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Tutorial

A tutorial on implementing concurrent engineering in new product development programs

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Abstract

The 'concurrent engineering' approach has radically changed the ways that new products are developed in many firms. However, implementing concurrent engineering has not always proved easy. As the popularity of concurrent engineering has grown and its applications have become more diverse, the core concepts that define concurrent engineering have become more and more vague. In addition, managers have found that different project, company, and industry contexts often necessitate customized approaches to concurrent engineering. This tutorial clarifies the concepts and methods that are central to the concurrent engineering approach. In addition, it examines the need to tailor the elements of concurrent engineering to match specific program priorities and product characteristics. Finally, the tutorial suggests ways that managers can make early concurrent engineering attempts more successful. © 1998 Elsevier Science B.V.

Keywords: Concurrent engineering; Customized approach; New product development

1. Introduction

Recently, global competition has led to shorter product life cycles. Products are also becoming more complex due to rapid developments in microelectronics technologies and increasing consumer demands for lower costs, greater variety, and greater performance. Many well-known companies, including General Motors, Chrysler, Ford, Motorola, Hewlett Packard, and Intel, have responded to these increasing demands by adopting concurrent engineering (CE) approaches to new product development (NPD). In doing so, they have found that CE can improve product design quality while lowering development time and cost. This paper describes the core components of the CE approach and discusses the design and implementation of CE programs.

Concurrent engineering represents a dramatic evolution in NPD practices. Two aspects of CE that distinguish it from conventional approaches to product development are cross-functional integration and concurrency. Conventional NPD programs execute concept exploration, product design, testing, and production activities serially. Each of these development activities is typically controlled by only one functional organization at a time (e.g., marketing, engineering, manufacturing). As one organization completes its design and development activities, it then hands over control and responsibility to the next organizational function. In the CE approach, integrated, multi-functional teams work together, simul-

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taneously attacking multiple aspects of new product development. Control and responsibility are shared among functions and development activities overlap. For example, manufacturing process designers do not wait until product specifications are completed before developing tooling and processing equipment. Instead, they work closely with product designers to concurrently develop product and process concepts. In doing so, manufacturing personnel influence the product design in ways that make the product less costly or more producible. Other functions are similarly integrated into the design process so that their concerns may also be addressed. Concurrent engineering can therefore be defined as the simultaneous design and development of all the processes and information needed to manufacture a product, to sell it, to distribute it, and to service it (McGrath, 1992, p. 91).

In practice, the scopes of concurrent engineering programs vary widely. Some programs address only narrow product producibility issues (e.g., ease of assembly) while executing product design activities. More comprehensive CE programs address the impacts of product design decisions on competitive issues and product life-cycle considerations. Fig. 1 illustrates the types of issues that can add to the scope of a CE program. As the program scope increases, additional stakeholders (e.g., designers, manufacturers, suppliers, customers) must be involved early in design and development processes. As the NPD program organization grows larger, the complexity of design decisions and related trade-offs increases, creating a greater need for a customized management approach to meet the specific needs of the NPD program. For example, managers can implement standard protocols across a wide variety of product development programs in order to ensure that product assembly issues are addressed early in product design. However, the protocols and approaches that managers use to address broad, strategic issues will differ, depending on the NPD program importance, the complexity and newness of the product, and the intended uses and markets for the product.

Section 2 both describes two foundational management initiatives for CE implementation and identifies a number of management methods and tools that support these initiatives. Section 3 examines the need to tailor the design of CE programs to match NPD priorities, product characteristics, and other needs of the project. Section 4 suggests ways that corporate-level managers can make early attempts at CE more successful. Section 5 concludes the paper by summarizing its findings.

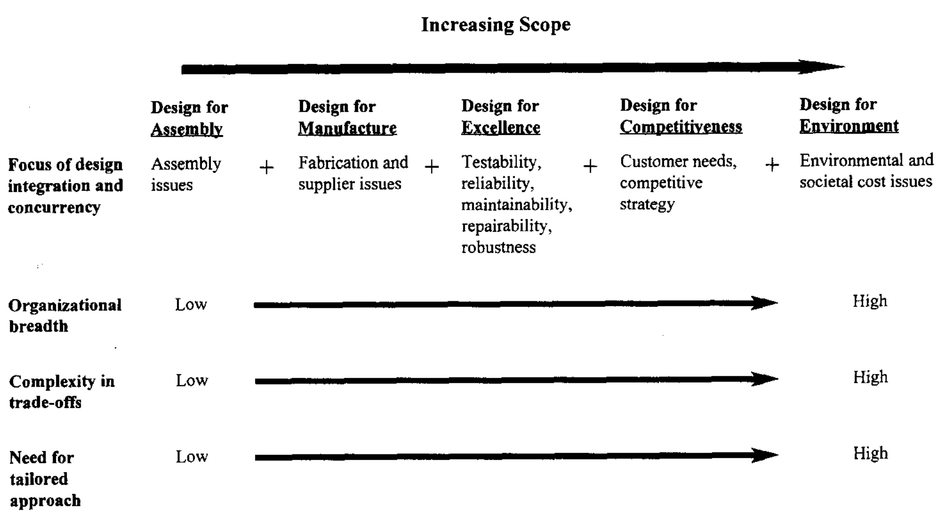

Fig. 1. The varying scope of concurrent engineering programs. Adapted from a figure in Clark (1992).

