H I G H L I G H T S

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"DESIGN FOR MANUFACTURABILITY"

Overview of Design for Manufacturability Approaches and Objectives

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1. A number of terms are used to characterize the term "design for manufacturability" or DFM. The terms include "simultaneous engineering," "concurrent engineering," "producibility," "design to production transition," "manufacturability assurance process," "early manufacturing involvement" and "design for assembly/test." These terms signify some similarities in methods and goals, but they also mask some differences.

2. Sometimes the goal of DFM is a smooth transition from design to full-scale production. The savings from a smooth transition result from reducing the number of engineering changes that have to be introduced late in the developmental cycle when such changes are costly. The smoothness of the transition depends on the clarity with which design and manufacturing communicate their respective objectives and criteria to each other.

3. Designing products for ease of assembly, test, etc. has the potential for further savings from lower costs and higher quality. This is because there may be as much potential for such savings during the design and development of products as during their manufacture.

4. Reduction in development cycle time may reduce costs still further (and accelerate revenue). Time is saved not so much by eliminating late engineering changes or designing products that are cheaper to make, but by shortening each development phase or by overlapping two or more phases.

5. The difficulty of achieving any of the above goals is influenced by the innovativeness of the product or process, the engineering capability of the firm, the tightness of the schedule, the inter-dependence between system components and how conservative or aggressive are the cost and schedule goals.

6. The evidence from comparisons of Japanese and American auto manufacturers is that overlap of developmental phases is high for both. However, the Japanese have a 50% shorter total development time. Thus, more than overlap of phases is necessary. The real time savings comes from the willingness of the Japanese to make commitments to begin tool and design and cutting before product prototypes have been completed.

7. The willingness of the Japanese to make such commitments is related to the way information is exchanged between design and manufacturing functions. The Japanese exchange information intensively and continuously, while the Americans do so infrequently and in batches.

8. European auto manufacturers have shorter development cycles than the Americans, but longer ones than the Japanese. The Europeans have less overlap between developmental phases and they exchange information in infrequent batches. However, when they do exchange information, the information is very thorough and complete. Their mode of information exchange is congruent with the low degree of overlap between their developmental phases. We have high overlap, but do not always take advantage of it.

Managing Cross-functional Interfaces Across the Product Development Cycle

Josê Martin
E. I. du Pont

1. du Pont has 140,000 employees and sales of 30 billion dollars a year. It has basically two types of units; industrial departments (that make money) and corporate departments (that provide services). Josê is responsible for manufacturing engineering within the Imaging Systems Department.

2. The Imaging Systems Department produces electronic imaging devices that generate, capture, manipulate, store, display and communicate electronic images. The department is organized into Research and Engineering (R&E), Marketing & Sales and Operations. Operations includes Information Systems, Manufacturing Engineering, and Manufacturing Services.

3. Time to market is imperative in the electronic imaging business. A number of activities need to be performed to assure that the development cycle is short, but managed as effectively as possible. The department uses a matrix type structure to

bring all the relevant functions and services to bear on the cycle. This assures that persons responsible for the core technology, process layout, personnel development, services, and the business plan are represented on the product team so that engineering changes can be introduced as quickly and efficiently as possible.

4. An ad hoc committee composed of all managers with relevant resources is convened whenever a product proposal is brought forward. Proposals may be made for new products or for the enhancement of existing products. The committee decides whether to go forward or to kill the proposal. If the decision is to go forward, then the managers have to commit resources. If sufficient resources are not available, then the product will have to wait until such resources are available. Productizing Engineering (PE) generally gets about 20% of the R&E budget for the product to carry out its support and transition to production activities.

5. Many of the functions have a history of autonomy so that much time and thought is needed to minimize potential weakness between development phases. The department tries to create an "enabling environment" for product teams in the form of rewards, tools, training and support. Rewards include bonus compensation at the end of the project for all team members. The department has also developed milestones at which the development cycle is checked to assure that all required services and activities have been performed.

6. The product team is headed by a business manager from the marketing function. Team members are selected by R&E, the sales manager and by José. These managers meet once a month for a day and assess team progress and commitment. The team is physically co-located, although member composition may shift over time. R&E plays a strong role early in the development cycle when an idea is being translated into proof of concept, then "Productizing Engineering" starts to play a strong role (José's responsibility).

7. PE plays an integrator role between R&E and manufacturing and industrial engineering. The PE assures that producibility, serviceability, maintainability, reliability, etc. are considered in the design and coordinates the activities of engineers who focus on fixtures, tools, and procedures for the manufacture of the product. The PE may be responsible for working with two or three different product teams simultaneously.

8. Team performance is measured in different ways for different functions. There are internal measures for manufacturing engineering that are based on performance specifications and budgeted time. There are external measures based on what users within the Imaging Systems Department think of PE's services. José hopes that CMTOC might be able to develop a data base of performance measures from contributing companies against which each company can compare itself to the others.

Survey of Design for Manufacturability Methods

Paul Cohen
Penn State University

1. Paul divided his presentation into several parts. The first part focused on design for automation. Given that the present level of automation is not yet intelligent enough to recognize randomly oriented parts, it is necessary to design parts so that they can move reliably to and from work stations without jamming or losing their intended orientation. For example, parts can be designed to reduce the likelihood of jamming or tangling and to have their orientation more quickly recognized by the automated equipment. They also can be designed to reduce the number of different assembly directions and motions required of the automated equipment.

