual does not conclude that the desired behavior is relevant to their task, the individual will not "buy into" the behavior. Lastly, the behaviors need to be pinpointed and active in nature. That is, goals should be stated pro-actively, e.g. the employee shall improve the quality of their work by reducing the number of mistakes 50% per year. Thus the stated goal is active and is an effective elaboration of the desired outcome.

The mechanisms for communicating the desired behaviors, evaluating the individual's performance, and developing corrective action plans must be integrative. We illustrate through the following negative example: The personnel appraisal system in this "mythical" company generates a grade of 1-5 for every employee, with 5 being the best. The grade is an aggregation of performance in 5 key dimensions. (The dimensions themselves are unimportant to this specific argument.) At the completion of year 19x1 an employee receives a grade of 4.9. The grade reflects a score of 98% of the available points and, as carry over from our scholastic institutions, is equivalent to a strong "A". With such a high score, the question is asked, "What is the inducement for self improvement?" At the completion of year 19x2 the same employee receives a grade of 4.8. Is this a significant shift? In the conventional system, the answer is no - the grade reflects a score of 96% against available points. However, looked at from a different angle the answer is, yes, this is a significant shift because the employee has missed a perfect score by 2x from the previous year. The problem with both these scenarios is that they focus on attaining the maximum number of points out of a fixed amount. In negotiations, this is referred to as a win-lose negotiation. Win-lose negotiations are, by definition, divisive versus integrative, and divisive relationships between organizational elements, in this case management and the employee, is specifically what we are seeking to avoid.

Instead of the strategy described above (which is frequently used in organizations) we propose that the performance measurement system for the individual involve an integrative process with the other members of the product development team. The KJ Method or NGT could be used to identify individual tasks, rank their importance, and establish their cause and effect relationships to other group members in an unambiguous manner. The employee would present the outcome of this process to his/her manager as the basis of their next performance review process. This brings management in at the process level, as opposed to the task level. The dialog would support isolation of, and agreement on, which areas required improvement. A corrective action plan could be developed, resources allocated by management, and an evaluation against the specific goals conducted after the requisite period. The goal is accepted by the employee based on their participation in setting the goals. Further, the goal is unambiguous since the KJ Method requires the definition of the measurement and test criteria. Lastly, the goals are accepted as relevant to the individual's tasks and the NPD group, thus goal congruence is promoted between the organization, the NPD Team, and the individual.

To summarize we have identified four attributes of the performance measurement system as it applies to individuals. First, the desired behaviors need to be accurately pinpointed. Second, the behaviors and skill set need to correlate with the individual's task/assignment. Third, the behaviors must map into organizational objectives. Fourth, the mechanism used to identify and provide feedback needs to be an integrative mechanism between the individual, the NPD Team, and management.

Product Development Process (The Task). The stated purpose of the integrated performance measurement system is to: 1) measure the status of a product in development, and 2) measure the efficiency of one development (sub)process against another. In order to apply any performance measurement system to support NPD, one has to establish that a documented product development process exists, is stable, and is adhered to. The product development process must reflect customer integrity in both directions. That is to say that at each stage of the specification and decomposition process the user's (external customer) needs are being met and the downstream functional organization's (internal customer) requirements are satisfied. The ability to satisfy internal customer requirements requires understanding internal organizational capabilities. In addition, the process must support the sustained competitive advantage identified by the business organization, and be allocated to both product-related and process/manufacturing-related activities. The product development process needs to provide time and quality measurement points which promote information sharing between marketing, engineering, manufacturing and finance early in the process Finally, the process must make use of integrative mechanisms, such as CAD systems, NGT, and the KJ Method, which permit unambiguous communication between the functional groups.

The NECIC Corporation provides an example of how one group stabilized their design process and developed a strategy for sustaining a competitive design and manufacturing advantage. The issue facing NECIC was how to balance risk-taking with caution, and in a complementary fashion, how to balance the issues of creativity versus more production-like operations. NECIC's approach was to focus creativity into areas which contribute to sustained competitive advantage. The process resulted in a two-year turn around from a low quality producer operating at a financial loss to a Demming prize winner operating at a profit. The turn around was accomplished by systemizing 90% of the integrated circuit design process. Systemization was accomplished through a combination of hierarchical design methodology and a CAD system which supported design reuse libraries and technical performance prediction.

