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Best Design Practices: An Analysis of U.S. Navy Contractors
(Running Title: Best Design Practices)

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Best Design Practices: An Analysis of U.S. Navy Contractors

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ABSTRACT

Rapid and successful introduction of new products has been proposed as a potentially significant source of competitive advantage for U.S. manufacturing firms. It therefore becomes necessary to identify those critical elements of the Product Development Process (PDP) that have a positive influence on new product success. This research seeks to identify and evaluate those distinctive product development and design practices, policies, and tools currently followed by companies (Navy contractors) that participated in an empirical research study known as the Best Manufacturing Practices Program. The paper presents a structured analysis of the research case studies and proposes a conceptual framework for BMP.

INTRODUCTION

The issue of productivity decline in manufacturing was recognized in the late 1970s, after U.S. manufacturing firms suffered a loss of market share in many industries. With the awareness of productivity decline, manufacturing firms implemented programs to revitalize and improve productivity [28]. Several disparate sources of competitive improvement were proposed such as increasing the quality of the products offered, shortening production times, direct labor and cost reduction, improving customer service and providing rapid product introduction. While all of these sources have demonstrated progress, those centered on more effective new product introduction appear most promising [15]. The competitive environment in the U.S. requires the development of high quality innovative products, but also mandates that the process of introducing new products to the market be accelerated and that the process be structured and managed appropriately.

Prior research has indicated that problems in competitiveness are directly related to the design and product development approaches followed by U.S. companies [3]. Two elements are fundamental for the success of a new product. First, innovation for the generation of new product ideas must be strategically managed and based on the combination of customer needs and the firm's technological opportunities. Second, once new product opportunities are clearly identified, the firm must possess a well structured, high quality product development process (PDP) to effectively and efficiently turn the idea into a manufacturable and marketable product. In order to identify what is a *high quality* product development process, it is necessary to study in depth current practices that companies have successfully implemented in the development of new products.

This paper attempts to identify and evaluate product development and design practices followed by companies that participated in the Best Manufacturing Practices (BMP) program conducted by the Department of the Navy [2]. Details of how the study was conducted are provided in a subsequent section of this paper. Background literature is first summarized, followed by a description of the research methodology. A model of PDP based on the case studies is proposed, and best practices and trends are identified. We conclude with discussion of future opportunities for both research and industrial practice.

LITERATURE REVIEW

New product development necessarily involves technological innovation, a subject that has been well addressed in the literature. Several studies have focused on the management of innovation in large industrial firms and attempted to identify important factors for successful innovation [27]. It has been found that these firms seem to have a strong market orientation, a strategy for introducing new products and a team approach for product development. However, many U.S. firms still are faced with problems of organizational bureaucracy, excessive project control and short term managerial perspectives that impede the development of new product ideas and investment in new product projects.

Even though innovation may be characterized as a somewhat *unpredictable* phenomenon, it has been proposed that innovation can be systematically managed if sources of idea generation are identified and nurtured [14]. The focus may be internal, where the organization attempts to develop and tap into the collective expertise and creativity of its personnel; or, the focus may be external, where competitive benchmarking, market analysis, and technological developments drive new product ideas. The firm, through the integration of its functional areas such as R&D, marketing, engineering and manufacturing, must possess the infrastructure to continuously identify these sources of opportunities and bring them to fruition. The video cassette recorder is an example where an American firm was able to successfully invent but did not possess the capability of developing it into a successful business initiative. Successful innovation requires more than just invention.

Existing empirical research has attempted to link various global system factors with new product commercial success or failure. Early research sought to identify those characteristics for new product successes [8,9]. Some studies have focused on external factors such as the market environment, while others have focused on internal factors such as the firm's organizational structure for product development and the firm's human and technological resources.

The first important factor identified throughout these studies is that of alignment -- both between the product and the customer and the product and the firm. It appears that commercially successful new products are those that identify and fill a unique market niche, and that satisfy the requirements of the customers in that niche. The technological demands of the product must also align with the technological capabilities of the company -- the firm must rely on taking advantage of the strengths of its existing systems.

The second important factor identified is successful management of the PDP. This includes clear communication of priorities, adequate financial and personnel resourcing, strong marketing and technical capabilities, and a structured, planned, and controlled approach to the development process. While it might be argued that many companies have grown proficient at aligning their products with market niches and their own capabilities, successful management of the PDP has been a skill that has eluded many firms.

Some of the studies cited also look at commercial failures. Sources of failure were typically categorized as product quality (defects, aesthetics, maintenance) or marketing (competitive assessment, price, estimation of sales potential) inadequacies.