2. Core initiatives for concurrent engineering programs

Even though the scopes of CE programs vary across firms and across NPD projects, two management initiatives remain central. First, managers must organize project personnel and must fashion program policies and procedures in ways that improve cross-functional integration and communication. Second, CE requires managers to improve methods for design analysis and decision making so that they foster design excellence.

2.1. Improving cross-functional integration

In order to address concurrently the many decisions involved in NPD, persons from different organizational functions must be willing to collaborate, share information, and resolve conflicts quickly and effectively. A number of management methods and tools have proven effective for encouraging these behaviors (see Table 1). These approaches support three core management activities that are central to improving cross-functional integration: (1) setting and analyzing goals, (2) directing and controlling integration, and (3) encouraging communication and awareness. For example of applications of these activities in firms, see Swink et al. (1996a).

2.1.1. Setting and analyzing goals

Clearly defined goals and initiatives reduce non-constructive conflict and increase collaboration (Pinto et al., 1993; Sherif, 1962). High-level program goals also motivate cross-functional integration by providing rallying points for team members from different functional areas. For example, a recent product development project at Texas Instruments had a goal of cutting product weight and cost by 30%. This objective provided the impetus for interaction between engineers from manufacturing, purchasing, design, reliability, producibility, and other functional areas. Team members found that clear, prespecified goals were useful in resolving conflicts between functional concerns, because they focused the team's emphasis on goal achievement, and not on assigning blame.

Early goal-setting in NPD typically centers on establishing program objectives. Many firms find that significant up-front efforts to determine the product performance needs of specific customers also yield great benefits. As part of a recent new truck engine development project, Cummins Engine created advising councils made up of key customers and distributors. The company flew council members to corporate meeting sites to discuss product needs and design ideas, and sent project design and marketing personnel throughout North America to interview individual users of engines produced by the firm and by its competitors. Project managers and design engineers interviewed truck fleet managers and truckers at truck stops. Engineers even rode with truck owner–operators for days at a time to determine what engine attributes were most important to them. Product designers found that several product features they had not considered to be important were actually highly valued by future customers. In addition, the first-hand knowledge gained by marketers and designers served to clarify design goals and reduce conflicts over design features.

A potential danger associated with this approach to information sharing is that competitors may gain access to proprietary product design information. Some customers may even be potential competitors via backward integration. Thus, it is important to consider competitive risks when choosing customers to survey and designing data-gathering efforts.

Another difficulty firms face in this process is how to properly balance the differing and sometimes competing needs of customers in different businesses and in different parts of the world. One approach for balancing competing customer needs is to narrow design attributes through product benchmarking, the process of identifying key parameters for the best competing products. For example, Ford's recent redesign of a bumper system for the Taurus identified a Honda bumper system as best in class. Where conflicting customer desires dictated different product design specifications, attributes closer to the Honda system attributes were chosen.

Goal setting in product development involves the difficult task of decomposing customer needs into design parameters. Quality function deployment (QFD) is widely regarded as a useful tool for translating customer needs into technical targets (Hauser and Clausing, 1988). Essentially, QFD requires a cross-functional team to generate and evaluate customer attributes and the requisite engineering specifications.

Table 1
Improving cross-functional integration: methods and tools

Setting and analyzing goals	
Costumer surveys	Formal or informal mechanisms for assessing: (1) external customers' desired product attributes, or (2) needs of internal customers (e.g., functional groups within the product development program). Data gathering mechanisms include direct interviews, surveys, focus groups, steering committees, etc.
Quality function deployment (QFD)	Methodology which employs interaction matrices to translate customer needs into design and process specifications
Cause/effect analysis	Systematic organization of data which highlights key issues/concerns in a system (e.g., pareto analysis, fishbone diagrams, block diagrams, etc.)
Product benchmarking	Development of goals or procedures based on competitors' products and processes or on industry norms
Super-ordinate project goals	Over-arching goals that are urgent and compelling for all groups and whose attainment requires the resources and efforts of more than one group. Example: reducing product weight and cost by 30%
Return map	Graphical representation of product cost and revenue forecasts over time. Used to assess the effects of product features, price, etc. on the projected amount and timing of profits
Directing and controlling integration	
Organizational rules	Organization-wide, documented, standard operating procedures aimed at directing and controlling cross-functional integration. Example: broad, outlined approach to concurrent engineering
Project specific rules	Project unique, documented procedures for problem or conflict resolution, aimed at increasing certain dimensions of cross-functional integration which are important to the project
Pre-project training	Specialized project training including key activities, responsibilities, events, and cross-functional integration procedures
Project contract	A detailed work plan specifying how the project will be conducted and outlining product goals, resource estimates, schedule, deliverables, etc.
Off-program initiatives	Organizational campaigns or philosophies developed outside the specific product development program. Can be general programs (e.g., zero defect, process re-engineering) or specific improvement efforts (e.g., CAD system upgrades, parts standardization, design standards generation)
Encouraging communication and awareness	
Cross functional teams	*Program team*: management review level team, usually made up of functional managers. Focus is on business integration and program management *Technical team*: product level technical team made up of program management, key customers, lead engineers, and functional representatives. Focus is on technical oversight and system integration *Design-build teams*: permanent teams whose mission is to design a particular assembly or sub-system and the process to produce it. Focus is on resolving performance/design/manufacture issues or conflicts *Task forces*: temporary team assigned a particular problem, investigation, trade-study, etc. *Integration teams*: consolidations of design-build teams in later stages of development. Focus is on revising design to produce product variants or next generation products
Team incentives	Monetary or other compensation which rewards team participation and performance
Liaison roles	Specifically charging person(s) to liaise between different functions to promote two-way communication
Secondment	Movement of a person from one department to another for a fixed term in order to interject the considerations of one function into another function
Role combination	Taking tasks that were previously performed by a number of people and bringing them together to be done by one group of people. e.g., each engineer does design, drafting, and NC programming
Collocation	Locating the work sites of key program personnel within close physical proximity
Open-door policies	Explicit lowering of organizational or other barriers to improve accessibility and communication between functions or managerial levels
Meetings	*Periodic review meetings*: daily or weekly meetings which review progress toward specified action items *Milestone meetings*: key design review oriented meetings held at the end of a design/development phase
War room	Dedicated meeting rooms where key status reports, charts, etc. are displayed continuously
Design database	Shared database which can be accessed by multiple functional representatives
Electronic communications	Electronic mail, electronic/telephone conferencing, etc.