Evaluated against Robertson and Allen's criteria (page 23) NECIC viewed and used CAD systems as supporting human capital The remaining 10% of the process was identified as the "creative" element where standardized designs were insufficient and where a competitive advantage existed The integrative mechanisms used to support the creative component of the design were the more classical small, well-established teams Lastly, the creative component from one project became the standard design sub-element for future designs The key was identifying the necessary creative/risk and standardization profile One consequence of this activity was that engineering resources could be focused on the "creative task" versus being diluted by the necessity to recreate older designs

To summarize we have identified four attributes of the performance measurement system as it applies to the product development process First, the production and assembly processes must be stable Second, the NPD process provide customer integrity in both directions Third the process should reflect a long tern sustainable competitive advantage Fourth, the process requires time and quality measurements at intermediate and end points

Societal Enablers (The Informal Organization). This work has argued that the ability to communicate unambiguously, to share common objectives, and to trust members not directly within one's sphere of control are key elements to NPD success The key leverage points, identified in Chapter One, within the NPD process are the concept formulation, selection, and system design phases. Therefore the organization must provide mechanisms to facilitate these phenomenon The mechanisms which can achieve these phenomenon are varied For example, in Japan and France, project teams work together for significantly longer periods of time than in the United States. Familiarity based on years of working together may result in clearer communications and the development of trust, since both parties recognize that the relationship is a long term relationship (with subsequent opportunities for reprisals) U.S firms have favored faster rotation periods for product development teams based on the premise of that rotation fosters greater creativity and provides promotional incentives. The argument that lower group age (newly formed groups) is more productive and creative is supported by Allen and Katz (1982) in their investigation of the "Not Invented Here Syndrome". Given that enhanced creativity is a competitive advantage, a firm might logically attempt to optimize in both directions by maintaining a higher rotation rate while accelerating the team building processes, which promotes unambiguous communications and the development of trust. The Nominal Group Techniques, KJ methods, and CAD/CAM applications are all examples of techniques which can be utilized as societal enablers to improve the nature of communications within and between functional organizations.

The Performance Measurement System Check List

In the previous segment, Nadler's four elements in a congruence model for organizational behavior were redefined and applied to form the basic outline for a performance measurement system. In this segment, specific behaviors within each of the elements are itemized in a check list. The check lists are intended to support an organization involved in the planning stages of implementing concurrent engineering and a performance measurement system. The check lists for the product development process were developed using cross-functional teams and the KJ Method. These processes were used in order to gain a full organizational representation and identify and articulate the common goals. The societal enabler check list addresses the question of whether the organization has and is using integrative mechanisms such as the KJ Method, NGT, or CAD/CAE systems, to achieve goal congruence. The check lists for the individual and the business organization are based on the organizational behavior and behavioral psychology arguments of Chapter One. (For the purposes of this paper we assume that the business is a moderate to high technology based business.)

Development Process Articulation

This product development process checklist is an abbreviated version of the current CQM research into performance metrics for product development. This check list covers the first two identified phases of the product development process: the customer requirements and needs assessment phase, and the concept analysis and selection phase (refer Figure-2). The list reflects the tree diagram structure discussed in Chapter Two. Each indentation indicates a movement down one node in the tree. The underlined sentences are the performance metrics which support the higher level questions and goals. The reader will note that the metrics towards the top of the checklist reflect external customer requirements while those metrics towards the bottom reflect internal/downstream customers. This alignment of goals is the direct result of the KJ Methodology employed.