It has been pointed out that the majority of new product success and failure studies have not investigated in detail the activities that comprise the PDP itself [11]. Instead, the studies have focused on general dimensions that describe the setting of the project such as strategy, synergy, and technology and market selection, and have failed to identify key success factors in PDP management. The Booz-Allen and Hamilton [5] and Cooper and Kleinschmidt [11] studies attempted to identify the extent to which various PDP activities are followed in industry, and how proficiency of these activities has an impact on product success. They found that companies which took a more formal and structured approach to product strategy formulation and PDP were more likely to have successful commercial products, as well as being more productive internally, i.e. the ratio of successful products to new product ideas increased.

It was also found [11] that PDP is deficient in many companies because they do not follow systematic PDP approach. Important activities are often overlooked, including detailed market study/market research and initial screening and preliminary market assessment. In addition, the studies identified the need to develop a PDP model that describes the activity plan for new product development. The implementation of a model allows the firm to plan and organize the different tasks in the development of a new product, to impede the omission of critical activities, and to effectively allocate time and resources for those activities.

Existing literature has typically conceptualized the PDP as a sequential process involving different stages, where each stage can be perceived as a main task comprised of a set of activities [5,10,21,30]. Following, the seven main stages presented in the Booz-Allen and Hamilton study, typical of the others also, are listed:

Stage I: New Product Strategy
Stage II: Idea Generation and Screening
Stage III: Preliminary Assessment
Stage IV: Conceptualization
Stage V: Product Development
Stage VI: Testing
Stage VII: Trial
Stage VII: Launch

Cooper [10] stresses the sequential nature of the activities. However, the model proposed in this study differentiates technical/production from market activities, which can be carried out simultaneously at each stage. A PDP model that emphasized the overlapping of the development phases and the multi-disciplined team approach was proposed by Takeuchi and Nonaka [29]: "...a holistic or rugby approach - where a team tries to go to the distance as a unit - may better serve today's competitive requirements". Under the traditional sequential PDP approach, functions are specialized and segmented. Under the holistic approach, product development is carried out with constant interaction of a disciplined team, whose members work together from the beginning to the end of the process. The overlapping of stages allows the team members to acquire knowledge right from the beginning of the project, enabling them to become efficient problem solvers.

The few studies that have investigated the activities comprising a successful PDP have found that in many companies some critical PDP activities for new product development are omitted or are superficially performed. In general, the studies have focused on marketing-related activities, yet other activities are of importance. Hise, O'Neal and Parasuranam [19] point out the fact that previous empirical studies did not comprehend the technical design activities required in the design stage of the PDP. Their research investigated the relationship between product success and technical key activities in the PDP. Seven product design activities practiced within industrial product firms were identified and investigated: development of rough drawings, development of detail drawings, creation of crude working models, testing of crude working models, creation of prototype designs, testing of prototype performance, and final modification before release to production. The main conclusion was that it appears that the performance of specific product design activities results in higher commercial success rates. In addition, it seems that even though there exists a major emphasis on accelerating the new product development cycle, the simple observation is that the more design activities that are implemented and actually performed, the more the product is likely to succeed. Interestingly, of the 31 companies that were investigated, only 34 percent performed completely all seven design activities.

In summary, previous empirical research has given major attention to managerial and environmental factors that affect product success, such as new product strategies, market environment, marketing and R&D interface, and the nature of the competitive environment. Other research has focused on conceptualizing and describing the set of activities and their interactions involved in product development by proposing PDP models and highlighting the importance of effective implementation of the PDP model within companies. Few studies have focused on determining the extent to which PDP activities are actually implemented, and even these have explored mainly marketing related activities.

Less attention has been given to specific engineering management and design practices. The one study that investigated technical dimensions illustrates a positive link between product success and proficient implementation of design activities.

The BMP surveys present am opportunity for new insight. They represent a different type of study that focused on identifying the *best* engineering and design practices used in industry. The purpose of this research is to analyze the different case study reports from the BMP Program in order to: (a) identify those design practices that are commonly used at present, (b) identify future trends for PDP, (c) discuss efforts placed in industry to enhance PDP, and (d) determine the extent to which companies are using sophisticated technologies in development of new products.

BEST MANUFACTURING PRACTICES PROGRAM: AN OVERVIEW

The Best Manufacturing Practices (BMP) Program was initiated in 1985 by the Director of Reliability, Maintainability and Quality Assurance for the Office of the Assistant Secretary of the Navy for Shipbuilding and logistics. It was created with the purpose of exchanging information concerning practices that are being implemented in industry. Interested companies request a survey, and determine what should be addressed in the survey. In addition, the company has control over the information to be published in the final report. The surveys do not involve any area that is considered proprietary to the company [2].