House and Price (1991) proposed an interesting mechanism for tracking a program's monetary and time-related goals: the 'return map'. The process involves forecasting project costs and returns over time and estimating how changes in product design might effect these outcomes. Graphs are used to identify project performance expectations at several critical points along the project time line. Estimating time-to-market, project break-even time, etc. early-on in the program requires marketing, design, and manufacturing personnel to work together to define and adopt goals pertaining to product cost, profitability, and the development schedule. As the project progresses, these targets provide super-ordinate goals for all functions. In addition, high level cost goals can be allocated to component levels of the product to provide specific production cost targets for design teams (see discussion of design-to-cost methods in the final paragraph of Section 2.2.2). By tracking performance against these goals, functional managers can continually reassess their activities against overall project success.

By clearly prioritizing project goals, managers can influence both the degree of interaction between certain persons and the emphasis of their interactions. For example, setting aggressive product cost goals is likely to stimulate intense manufacturing-design interactions, since both parties are needed to generate and evaluate cost reduction ideas. On the other hand, if minimizing the cost of initial product development activities is highly prioritized, manufacturing-design interactions may be stifled due to an unwillingness to pay the up-front labor costs of early manufacturing involvement. Development project managers should carefully identify the greatest needs for functional integration and design program goals accordingly.

2.1.2. Directing and controlling integration

Project managers must also design procedures that direct and control functional interactions. Many firms have corporate standards and procedures which direct conflict resolution activities and establish forms of communication between different functional organizations. Unfortunately, bureaucratic policies frequently hinder cross-functional integration. Moreover, the complexities and uncertainties associated with product development often necessitate the use of project-specific rules and procedures.

Some firms formally document the major phases and general deliverables for any product development program in the form of a program contract. A 'blank' program contract contains templates for establishing the 'who, what, where, when, and how' of specific, key tasks on the project. Intense preprogram training may be connected with the development of the program contract, including discussions which identify the most important project management aspects and product design requirements. The effectiveness of program contracts and training processes lies in the ability to adapt broad organizational rules and procedures to the specific needs of the program at hand.

Corporate initiatives such as quality and productivity improvement programs are often useful for directing integration. A number of NPD projects have effectively integrated key components of corporate initiatives into their program management plans. For example, one program manager leveraged a company-developed quality improvement procedure by establishing it as the basis for team interaction and problem solving on his project. In another case, a project manager was able to institute major procedural changes by establishing his project as part of a larger, organization-wide effort to generate product design standards. The potential danger of relying heavily on a corporate initiative is that project specific goals may be overshadowed by the initiative. Compliance with a standardized procedure should never take precedence over achieving key project objectives.

2.1.3. Encouraging communication and awareness

The use of cross-functional teams is a fundamental method for fostering communication on CE projects. While team arrangements vary, three organizational levels of teams frequently appear in NPD programs: a program management team, a technical team, and design-build teams. Fig. 2 illustrates relationships among the teams.

Program management teams typically include the program manager, marketing manager, finance manager, operations manager, aftermarket manager, and design managers. This group provides management oversight and planning, approves large resource allo-