Customer Requirements and Market Needs Assessment Phase

- What is the Accuracy of the Customer Needs Assessment?
  - How deep was the exploration of each customer need?
    - What is the relative stability of the customer requirement over the product life cycle?
      - Performance Metric — Rank the relationship of the customer requirement to current needs.
    - How complete are the set of customer requirements for each need?
      - Performance Metric — Rank the level and degree of detail of customer requirements within each segment.
  - How extensive was the coverage of the total market need?
    - To what degree are the relevant views are represented in data collection?
      - Performance Metric — Rank how many customers in each segment participated in data collection.
    - What is the relative coverage of the potential customer requirement segment?
      - Performance Metric — Rank the relative diversity of customer requirement breadth.

- What is the utility of the requirement in Product development activities?
  - Ability to communicate compelling market needs?
    - Degree of commitment of the product development team
      - Performance Metric — Rank the degree of involvement of the product development team in customer requirements development.
  - To what degree do customer requirements accommodate customer oriented trade-offs?
    - Degree to which the customer requirements support trade-off analysis.
      - Performance Metric — Rank the number of customer requirements which are interdependent.

To what degree do customer requirements facilitate a common interpretation of customer needs?

Degree to which customer requirement statements are unambiguous

Performance Metric — Rank the level of abstraction of the customer requirement.

Concept Analysis Phase

Evaluation of concept's ability to realize the customer requirement.

Evaluation of the concepts ability to generate internal support.

Evaluation of the concept generation process.

Performance Metric — Rank the number of concept alternatives for each customer requirement.

Degree of commitment of the team to the concept.

Performance Metric — Rank who participated in the concept generation process.

Evaluation of the concepts ability to succeed.

Does the concept address a vital market need?

Performance Metric — Rank the ability of the concept to satisfy individual needs.

Has the concept been validated for customer benefit?

Performance Metric — Rank the method of verification of concept's fit to market need.

Does/can the concept excite the market?

Performance Metric — Rank how creative the product concepts are.

Evaluation of concept(s) against operating environment.

Evaluation of concept against external factors

Have the concepts been judged against externalities?

Performance Metric — Rank the concept against the competition.

Evaluation of concepts against corporate capabilities

Have the concepts technical considerations been evaluated

Performance Metric — Rank the percentage of the concept which is dynamic (not proven).

Have the concepts been evaluated for fit to corporate competencies?

Performance Metric — Rank whether the concepts have been evaluated for cost/time considerations.

Business Level Articulation

Previously four behavioral inputs and outputs from the Business Organization as it applies to the NPD process were identified. First, the organization must articulate its expectations with respect to the new product. Second, the organization must share its expectations with respect to competitive and market responses. Third, the organization must commit the resources to support an effective NPD process. Fourth, the organization must be proactive in the early stages of the process. The organization needs to implement, monitor, and consistently respond to the signals being sent by the performance measurement system. The Business Organization checklist is broken down according to these four behavioral dimensions.

Expectations relative to the product.

1. Is there a strategy which is written down?
2. Does the strategy reflect product migrations?
3. Does the strategy identify the underlying building blocks (technologies), and the competitive advantage of the firm in this product area?

Anticipated external responses to the product.

4. Does the strategy reflect market responses to production quantities, price shifts, etc ?
5. Does the strategy reflect competitive responses from competitors?

Strategic resource allocation.

6. Do the management practices regularly assess current and future resource allocations?
7. Does management provide task oriented training courses, materials, and time?

Proactive process response

7. Does the strategy explicitly identify the necessary manufacturing capabilities? Performance capabilities, such as chip placement within 20 mil at a production rate of X chips/hour. Stability criteria, the same process should reflect a defect rate of no greater than 100 ppm in year X, 50 ppm in year X + 1, and 3.4 ppm in year X + 3.

Individual Level Articulation

Previously four attributes of the performance measurement system as it applies to individuals were identified. First, the desired behaviors need to be accurately pinpointed. Second, the behaviors and skill set need to correlate with the individual's task/assignment. Third, the behaviors must map into organizational objectives. Fourth, the mechanism used to identify and provide feedback needs to be an integrative mechanism between the individual, the NPD Team, and management.

Behavioral Pinpointing.