The surveys were conducted by a team of government experts from the Army, the Navy and Air Force, NASA and other government agencies who visited the company's facilities. The purpose was to document the *best practices* that were distinctive for each company and were perceived to be helpful for other companies. Therefore, reports of practices commonly used in the industry were not the focus of the surveys. The surveys were based on on-site observations as well as on conversations with factory workers and supervisors. After the visit, a draft report was sent to the company for editing, final review and approval.

RESEARCH METHODOLOGY

The methodology followed in this study involves the application of content analysis on the BMP case data. Content analysis is a proven technique that examines artifacts of social communications, such as in written documents like the BMP data. As defined by Holsti [20], content analysis is "a technique for making inferences by systematically and objectively identifying special characteristics of messages". The research method involves the analysis of a collection of artifacts in order to find recurring patterns. The methodology can help to focus on both quantitative or qualitative aspects of the case data.

Content analysis can be classified in two different categories. First, manifest content is characterized by the counting of the elements of analysis which are physically present. Second, latent content is characterized by extended analysis involving interpretation of the symbolism embedded in the data reported.

In this study, the text from the 31 BMP documented case studies available is the artifact for study. From these case studies, the best management and design practices, policies and tools related to product development were the units of analysis to be counted. The approach involved both manifest and latent content analysis, since frequency of occurrence of practices, policies and tools were counted, and the results used to infer the companies' approach for product development, and to identify future trends in PDP.

In order to identify the main categories and dimensions for the classification of PDP policies, practices, methodologies and tools, a type of *grounded theory* approach was followed. The development of inductive categories permits one to link or ground these categories from the data from which they are derived [16]. In this study, the main categories and dimensions were developed directly from the texts, since the surveys reported a variety of practices currently implemented in the companies. An extensive list of policies, practices and tools was derived. These elements were grouped in main dimensions via the affinity diagram technique [24] to provide a conceptual framework for the research. After a conceptual framework was developed, the cases were reexamined in order to determine the frequency of particular practices.

PDP MODEL AND BEST PRACTICES

As mentioned earlier, principal dimensions of product design and development were initially identified directly from the case studies. The conceptual framework illustrated in Figure 1 was developed, with some similarity to PDP frameworks proposed in previous literature (e.g. [5]). Notice that the framework maintains the sequentiality of the principal stages. However, it introduces concepts that influence the performance and quality of the PDP, such as the product strategy, which determines the product development policies (i.e. team approach, design for producibility and design documentation) and the organizational approach followed for product development; the design tools (i.e. computerized tools, Taguchi methods, QFD, etc.) that provide support throughout all the product development cycle; internal feedback, which represent all the company's procedures to provide feedback from subsequent phases; and finally, external feedback, which represents customer involvement through all the stages. It is fundamental to have an effective system of transmission of information along the different phases. Such coordination is represented by the double arrows and dotted lines in the figure. In this section the PDP model will be described, as well as the most important practices found in the BMP surveys corresponding to each of the PDP activities. Please note that there were some categories (New Product Strategy, Pilot Production, Production) which did not directly arise from content analysis of the BMP data; they were included in the model, nevertheless, to give a more complete picture of the PDP.

New Product Strategy

New Product Strategy determines the business requirements that the new products should satisfy in order to be competitive. The requirements can be both company or market driven, which determines the role played by the new products. The firm's new product strategy drives the policies to be followed in the development of new products. There was no information in the BMP data corresponding to this category.

Design Policies

Design policies include established design procedures, guidelines and practices that must be followed at the different stages in the development of new products. Design policies cover areas such as producibility, standardization and commonality, design documentation and personnel. Of the 31 BMP survey reports, 55 percent of the companies have some form of design policy documentation. However, the design policies identified have a wide variety of forms. Some policies stress the general goals that should be accomplished in the design, such as cost reduction, product and quality improvements, design for producibility, smooth transition from R&D to production; others reflect the practices to be followed and tools to be used, such as CAD, CAE, design reviews, team approach, functions involvement (as manufacturing, engineering, marketing, quality assurance), cost target systems, design trade-off analysis, etc. Other policies solely state product specific approaches that should be followed for new product design.