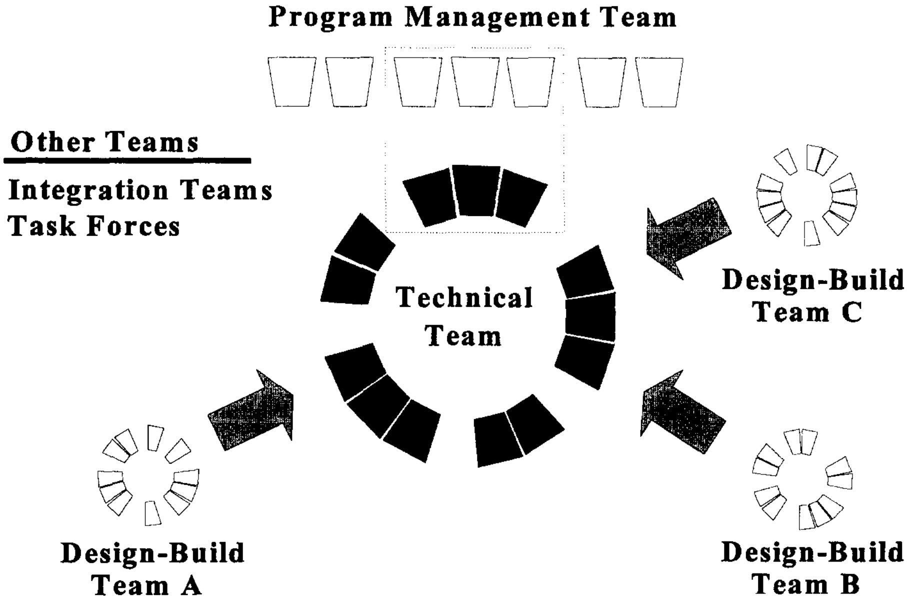

Fig. 2. Concurrent engineering team structure.

cations, approves and controls the project budget, and manages the project schedule.

The technical team reports to the program team and provides technical oversight, approves key design decisions, and maintains consistency between design elements. Engineering managers from design and functional support areas are typically members of the technical team, along with representatives from marketing, service, manufacturing, quality assurance, test engineering, drafting/documentation, and key customers and suppliers.

Membership of design-build teams replicates the technical project team at lower levels of the product structure. Each team is oriented around a particular product component, with responsibility for delivering designs, prototype hardware, process plans, sourcing strategies, quality engineering, maintenance plans, and after-market support plans. These teams are frequently co-led by design and manufacturing engineers who maintain high degrees of design authority and budget control. Suppliers and counterpart engineers from partnering companies also get involved at this level.

Managers often mention that it is difficult to get team members to work together as an actual team, not just as an 'information exchange group'. The key to fostering teamwork is to vest the team with responsibility for its deliverables and the authority to obtain necessary resources. Without these, most people will focus on their individual responsibilities and will view team membership as irrelevant to their 'real jobs'.

Most firms use 'recognition' as the primary incentive for motivating individuals and teams. For example, some firms establish a corporate management office that formally registers teams and that reviews documented product design improvements or cost-saving suggestions. Team participation may be also assessed as part of an annual review process, addressing each employee's ability to participate in teams or to lead teams.

Incentive schemes can provide even greater motivations for teamwork. An innovative approach taken at Thomson Consumer Electronics was to structure incentives for the project team as if it were a small venture company. Each of the technical team members received a confidential allocation of project-stock shares based on his or her importance to the project. The value of the shares was increased or decreased according to the timely achievement of milestones. Timing of the payouts on the value of shares were tied to performance in initial production and in the first year's service calls (Swink et al., 1996a).

Some companies encourage teamwork by increasing each team member's sensitivity to the needs of the other team members. Larger projects establish liaison positions for personnel who act as go-betweens, and sometimes mediators, for major functional groups. Other approaches give team members a broader base of experiences through role combination or secondment (see Table 1). These approaches increase awareness of functional concerns by moving personnel or responsibilities between functional departments (Voss et al., 1991).

Providing access to people and information is important. One way managers ensure access is through collocation, that is, placing the work sites of personnel physically close to one another. The daily contact and socialization enabled by collocation also encourages team building and communication. The prevalence of sophisticated electronic communication systems has caused some to question the need for collocation, particularly since it can be very expensive (Rafii, 1995). However, many project managers still believe that there is no good substitute for face-to-face contact.

A simple and effective way to provide ready access for team members to project information is to centralize materials in a 'war room'. Many firms use war rooms as repositories for prototypes, schedules, performance reports, and other project information. Electronic mail can be a powerful tool for rapidly communicating product and project information to wide audiences. In essence, electronic mail can be used to create a 'virtual war room' on electronic networks. Information can also be centralized on computer-aided-design (CAD) databases that provide instant access to the most current design data. Information can then be quickly downloaded for use in process planning and computer-aided manufacturing. Further advantages of CAD systems are discussed throughout Section 2.2.

2.2. *Improving design analysis and decision making*

An excellent product design maximizes customer satisfaction while leveraging the company's production, sales, and service capabilities. In order to produce excellent designs, successful CE programs utilize methods and tools aimed at improving design analysis and decision making. These methods and tools may be grouped under the following objectives: (1) capturing and applying best practices in design, and (2) facilitating design generation and analysis. Brief descriptions of these methods and tools are given in Table 2.

2.2.1. *Applying best design practices*

The conventional way of ensuring that good design practices are followed is to give functional engineering representatives approval authority for all designs. Many firms now include functional review stages as part of their standard design generation processes. A designer creates a part design, for example, that is then serially reviewed and revised by a number of functional experts. The inefficiency of this process is that rework is institutionalized and very little learning is transferred to the designer.