1. Have the desired behavioral attributes been identified? For example, one general set of desired behaviors is information sharing. Specific behaviors within that set could include such activities as:
   - Upstream and downstream communication within the development process.
   - Customer supplier orientations developed and maintained within the organization.
   - Integrating knowledge
   - Bringing cross functional people to their decision process?
   - Setting and meeting internal customer commitments? (Rewarding follow-through on internal commitments is important to supporting trust internal to the organization, particularly if personnel rotations limit the development of trust through time based relationships.)
   - Calling for or requesting resources when needed?
   - Awareness of their competitor (external) and how the competitor approaches similar problem.

Behaviors Correlated to Task and Mapped to Organization.

2. Have the individual behaviors or approach(es) been differentially defined such that the behavioral expectations change as the individual moves across the different development phases?

For example, more creativity in all areas may be favored during concept formulation and selection. In contrast, design re-use and proven designs for "standard" aspects of the job may be emphasized during later design phases.

3. Have specific positional attributes been identified? For example, a group leader may be evaluated along three specialized dimensions: Individual (leader), the leader's interaction with his/her team, and the leader's administrative abilities. These three dimensions can be further refined and defined, as described below:

<u>Leader Individual Behaviors</u>		
Conceptual Thinking	High self-confidence	High Commitment
Concerns for Impact	Career Orientation	Initiative
<u>Interaction with the Team</u>		
Effective use of Others' strengths		Use of Wide Data Net
Accurate Assessment of Others		Development of Team Members
Directive Influence	Ownership Building	Persuasive Use of Data
Able to motivate /influence others		
<u>Task and Administrative Behaviors</u>		
Systematic Planning	Logical Reasoning	Concern for Effective Results
Concern for Quality		

Feedback Mechanism to Support and Correct Behaviors

4. Are the desired behaviors publicized and part of the human resource development system?

5. Has an immediate reward system been developed and is in implementation? immediate reward systems include monetary rewards, vacations, "prizes", or public recognition.

6. Has a longer range organizational commitment mechanism been developed and implemented? Longer range commitment mechanisms may include educational programs, more frequent access to senior executives for informal counseling and discussions.

7. Is a feedback/training system in place to assist employees to identify and correct skill deficits?
8. Does the personnel system adjust for the degree of risk in the assignment (stretches)?
9. Has the HR system been developed so as to be integrative versus divisive?

Societal Enablers

In the previous section on societal enablers, we identified four potential mechanisms which supported the development of an unambiguous vocabulary, shared goals and trust. These mechanisms included a culture which discouraged rotational assignments, Nominal Group Techniques, the KJ method, and selective use of CAD/CAM. The key attributes of all these systems and any other candidates would be:

1. They support the development of unambiguous vocabulary either through a process such as semantic scrubbing or through use of physical models.
2. Individual creativity is enabled and channeled.
3. Group judgement and consensus building are supported.
4. The design is depersonalized so that feedback is readily accepted.
5. Although the process depersonalized the design to support feedback, ownership is assumed by all members of the group.
6. The information media is rich, i.e., it supports a high bandwidth. For example, face to face communications and CAD/CAM are high bandwidth media, versus, written design specifications which are a lower bandwidth media.
7. Problem focus is maintained through out the team. This can be achieved through management and marketing reviews, internal promotional programs such as mock-ups and posters, or any other vehicle which continuously reminds the team of the intended end customer.

8. A high frequency of information transmission is supported and achievable through physical co-location, frequent site visits, or advanced communications systems such as Virtual Video Conferencing. The purpose is to increase the probability of incidental contact between all functions associated with the development project.
9. Direction of communication (Bilateral vs. Unilateral).
10. Timing of upstream and down stream information flows (early release of preliminary info).

One cautionary note is in order: A key attribute of any control system is that it must be utilized and adhered to. A control system which does not monitor progress against a fixed goal is rapidly ignored. The process is ignored because the power in the system is derived through its ability to influence rewards and punishments. It is too common to find firms with sophisticated monitoring systems, HR appraisal systems and New Business Development Systems which are not utilized as true control systems. That is to say employees may receive raises and promotions but never receive constructive feedback nor are they managed against specific process goals. New Business Development organizations may forecast new opportunities year after year but never be held to how well the forecast was met.