Some companies have extensive and detailed design guidebooks that cover all the aspects of the new product development process, and provide an overall perspective of the company's design process and detailed information regarding different design dimensions. However, detailed documentation is rarely found. Only 3 out of the 31 companies (9.6 percent) appear to have detailed design policy documentation. An example is **IBM Corporation Federal Systems Division**, which is in the process of developing a set of structured design guidebooks which cover ***all*** aspects of the development process. The purpose is to provide a formal framework for a disciplined design approach as well as a good training curriculum for junior engineers. The guidebooks available cover a variety of areas: 1) Program overview, 2) Logic Design, 3) Mechanical Design, 4) Analog Design, 5) Diagnostic Software, 6) Microprogramming, and 7) Power Supply Design.

In two of the companies design policies are a result of the total quality approach implemented in the companies. For instance, **Control Data Corporation, Government Systems Division**, is in the process of developing mechanical design guidelines as a result of Total Quality Management Process (TQMP) recommendations. The main objective of the product development approach is for engineers to *do-it-right the first time* [13]. The result is a functional framework for the design process which covers different product development areas: 1) Design Process, 2) Aerospace Specifications, 3) Component/Material Selection, 4) Human Factors, 5) Mechanical Tolerancing, 6) Product Assurance, 7) Reliability and Maintainability, 8) PCB Design and Documentation, 9) Thermal, 10) Structural, 11) Manual and Automated Assembly, 12) Mechanical Computer Aided Design, 13) Tests, and 14) Finishes.

For **Westinghouse, Electronic Systems Group**, the multi-disciplined team approach and meeting of customer requirements are the underlying goals of the PDP. Total quality implementation for product development is stressed in meeting all systems requirements, setting and achieving project goals in a timely manner, reducing overall costs, maintaining design and manufacturability efficiency, and finally, ensuring customer satisfaction.

Most companies commonly have design guidelines, engineering standards and/or checklists related to the design disciplines concerning a specific product. Generally, the standards and guidelines are written by company experts that have domain knowledge and incorporate lessons learned from past experiences. Some examples are guidelines for systems design, electromechanical design, mechanical engineering design, software and test equipment design and electronic design.

The rest of the companies (45 percent) did not report having written documentation of design policies for new product development. However, this does not mean that a company does not have a policy regarding design of new products. The PDP and design practices used and being implemented may implicitly constitute design policy. In addition the practices and tools used provide some introspection of design policy. For instance, practices and goals such as concurrent engineering programs, the team approach concept, the design rules for the transition between design and manufacturing, and the use of CAD/CAE tools, reflect the firm's commitment toward product development.

Table 2 shows the most common design policies under implementation. It indicates that the most common philosophies under implementation are design for producibility (52 percent of the companies), the team approach (45 percent), design guidelines (42 percent), transition to production plans (39 percent) and concurrent engineering (36 percent). Results indicate that the most common and widely used practices can be linked together in two directly related approaches: design for producibility and simultaneous engineering.

Producibility [4] refers to methodologies, practices and rules that must be followed in the PDP to ensure that the product can be efficiently and effectively manufactured and assembled. In the BMP surveys, design for producibility was identified in different ways. Usually, it involved the specific existence of producibility guidelines or a producibility group in charge of developing the producibility guidelines, where the manufacturing function is early involved. An interesting case is reported by **Texas Instruments, Defense Systems and Electronics Group**, which has implemented the guidelines in a *Producibility Advisor*.

The team approach is also a commonly used practice. Multi-disciplined teams for product design generally are comprised of people from the engineering and manufacturing functions. Functional cooperation is a must for concurrent engineering. It appears that more companies are following the team approach, where the team is responsible for the product development from its initial stages of conceptualization and screening until product launch.

Design guidelines reflect a formal documentation of the company's design policies. It appears to be a commonly used practice to provide written design rules to be followed by in the design process.

It appears that several companies had developed complete design documentation that covered the different dimensions of the design process.

Transition to production programs appears to be a practice moderately used. This practice is directly linked with concurrent engineering, design for producibility and team approach practices already mentioned. The aim is to provide a set of guidelines to smooth the transition from design engineering to production. For some companies, the transition to production plan was strongly influenced by the implementation of the DoD 4245.7 - M templates concepts [31].

Standardization [4] and commonality policies involve the use of standard parts and components in different products for more efficient operations at the design and production stages. This practice reduces costs of production as well as complexity of information systems and simplifies the production process. Standardization appears to be a moderate practice in use (23 percent), and when used is focused on parts and components. It is worthwhile to note that at **Hughes Aircraft Co, Missile Systems Group,** the concept extends further. A special management board and committee has been formed to promote *corporate commonality*, in a variety of areas including: packaging, processing, testing software, common planning, tracking inspection and documentation, common test equipment, methods and procedures, common design tools and common testing methodologies. The aim of *process commonality* is to reduce complexity for any type of process.