A more productive and efficient solution is for designers to incorporate good design practices in the initial process of generating the design. In order to minimize design rework, progressive firms are seeking innovative ways to train designers in good design practices. Depending on the nature of the designer's tasks, training in general design axioms or guidelines may be appropriate. In other cases, training in specific design rules which pertain to commonly used manufacturing processes may be more effective.

Many companies have put great effort into generating design guide documents. These often voluminous works are distributed to designers, where they usually sit idly on the engineer's shelf gathering dust. To reinforce published design rules, some firms are creating internal consulting groups, staffed by skilled and experienced engineers, and separated organizationally from other functional units. Representatives from the group are routinely assigned to NPD projects to assure that state-of-the-art design practices are followed and to serve as liaisons to functional experts.

Computer-aided-engineering (CAE) tools also reinforce good design practices. Sophisticated CAD systems act as databases that can rapidly transmit design data to co-workers in locations around the world. Further, CAD systems can create and analyze three-dimensional models of parts and assemblies,

Table 2
Improving design analysis and decision making: methods and tools

Capturing and applying best design practices	
Functional approvals	Including specialty engineering groups and manufacturing engineering as sign-off stages in the design generation process
Internal consultants	Formal organizational unit populated by experts in process-oriented fields (e.g., assembly, metal fabrication, test, etc.) who act as consultants to design engineers
Design axioms	Fundamental principles of good design which apply to a full range of design decisions, stages, and processes (e.g., (1) Each functional requirement should be satisfied independently by some aspect, feature or component within the design; (2) Good designs provide required functions with minimal complexity)
DFM guidelines	Design practices derived from design and manufacturing experience (e.g., (1) minimize part count; (2) modularize the design; (3) minimize assembly directions)
Process design rules	Highly specialized rules for a particular industry or process implementation (e.g., minimum producible wall thickness for investment castings is X inches)
Designer's toolkit	Adds physical examples, CAD-based aids, and other tools to process rules regarding a specialized manufacturing facility
Boothroyd–Dewhurst DFA method	Systematic, computer-based implementation of assembly-oriented design guidelines which includes a design efficiency rating system
Computer-aided DFM	CAE tools which integrate parametric, feature-based design capabilities with access to specific manufacturing process and quality data
Facilitating design generation and analysis	
Group technology	Classification and coding approach which seeks to exploit geometric or production similarities among parts
Preferred parts or supplier classifications	Approach which seeks to limit designers' choices of components, materials and sources to preferred, approved, or standard items
Taguchi methods	Statistical design of experiments approach for producing 'robust' designs
Failure mode and effects analysis	Methodology for studying the causesand effects of potential manufacturing process failures
Manufacturing process simulation	Computer-based facilities which simulate the variation of manufactured outputs for given design parameters
Rapid prototyping	Dedicated facilities which quickly produce physical models to support tooling or process design
Value analysis	Multi-disciplinary evaluation of product function to cost ratios. It seeks to maximize performance per unit cost
Design-to-cost methodology	Systematic approach for allocating production or product life-cycle cost targets to sub-system elements

reducing the need to build expensive and time consuming physical prototypes. For example, CAD systems can automatically analyze assembly designs to identify areas of potential interference between parts. Many CAD systems embed process information and design rules directly into the design software so that it may be linked to certain design features. For example, when a designer draws a hole, he can then simply highlight the hole and a pull-down window of information automatically provides a listing of processes that could create the hole, typical dimensional tolerances, defect rates associated with each process, and any other rules-of-thumb related to the feature. Some companies have created expert systems that enhance the evaluation of design choices. In addition, numerous off-the-shelf CAE systems exist that address stress and thermal analyses, mechanical assembly, printed circuit board design, and integrated circuit (IC) design.

These systems provide designers with real-time access to best design practices. As a result, elements of good design are incorporated into product components as they are generated, reducing the need for rework following functional reviews. An added benefit is that constant reinforcement helps designers learn design rules more quickly, because they are applying the rules instead of simply reacting to critiques and suggestions from technical specialists.

2.2.2. Facilitating design generation and analysis

In large organizations, designers often waste time and resources by unknowingly recreating existing designs. CAD systems can be linked with databases that contain information on preferred components, existing designs from other products, and suppliers of purchased items. Group technology-based classification and coding systems create alpha-numeric codes to represent vital functional or processing characteristics for parts and components. These systems enable designers to easily search design databases for existing designs which meet their current needs. Similarly, databases which prioritize certain components and vendors can speed up a designer's search for suitable parts. Coding systems also allow manufacturing planners to identify 'families' of parts that have similar design or processing characteristics. These approaches reduce design time and reap enormous benefits in manufacturing because fewer unique parts must be fabricated and inventoried, less special tooling is needed, production scheduling is simplified, and less disruption is experienced.

Many design tools and methodologies exist for facilitating process-oriented design analyses. Taguchi methods (Ross, 1988), failure mode and effects analysis, simulation, and rapid prototyping can be used to evaluate design performance and producibility tradeoffs. Product cost budgeting and value analysis techniques can also be useful for evaluating interdependent relationships of design choices. Design-to-cost methodology is an approach in which an overall unit product cost goal is broken down into specific cost targets, one for each of the major components making up the product. Once an individual cost target is set, say, for a subassembly, then alternative means for reaching the cost target can be evaluated. Value analysis and tradeoff analyses can be executed to optimally allocate dimensional tolerances, functional requirements, and other cost drivers among components in the subassembly. These analyses provide a basis for interaction and joint decision making involving teams made up of designers, product support and manufacturing representatives, and suppliers.