The Intervention Plan

This work shall briefly present and discuss an intervention plan to implement a performance measurement system. We advise the reader to resist the temptation to adopt turn key systems. That is to say, while the result of the CQM research is a set of product development metrics, an organization may be ill advised to adopt the metrics (or any other set) wholesale. implicit in the research was a methodology which lead to mutual understanding of intent and acceptance of the metrics as valid. Historical data suggest that implementation of an off-the-shelf monitoring and control system over engineers will be poorly received. In fact, it may be actively resisted. One explanation for this resistance is that implementing a monitor and control system would shift power away from the engineers. We therefore propose to treat the implementation of a measurement system as an organizational change process.

As stated in Chapter 1, the change process may be viewed as a three-step sequence Schein (1989): motivating change, managing the transition state, and stabilizing the future state. Table-4 details a number of mechanisms which can be used to initiate and maintain change. It also identifies the relative speed of the change process as correlated with the approach. While top down directed changes tend to be the fastest, they require, and are strongly dependent, on a charismatic leader. Education and communication are the weakest motivators since they lack explicit incentives to change.

Table-4
Change Approaches

Methodology	Notes/Commentary
Education & Communication	weakest motivator (slowest)
Participation & Involvement	GE's Work Out as an Example
Facilitation & Agreement	
Negotiation and Agreement	
Manipulation & Co-operation	Middle management driven change
Explicit & Implicit Coercion	Strong upper management (fastest)

Irrespective of the approach, all change initiation processes must address three key criteria: First, they must surface dissatisfaction with the present state. This requires the ability to clearly articulate what the current state is. Second, the process must elicit participation in the change. The participation may be achieved through facilitation, implicit coercion, or explicit coercion. The ability to explicitly coerce a large group of skilled engineers seems unlikely. A more likely process is to involve them in the development of the metrics for one another. Again, the CQM results may act as a guide rather than a solution. The process must provide rewards for demonstrated behaviors which support the change. Third, time and opportunity to disengage from the present state are required.

One key aspect of managing the transition state and stabilizing the future state is shaping the political dynamics of change. The proactive role of the leader as the designer of the new system is advocated by the TQM movement and Senge (1990). Another element is to assure the support of key power groups. In the case of product development, one of the power groups being threatened is frequently the first line engineering manager. First line managers are typically a choke point. They are close enough to the actual work to have significant technical skill to evaluate the product in development. However a performance measurement system for NPD threatens to standardize and thereby devalue that skill. Thus, standardization would negatively influence the manager's power base. One mechanism to avoid this is to involve first line management in a key facet, e.g. the continuous improvement aspect, of the new NPD process. It implies they will be involved in the monitoring process and have key inputs to changes which are designed to improve the overall organizations performance.

Conclusions

This paper has presented the foundations of a performance measurement system tailored to NPD. The importance of the early phases of NPD were identified as critical to overall product and firm success. Therefore, these early phases deserve a more robust treatment by management. This paper also identified the need and ability to influence individual behavior to achieve goal congruence between the individual, the NPD Team, and management. To achieve this influence the performance measurement systems must specifically impact four sub-elements of the firm: The formal business organization, the individual NPD members, the NPD Process itself, and the societal enablers within the organization. Lastly, this research identified NGT and the KJ Method as integrative processes which facilitate communication across organizational boundaries through the development of a common language, can be utilized to set shared goals, and blend creativity and structure to maximize the effectiveness of the organization.

REFERENCES

[1] Allen, T.J., Katz, R. "Investigating the NIH Syndrom: A Look at the Performance Tenure and Communication Patterns of 50 R&D Project Groups." R&D Management Vol 12(1) 1982.

[2] Beer, Michael, Eisenstat, R.A., Spector, B. "Why Change Programs Don't Produce Change." Harvard Business Review Nov-Dec 1990.