Some of the companies surveyed develop PDP-related software in-house. These companies (6.5 percent), such as **Rockwell International Collins Defense Communications**, employ a project management approach to monitor and control software development. Project Management, important as it is to the success of PDP, was not mentioned often within the case data. **Unysis Corporation, Computer Systems Division** and **GTE Government System Corp, C3 Systems Sector**, specifically reported using a project management approach for design of new products. Other companies obviously employed a project management approach, but it was not cited as a significant element.

Idea Generation and Screening

The Idea Generation and Screening stage involves the generation of the product idea based on identification of customer needs and on the company's technological opportunities. Screening is the first evaluation of the new product idea, and represent the initial decision to commit resources to the idea.

These type of activities which are mainly marketing related were barely mentioned in the BMP surveys, due to the fact that design practices were the main focus of the BMP Program. Effective idea generation and screening were apparently assumed preconditions to the design practices discussed.

Preliminary Assessment

The preliminary assessment phase consists of the evaluation of different design concepts/alternatives in order to identify a feasible and attractive project. It involves assessment of the market potential and the competitive environment, and the consideration of costs, technology and resources to be employed. Different procedures can be employed for evaluation and selection of product alternatives. Some selection models are based on qualitative criteria, while others are based on quantitative criteria such as financial data.

Preliminary assessment was barely mentioned in the BMP surveys. From the total, only 13 percent reported to have some type of financial or risk analysis for project selection. Furthermore, only 6.5 percent of the companies indicated use of trade-studies in evaluation of alternatives based on costs and quality. One must presume that some sort of assessment is all PDP, however the predominant lack of discussion as a Best Practice element is intriguing and suggests informality.

Conceptualization

In this stage the product idea is expanded into a fully mature product concept. It involves the translation of customer needs into engineering specifications. The engineering specifications determine the way in which the product is conceptualized by designers. This phase requires the interaction of marketing and design engineering with the customer.

The team approach was consistently mentioned throughout the BMP surveys as a means to involve multiple sources of product knowledge. In most cases, however, this primarily involved only engineering and manufacturing. Marketing involvement in PDP was less frequently mentioned. The most frequent practice concerning translation of customer needs in engineering specifications was Quality Function Deployment (QFD), but it was only reported by 7 percent of the companies.

Design Evaluation and Selection

In this stage engineering analyses are performed in evaluation of design alternatives and typically involve mathematical modeling of the yet-developed product. For evaluation and selection of alternatives, the BMP surveys reported the performance of several different analyses using computerized tools before the selection of the final design and before the development of a prototype (Table 3). The most common practice was thermal analysis (16.3 percent), followed by practices such as finite element analysis (13 percent), aeroscience analysis (9.6 percent), graphical structural analysis (6.5 percent), fluid dynamics analysis (6.5 percent), signature analysis (3.2 percent), etc. Only 6.5 percent of the companies reported to perform worst case analysis (tolerance and/or vulnerability analysis).

Prototype Development and Testing

After the selection of the final product alternative, the product idea is turned into a prototype with designated specifications. In this phase the prototype is subject to physical tests that measure functional performance, robustness to the environment, and reliability. The goal is to verify that the product is capable, reliable, and that it conforms to all specifications.

Prototype testing practices identified within the BMP surveys are listed in Table 4. The results indicate that testing of prototypes during the design process is a common practice. In addition, a wide variety of different types of tests were mentioned depending of the types of products developed in the firms. The most common tests identified were thermal cycling (45 percent of the companies), failure modes and effect analysis (29 percent), electrical and vibration test (23 percent), stress analysis (23 percent) and reliability and maintainability analysis (23 percent). It is interesting to observe the wide variety of tests and testing methodologies being used. Some practices are worthy of mention in that they attempt to decrease the product development cycle time. Functional and environmental tests appear to be important at the prototype stage, since they evaluate product performance in a simulated customer environment. Furthermore, the implementation of automated testing technologies seems to be a future trend.

The results indicate the growing importance of *design for testability*. Design for testability is a practice that can be implemented not only to improve the end product quality but to improve the new product development process. With the implementation of different tests along the process, the design can be tested at different points of development for functionality and for verification of conformance to specifications. Design errors can be detected more quickly, which improves the new product development process quality. The concept of testability goes further than selection of tests. It implies that tests should be designed and developed accordingly to evaluate each product's functionality. Therefore, testing methodologies and testing equipment are important factors for the good performance of the new product development process.