3. Designing a concurrent engineering program

To maximize the effectiveness of CE, managers need to identify the specific challenges of each project and to customize NPD processes to address these challenges. Fig. 3 suggests that NPD program priorities and project/product characteristics influence choices in CE program design. Managers should also consider company culture and the level of experience program personnel have with CE. These issues are briefly discussed in the following sections. (For recent research addressing the linkage of CE program forms to NPD project priorities and characteristics, see Swink et al. (1996b)).

3.1. NPD program priorities

One of the difficulties associated with implementing CE is deciding what activities should be done concurrently and where the most important points of integration are. Program priorities should drive these decisions. Customer desires and competitive threats establish the relative priorities placed on design quality, product costs, and product introduction speed.

Excellent design quality differentiates products via superior product performance, features, reliability, serviceability, durability, or aesthetics (Garvin, 1989). Design quality is often highly prioritized if customer needs are not clearly understood. This emphasis dictates intense interactions between marketing and design engineering personnel. Product cost is often a high priority in incremental product redesign projects. When new technologies or other product differentiation dimensions are absent, product cost becomes a primary basis of competition. Interactions among designers, suppliers, and manufacturing personnel are important in this situation. The timing of a new product's entry into the marketplace is critical when opportunity costs are high, such as when a competitor is developing a similar product. Under these conditions, management should prioritize development speed (Krubasik, 1988).

3.2. Project / product characteristics

The configuration of a CE program also depends on the complexity of the product, the level of innovation attempted in the development effort, and the technical risk involved in the project. Product complexity is reflected by the number of people, functional specialties, and outside suppliers involved in NPD and by their degrees of interdependency (Griffin, 1993). The hierarchy and constituency of project teams and integration systems should be designed to ameliorate the negative effects of this complexity. The level of innovation in NPD projects is often an important determinant of development time and product quality (Clark, 1989; Griffin, 1993). The inclusion of many product components or development tasks that are new to the developing company may call for new relationships among development partners. Technical risk results from high levels of uncertainty regarding product or process technologies (Moenaert and Souder, 1990). New technological developments increase the need for interactions among designers and team members inside and outside the firm who have the expertise needed to reduce technical uncertainties.

3.3. Linking the CE program design to product development needs

Teaming arrangements, integration systems, goals, policies and controls, and the scheduling of activities provide the mechanisms for ensuring that the CE program is consistent with the priorities and challenges of the development project. These program design choices need to be internally consistent and mutually reinforcing. At the same time, the CE program design should stimulate group interactions considered to be crucial for meeting design quality, product cost, and project timing goals.

Eight major groups play important roles in the product development process (these are illustrated in Fig. 4). Since no single group can be the repository of all the knowledge needed to complete NPD, these groups must integrate their knowledge of techniques, processes, and data. Product designers are at the heart of the development activity. They are charged with coordinating and completing the product development tasks on a timely basis and in keeping with the product strategy. Within the product design function, numerous specialty areas (like electrical systems, mechanical design, software, etc.) must be integrated so that performance and cost targets are maintained. Customers provide important information regarding product features, performance requirements, ease of use, reliability, etc. Marketing person-

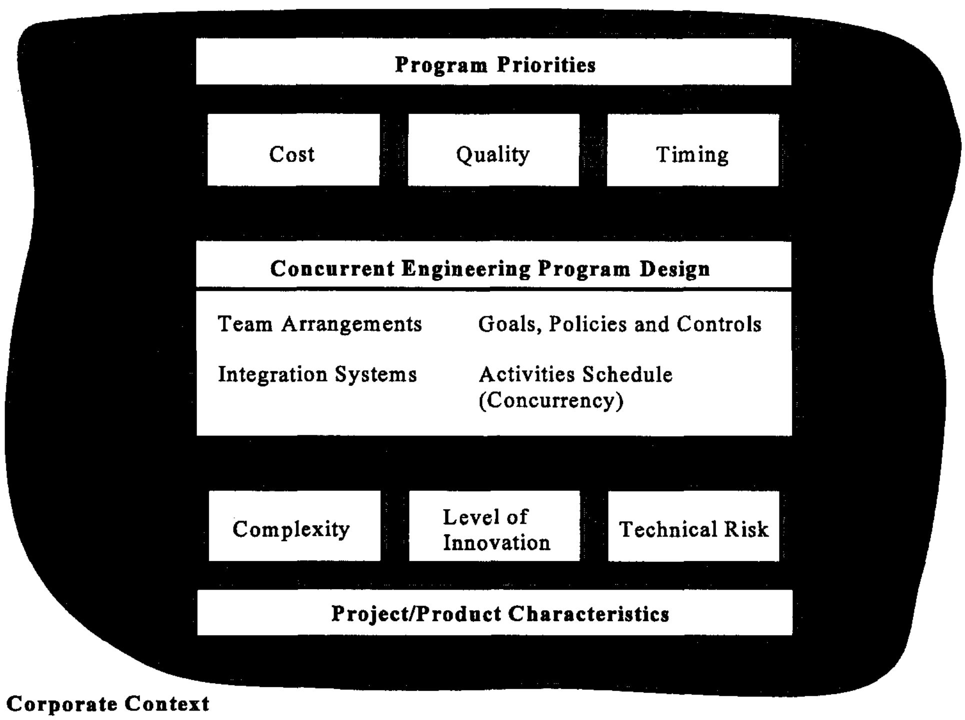

Fig. 3. Influences on concurrent engineering program design.