[3] Camp, Robert C. "Benchmarking: The Search for Industry Best Practices that Lead to Superior Performance." ASQC Press Milwaukee Wi. 1989.

[4] Clark, Kim B., Fujimoto, T., "Product Development Performance." Harvard Business School Press Boston MA. 1991.

[5] Clausing, Don, "Flexible Product Development." Presented at the Conference: Time-Based Competition: Speeding New Product design and Development, Nashville Tennessee, May 1991.

[6] Clausing, Don, "Concurrent Engineering." Presented at the Conference: Design and Productivity International Conference, Honolulu Hawaii, February 1991.

[7] Clausing, Don, Pugh, Stuart, "Enhanced Quality Function Deployment." Presented at the Conference: Design and Productivity International Conference, Honolulu Hawaii, February 1991.

[8] Daniels, Aubrey C. "Performance Management: R+." Performance Management Publications Tucker GA. 1989.

[9] Delbecq, Andre L., et. al. "Group Techniques for Program Planning - A Guide to Nominal Group and Delphi Processes." Scott, Foresman and Company Glenview, IL. 1975.

[10] Griffin, A., Hauser, J. R., "The Marketing and R&D Interface." MIT Sloan Working Paper # 3350-91-MSA October 1991.

[11] Hayakawa, S. I. "Language in Thought and Action." Harcourt Brace Jovanovich, New York NY 1989.

[12] Johnson, T.H. Kaplan, R.S. "Relevance Lost: The Rise and Fall of Management Accounting." Harvard Business School Press, Boston MA. 1987.

[13] Merchant, Kenneth "The Control Function of Management." Sloan Management Review Summer 1982 pp 43-55.

[14] "Microgravity Flight Projects Cost Study Report." Microgravity Science and Application Division NASA July 1991.

[15] Murotake, D.K. "A Double-Edged Sword: Relationships Between The Engineering Use Of Computer Tools and Project Performance." Doctoral dissertation, Massachusetts Institute of Technology, Sloan School of Management 1990.

[16] Nadler, David A., Tushman, Michael L. "Beyond the Charismatic Leader: Leadership and Organizational Change." California Management Review Winter 1990.

[17] Nadler, David A., Tushman, Michael L. "A General Diagnostic Model for Organizational Behavior: Applying a Congruence Perspective." Reading in the Management of Innovation. Harper Business Press 1988.

[18] Nadler, David A. "Concepts for the Management of Organizational Change" Reading in the Management of Innovation. Harper Business Press 1988.

[19] Nevins, James L., Whitney, D. E., "Concurrent Design of Product and Process." McGraw-Hill Publishing New York 1989.

[20] Quinn, James B. "Managing Innovation: Controlled Chaos." Harvard Business Review May-June 1985.

[21] Robertson, David, Allen, Thomas J., "CAD System Use and Engineering Performance in Mechanical Design." The International Center for Research on the Management of Technology-MIT, January 1991, Working Paper #32-91.

[22] Robertson, David, Allen, Thomas J., "Managing CAD Systems in Mechanical Design Engineering." TheInternational Center for Research on the Management of Technology-MIT, Working Paper #3-90.

[23] Schein, Edgar "Planning and Managing Change." March 1989 MIT Working Paper.

[24] Senge, Peter M., "The Leader's New Work: Building Learning Organizations." Sloan Management Review, fall 1990 Vol (32)1.

[25] Senge, Peter M., "The Fifth Discipline." Doubleday New York NY 1990.

[26] Smith, Preston G., Reinertsen, D. G., "Developing Products in Half the Time." Van Nostrand Reinhold, New York 1991.

[27] Sterman, John D., "Misperceptions of Feedback in Dynamic Decision Making." Organizational Behavior and Human Decision Processes, 43, 301-335 1989.

[28] Urban, G., Star, S., "Advanced Marketing Strategy." Prentice Hall Englewood Cliffs NJ. 1991.

[29] Utterback, J., Tuff, T., Meyer, M., Richardson, L., "When Speeding Concepts to Market Can Be a Mistake." ICRMOT MIT Working Paper #45-91, March 1991.

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