An interesting practice that shows the design for testing approach is shown by companies such as **Hughes Aircraft Co., Missile Systems Group, Litton Applied Technology Division,** and **Texas Instruments Defense Systems and Electronics Group**. These companies emphasize the use of common and networked testing equipment that can be used for a variety of products, which improves the transmission of information and decreases product development cycle time.

Specific tests can be found that are implemented in companies, such as automated chemical analysis, wind tunnel measurements, gear testing, shock inclination and packing tests. The practices involving product specific tests demonstrate the firms' testing policies. A low percentage reported (3.2 percent) to be following these special types of tests, but this can be due to the fact that diverse industries and products were evaluated. In addition, it must be presumed that many of the tests were proprietary in nature, and consequently not presented in the case data.

Pilot Production

Pilot Production is the initial production run with the objective of testing the production process and its final outcome. There was no information in the BMP data corresponding to this category.

Production

Production as used here is the introduction of the final product into full scale manufacturing and product release. While there was information on this category, it was too large to encompass within the context of the content analysis process.

Design Tools

Different Design Tools are provided by management to be utilized at the different phases of the product design. With recent technological advancements a wide variety of computerized design tools (i.e. CAD, CAM, CAE, Artificial Intelligence tools, etc.) are available that can be used to reduce new product development process cycle time and hopefully improve product quality. The use of these design tools must be driven by a firm's design policy in order to be effectively used by the design personnel. The importance of implementing design tools is part of the firm's policy. As stated in **Rockwell Autonetics Electronics Systems** survey, "AES found that these CAE tools could not be imposed into the existing process and culture; therefore a new process and culture centered around the use of CAE tools was required."

A variety of design tools are used by the companies surveyed. The results are indicated in Table 5. The use of computerized tools in design of new products appears to be a common practice being implemented. Seventy-one percent of the companies reported to have databases such as parts and components databases, CAD/CAM databases, specific design databases, engineering databases, field service databases, quality databases, etc. Furthermore CAE simulation appears to be gaining increased importance for new products design, as reported by 64.5 percent of the companies. CAE simulation is used to perform analysis and evaluation of design alternatives such as functional simulation, electrical and digital simulation, software simulation, discrete manufacturing simulation, and product specific simulations such as flight simulations. These results lead one to infer that companies are stressing the performance of computerized analysis at the design stage in lieu of actual prototype testing. The availability of the technology makes it possible to evaluate the design in the early stages, even critical functional and environmental tests that would otherwise be conducted on the prototype. In addition, computerized analysis decreases testing time, which reduces overall product development cycle time.

CAD and CAM appear to be widely implemented (61 and 45 percent respectively). It is possible that many of the other companies not mentioning CAD/CAM have informal systems, thus increasing the actual percentage even more. Furthermore, it appears that the trend is to implement CAD-3D and solid models (26 percent).

Another trend appears to be integration of CAD, CAM and CAE within the context of CIM. Twenty-three percent of the companies reported to be working on CIM integration and having common databases to network CAD, CAM and CAE. CAD/CAM integration is reported by 48 percent of the companies. However, only 9.6 percent specifically reported a direct integration between CAD and CAE. This integration appears to be one of the promising steps taken by companies in order to achieve a faster response to the market by reducing the new product development cycle time, providing information that can be used by the various functions that are involved in the new product development process.

A new trend in the design process itself appears to be the use of Expert Systems in the form of Design Advisors. From the total, 13 percent of the companies are using some kind of design advisor for producibility, knowledge based design rules, advisors for testing and component level diagnosis. For instance, **Rockwell International Collins Defense Communications** and **Texas Instruments Defense Systems and Electronics Group,** reported the use of producibility advisors. Furthermore, **Litton Systems Inc., Amecom Division**, reported the implementation of design rules and guidelines for producibility, through the storage of knowledge from previous designers and experiences, practice with the goal of decreasing design errors and later changes.

McDonnell Aircraft Company provides an interesting case of use of computerized tools, specifically experts systems and CAE simulation. The company has implemented a variety of sophisticated analyses and evaluation tools such as electrical system designs, automated forging designs, automated finish selection advisors, integrated structural analysis, computer graphics structural analysis, experimental modal analysis, computational fluid dynamics, automated mass properties system, crew system design analysis, stress separation analysis, etc. This example is a good demonstration of how design advisors and CAE tools can be used substantially in different areas of product design.