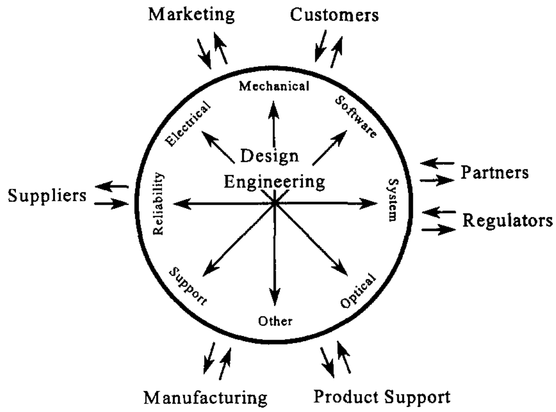

Fig. 4. Interacting groups in concurrent engineering.

nel help gather and interpret this information in light of the overall business strategy and intelligence regarding competitors' products.

Partners and regulative groups can have substantial influences on the design engineering group, especially when product components involve new or unfamiliar technologies. Many benefits have been tied to the early involvement of suppliers in NPD. In addition to offering suggestions and technical solutions, suppliers can bring an unbiased outside perspective to decisions. Early involvement also provides opportunities to evaluate and solidify relationships with suppliers. Manufacturing and service support groups play crucial roles in defining the company's core competencies, in assessing manufacturing and product support requirements, and in designing the processes needed to produce and maintain the product.

The degree of influence that each of these groups exerts in NPD should reflect program priorities and project characteristics. Leadership roles should be played by functions who can reduce uncertainty in the areas of greatest need. For example, uncertainty can exist regarding customer preferences, competitor moves, product technology, process technology, and supplier capabilities. After recognizing the particular needs of the program, managers can design team arrangements, integration systems, goals, policies, and controls to prioritize and motivate the proper intensity and timing of needed interactions between personnel.

Scheduling concurrent execution of design and development activities can also stimulate needed cross-functional interactions. Fig. 5 illustrates relationships among three different types of concurrency. *Project phase concurrency* involves simultaneously developing market concepts, product designs, manufacturing processes, and product support structures. *Design concurrency* involves the overlap of design disciplines (e.g., system, software, electrical, and mechanical engineering) so that system level and component level designs are produced concurrently. *Product concurrency* is the overlap of separate but related new products requiring coordination between NPD programs. For example, product concurrency exists in the concurrent development of first generation and next generation products, or in the development of separate product variants. The arrows pointing to the left in Fig. 5 indicate that concurrency increases as latter activities are executed earlier and earlier in time. As more concurrency types are employed and levels of overlap become greater, there are concomitant increases in the number of relationships that must be managed and in the severity of design risks that are undertaken.

4. Keys to successful implementation of CE

The previous sections of this tutorial have emphasized the importance of various managerial methods and tools for implementing a CE program. The involvement of corporate-level management is also important to the success of CE, especially for initial attempts to change to this innovative approach to NPD. Discussions with product development managers have revealed four critical corporate management factors. To increase the probability of success, managers must: (1) elevate the project, (2) elucidate goals, (3) eliminate barriers to integration, and (4) elaborate CE processes.

4.1. Elevate the project

For most firms, CE is an unconventional approach to product development, requiring personnel to behave in non-traditional ways that violate prevalent habits and management philosophies. Consequently,

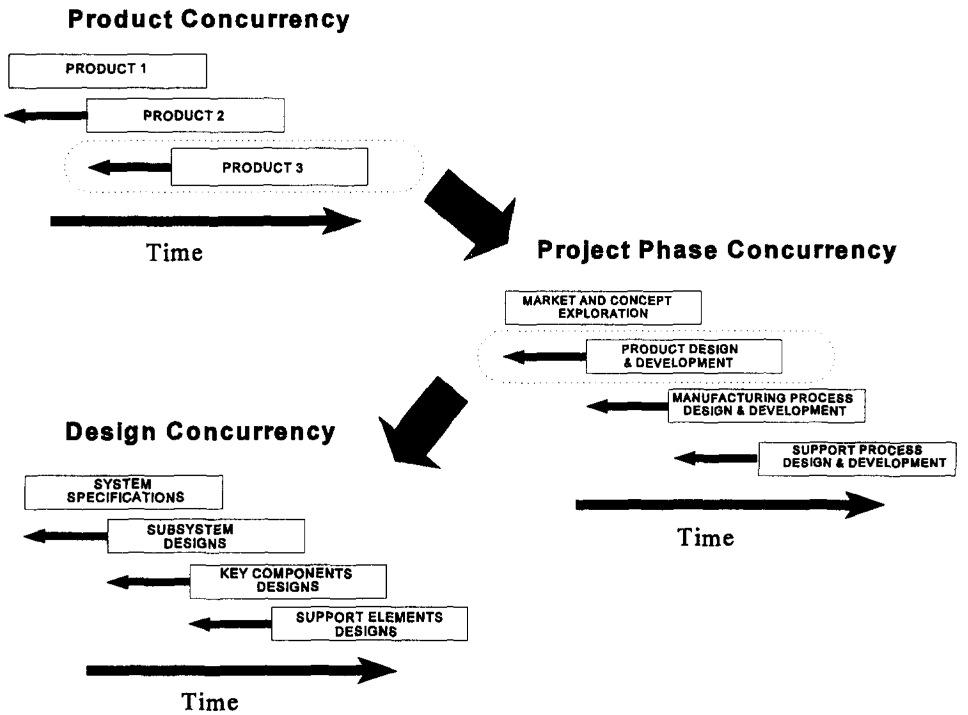

Fig. 5. Different types of concurrency.

for early attempts at CE it is vital to get people to view the project as 'special'. Creating a crisis environment is one way to break people of conventional practices. A sense of urgency can encourage team members to overcome barriers formed by the corporate culture and standard operating procedures. Furthermore, when team members perceive that the project is unique, they often become more interested, take greater ownership, and are more willing to take risks.

Top management commitment is crucial to success. A high level champion for the project provides the energy and enthusiasm needed to get people to change. Committed top level managers are also more willing to fight for necessary project resources. This is especially important since CE development programs can be expensive to implement initially. Resource requirements for early development stages are often higher than those for conventional development efforts.

4.2. Elucidate goals

Goals drive performance! In CE projects it is important to define goals that stimulate interactions between the right groups of people, at the right time, and to the right extent. Defining common goals that span different functions is a very effective means for stimulating integration. Common, globally-identifiable goals produce a common language for the project and a common sense of purpose. In addition, team-based performance measures and feedback that are related to super-ordinate goals allow team members to share the success or failure of their efforts.

Goals which are tied to customers' needs can serve as rallying points for team members from different functional areas. Focusing on the customer produces a higher quality, customer-pleasing product. In addition, customer-focused goals help to resolve conflicts between different functional groups. Team members stop looking at each other and playing the blame game. Instead, they are compelled to work together to satisfy the customer.

4.3. Eliminate barriers to integration

A fundamental barrier to integration in most large organizations is the bureaucracy. Standard operating procedures often create functional barriers which must be broken down. In these situations, it may be useful to separate the project from the larger organization by dedicating resources and by realigning reporting relationships and reward structures, at least temporarily.

Forming teams can cause conflicts and upset well-established domains of power. Team members may be put in situations where they must choose between benefiting the project and benefiting their own home functional areas. Functional leaders may try to exert control over portions of the project that they consider to be exclusively within their domains. Project leaders should try to anticipate these struggles and manage the shifts in power.

Poor communication between project team members can also create barriers. Consequently, real-time feedback and effective communication must be key priorities for the project. Computer networks, design databases, and CAE tools are all fundamental for supporting CE processes.

Program managers must identify barriers that present the greatest obstacles and apply appropriate tools and approaches to break them down. The methods described in Tables 1 and 2 offer means for doing so. Unfortunately, firms often find barriers difficult to overcome because of restrictions presented by unionized compensation arrangements, strong bureaucracies, and strictly defined job categories.

4.4. Elaborate concurrent engineering processes

Team members require more than technical skills and information access to be effective players in a CE environment. They also need a clear understanding of the CE process itself. A well-defined process must be established and clearly articulated to all team members within and outside the firm.

Defining the process means developing a shared vision of the important dimensions of CE. Managers need to explore how CE approaches can be tailored to meet specific project needs. Furthermore, managers need to capture learning from CE experiences, and to leverage the learning by peppering NPD projects with people who are experienced in the process. Sharing project documentation and post mortem project analyses across divisions within the firm can be helpful in disseminating learning.

For most companies, the process of CE begins with a recognition of elementary relationships among the activities each functional area performs. To maximize the effectiveness of CE, however, this initial recognition must evolve into a holistic view which captures all of the interactions and interdependencies among development activities.

5. Conclusion

This tutorial has sought to identify the core initiatives that are common to most visions of CE. At the same time it has emphasized the need to customize each implementation of CE in accordance with particular NPD program requirements. A number of management methods and tools have been described. In addition, the tutorial suggests some key strategies for increasing the probability of success for a firm's early attempts at implementing CE.

Concurrent engineering processes are sometimes viewed as expensive in the short term, requiring resources and levels of commitment that may not be available. However, when appropriately used, CE can produce organizational benefits that far exceed the profits associated with any single product. For example, some companies have documented savings in overall product development costs of 20%, reductions in development time of 50%, and reductions in engineering design changes of 45–50%. More importantly, successive CE development programs build upon one another. Improved design processes lead to improved products and services. CE experiences produce engineers and managers who are more aware of the company's goals and of the needs of other functional areas. Combining this type of organizational learning with effective CE processes can provide fundamental sources of competitive advantage.

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