Internal Feedback

Internal Feedback provides information along the PDP that will ensure smooth transition between the different stages, that will eliminate errors in the final stages and will eliminate process disruption. Design reviews and engineering change procedures are examples of internal feedback practices. Design review is a widely used practice, reported by 42 percent of the companies. Approaches include formal, informal, preliminary or critical design reviews, specific design reviews for producibility and engineering reviews**.** Design reviews are usually performed with personnel from different multi-disciplinary functions with the purpose of verifying the current status of a design. Even though companies reported implementation of design reviews within their new product development process, no specifics concerning the number of reviews and points during the process were given. An exception is **Rockwell Autonetics Electronics Systems**, where a flowchart of the electronic design process indicates 5 design reviews: at the completion of requirements definition, concept design, detail design, simulation and analysis, thermal analysis, and prior to the product database release.

A second practice that reflects internal feedback practices is the existence of engineering change procedures. It is not, however, widely used, reported only by 13 percent of the companies. For instance, at **GTE Government Systems Corporation, C3 Systems Sector**, the design change procedure was implemented for the purpose of better tracking the source of design documentation problems. The new design form contains 21 different possible justifications for a design change. **Litton Data Systems Division**, reported a considerable reduction on the average time to process *Engineering Change Orders*. The major change in the procedure was the inclusion of senior personnel to screen the *Engineering Change Requests*.

Internal feedback practices aim to reduce time devoted to implement design changes as well as to decrease the paperwork in administrative procedures. It appears that more work needs to be done here.

External Feedback

External Feedback involves the customer participation and involvement throughout all the stages of the PDP, beginning at idea generation and screening (i.e. customer surveys), up to customer feedback when the product is in the field. It is startling to notice that customer participation was not frequently mentioned in the case study data. This oversight is begging of opportunities.

SUMMARY OF RESULTS

This purpose of this study is to identify common practices used in industry in the development of new products. The content analysis approach employed for evaluation of case studies proved to be a useful tool in organizing and structuring insight. The case studies themselves were the outcome of an empirical research done by the Department of the Navy, with the main goal of identifying manufacturing practices that were distinctive of the companies (Navy's contractors) that participated in the Best Manufacturing Practices Program. The case studies were revealing in both content and lack of content.

The frequency of occurrence of practices, policies and methodologies was counted. The practices, policies and methodologies were the unit of analysis for the content analysis, and were initially grouped together in major new product development dimensions, in order to determine the extent and emphasis given by different companies, as well as for identifying future trends. The frequency of occurrence of the units of analysis leads to infer the following conclusions:

- It appears that the process of design and development of new products is gaining importance among industries. This is reflected in the fact that a variety of sophisticated tools were mentioned, as well as the implementation of design policies.
- With regard to design policies, there is not an agreement on what should be covered by design policies. Some companies emphasize that design policies must be explicit in all the different areas that are comprehended in design and development of new products. However, this is

rarely the case, and design policies were identified in a less general form, emphasizing particular areas such as established design procedures and tools to be employed, and design rules. Furthermore, there appears to be a recognition of the importance of implementation of specific design policies concerning the development of new products as a means of achieving and maintaining a formal new product development process.

- The practices that were most frequently mentioned were simultaneous engineering (team approach), design for producibility, transition to production programs and concurrent engineering practices. The higher frequency of occurrence of these practices reflect the growing importance of functions working together, and of having communication channels created along the PDP cycle, implying that the traditional sequential approach with separate responsibilities for each stage is not valid any more. However, approximately half of the companies surveyed did not report having implemented producibility or design for assembly practices.
- It appears that appropriate implementation of design tools have a positive impact on accelerating the new product development cycle time and on decreasing costs. The use of sophisticated tools for design analyses saves costs in the sense that less number of prototypes are needed. As the technologies are enhanced, a lessor number of prototypes are required. It was found that a strong emphasis is given to computerized design analyses, compared to those performed at the prototype at the post-design stages.
- Design for testability is a concept that was mentioned by some companies and it seems to be an important aspect of the new product development process. The aim of a *testable product* is to design a product that can be subject to different performance and environmental tests during different stages of the product development stages. The development of the appropriate and critical tests not only enhances the quality of the new product development process, since design errors can be detected at early stages, but also assures a better quality product.

However, *design for testability* requires a company's infrastructure for designing and developing the appropriate test procedures, for acquiring and implementing the test methods and equipment and for training the personnel.

CONCLUSION

The analysis conducted in this research is consistent with previous literature. It appears that companies recognize the importance of rapid product introduction as a source of competitive advantage. Companies have implemented different policies, practices and methodologies to improve PDP and to reduce its cycle time. In general, a structured approach to PDP was not found in the BMP surveys. Instead, some companies have implemented different types of *best* practices and policies driven by their competitive strategies and by available technologies. From the results, is evident that companies are placing efforts in implementing sophisticated technologies and design practices, but lack in formalizing (and to some extent standardizing) the entire PDP process.

Even though some common design practices and methodologies were found among the companies, the findings are not conclusive in the sense that the practices were not implemented by the vast majority of the companies. It appears that while awareness of PDP importance is growing, companies are still struggling to find the right mix of techniques and approaches that ensure new product success. More empirical research is needed to identify the existence of a formal PDP, and to evaluate those critical PDP elements that have an impact on new product success. Specifically, a better understanding of the interaction between the organizational and technical elements of PDP is needed in order for companies to take the appropriate planned and strategic actions necessary.

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Table 2: Design Policy

PRACTICES	%
Design for Assembly	52
Team Approach	45
Guidelines	42
Design Reviews	42
Transition to Production	39
Concurrent Engineering	36
Functions Involvement	26
Written Procedures	23
Design Testability	26
Communication Procedures	16
Personnel Exchange	16
Engineering Change Procedures	13
Checklists	13
Templates	6.5
Project Management Approach	6.5

Table 4: Design Tools

PRACTICES	%
Databases	71
CAE Simulation	64.5
CAM	61
CAD/CAM	48
Parts, Components Databases	32
Software Simulation	29
CAD-3D	26
Analog and Digital Simulation	23
CIM Integration	23
CAPP	16
Solid Models	16
Design Advisors	13
CAD/CAE	10
Automated Drawing and Retrieval	5.5
Design Advisors for Producibility	

Table 5: Prototype Testing

PRACTICES	**%**
Thermal Cycling	45
Failure Modes and Effect Analysis	29
Electrical Tests	23
Vibration	23
Stress Analysis	23
Reliability, Maintainability and Availability	16
Functional Tests	16
Integrated Testing	13
Automated Testing	10
Automated Optical Inspection	10
Humidity	10
Design of Testing Programs	10
Test Equipment Design	6.5
Ultrasonic Testing	6.5
Noise/Acoustics Tests	6.5
Automated Calibration System	6.5
Digital Test Technology	6.5
Others	3.2

Table 6: Quality Management Practices

PRACTICES	%
TQM Approach	42
SPC	35.5
Suppliers Program	32
Problem Solving Methodologies	23
Quality Circles	23
Quality Reporting System	16
Taguchi Methods	13
Defect Reduction Program/Defect Analysis	10
Others	3.2

Table 1: Companies

No.	Company Name
1	Control Data Corporation, Government Systems Division
2	Engineering Circuit Research
3	General Dynamics, Forth Worth Division
4	General Dynamics, Pomona Division
5	General Electric, Naval and Turbine Systems
6	GTE, Government Systems Corporation
7	Harris Corporation, Government Support Systems Division
8	Honeywell Inc, Underseas Systems Division
9	Hughes Aircraft Co. Missiles Systems Group
10	Hughes Aircraft Co. Radar Systems Group
11	Hughes Ground, Systems Group
12	IBM Corporation, Federal Systems Division
13	ITT Defense Technology Corporation, Avionics Division
14	Litton Data Systems Division
15	Litton Applied Technology Division
16	Litton Systems Inc., Amecom Division
17	Litton Systems Inc., Guidance and Control Systems Division
18	Lockheed Aeronautical Systems Co.
19	Lockheed Missile Systems Division
20	McDonnell Aircraft Co.
21	Motorola Inc. Government Electronics Group
22	Northrop Aircraft Division
23	Rockwell International Collins Defense Communications
24	Rockwell Autonetics Electronics Systems

No.	Company Name
25	Standard Industries
26	Teledyne Electronics
27	TI, Defense Systems and Electronics Group, Lewisville, TX
28	TI, Defense Systems and Electronics Group, Dallas, TX
29	Tricor Systems Inc
30	UNYSIS Corporation, Computer Systems Division
31	Westinghouse, Electronic Systems Group

Table 3: Design Evaluation

PRACTICES	**%**
Thermal Analysis	16
Financial Analysis	13
Finite Element Analysis	13
Aeroscience Analysis	9.6
Digital Circuit Analysis	9.6
Trade Studies	6.5
Vulnerability Assessment	6.5
Tolerance Analysis	6.5
Fluid Dynamics Analysis	6.5