2. Paul introduced some software that he and Deborah Madeiros have developed under contract to IBM. The purpose of the software is to minimize the number of parts in a product and to reduce the number of fasteners needed to assemble the parts. He demonstrated how the software could be used to redesign a pencil sharpener with fewer parts and fasteners. A greater percentage of the pencil sharpener could be assembled by a robot following the redesign. Finally, he compared the software with Boothroyd–Dewhurst and with Zorowski. He judged that Boothroyd and Dewhurst could be used to assess the cost of assembly. The Cohen–Madeiros software does not assess cost. However, he thought that the Cohen–Madeiros software had better heuristics for redesigning the product and recommended that his software be used first and then use the others for cost assessments. As of this date, IBM considers the Cohen–Madeiros software to be proprietary, so it is not yet available for sale to the public.

3. Paul reviewed some current work being done to develop tools to simulate the production process so that parts can be assessed for fit or tolerance and for identification of possible fixturing and positioning errors.

4. Paul reviewed the benefits of group technology and the conditions making its use increasingly valuable. With increasing parts variety and decreasing lot sizes, parts proliferation becomes increasingly costly. By grouping parts with common characteristics into part "families," group technology can reduce engineering costs by reducing the number of different parts that need to be designed. Common characteristics include common shape and machining processes. Manufacturing costs can be reduced also by simplifying factory layouts through use of manufacturing cells that make families of parts. Once parts can be grouped into families and factory layout simplified, the number of process plans that need to be developed and the time needed to develop them can be reduced also. Cohen and his colleagues, Mackowiak, Wysk and Yang, have developed a software package called "AUTOCODE" that can be used to assess parts for their common characteristics and then group the parts into families.

Panel on "Design for Manufacturability Approaches"

- **Al Brown -- McDonnell-Douglas Missile Systems**

McDonnell-Douglas calls its initiative "Concurrent Engineering" or "CE." Its CE program has four coordinated thrusts. One thrust is early involvement of all relevant functions as well as customer and suppliers. (Suppliers represent up to 70% of their total product cost.) Every design has a producibility review and sign-off from functions. Also, physical facilities are being designed to facilitate team co-location. A second thrust is to introduce automation where possible, e.g., CAD, CAE, MIS, so as to eliminate paperwork and encourage electronic communication between design, manufacturing, etc. A third thrust is validation of tools and techniques such as Quality Function Deployment, Design for Assembly, etc. A fourth thrust is development of an integrated strategic plan. CE is being applied to three candidate programs, the Advanced Air-to-Air Missile, the Tomahawk Block III and the Improved Harpoon.

- **John Dancy — Eastman–Kodak**

Kodak calls its initiative "Manufacturability Assurance." One of its goals is to shrink the time from concept to delivery. It has reduced development time in some cases by two–thirds. Kodak uses cross–functional teams as well as manufacturing sign–off and integrators. Manufacturability Assurance has a very large "tool kit" which includes most of the techniques usually associated with DFM, e.g., Taguchi methods, SPC, QFD, but also includes high performance work teams and performance management (a behavioral modification methodology tied to rewards). Common to these techniques is the goal of better communication of manufacturing process capability to the design function. A development engineer is responsible for the success of the process. The key is up–front specification so that specifications can be translated into quantitative capability. A Manufacturability Assurance Center is used to test process capability on a small scale. The career path for development engineers should require some experience in manufacturing.

- **Ajit Patra — Cleveland Pneumatic**

The design engineer (DE) and manufacturing engineer (ME) meet almost daily. The intent is to have the ME start designing the process early in the design stage. The primary coordinating mechanism is the weekly producibility meeting that is attended by the ME, DE, tool engineer, quality manager and program manager. The meeting is initiated by the ME. The program manager serves as an integrator between functions, but his primary function is to communicate with the customer. Solutions are reached by consensus, but manufacturing and design each have veto power. The approval of additional functions is needed for sign–off on engineering drawings, i.e., quality, materials and process. No drawing is released without approval by all. It is not always clear, however, what specialties should be involved early. This can lead to overlooking some valuable inputs.

The measures that Cleveland Pneumatic uses concern quality, e.g., rework hours as a percentage of standard hours and the number of nonconformance tags generated per part. Another concern is cost which is measured by standard hours/actual machining hours and by tooling cost overrun as a percent of estimated tooling cost. Reduced cycle time is measured by number of manufacturing flow days. In general terms, the goal of the producibility effort is to design parts that can be made easily. The approach reduces conflicts that occur late in development and cuts paperwork and rework.

- **Bob Thomas -- Corning Glass Works**

  One of Corning's major DFM efforts is being undertaken at a plant in State College, PA. The plant is owned jointly by Corning and Asahi of Japan and employs about 800 people. The goals of its DFM program are to reduce product and process development time, improve product quality and selection (first-time yield), and introduce new systems and methods to maintain continuous improvement. They are currently studying various systems and methods and evaluating them for appropriateness to their plant. They have established a working committee to guide the DFM effort and are developing measures by which Corning-Asahi can compare itself against competitors. They have developed an "as is" document which states their current practices and performance level as well as a "to be" document. Some transition projects to help them achieve their "to be" status include product/process modeling, a system of check lists, and the development of user friendly software that incorporates process design rules. They are also undertaking efforts to improve communications between process designers, marketing and manufacturing personnel.

Managing The Design/Manufacturing Interface

Mike Hottenstein
Penn State University

1. Mike visited 34 companies during his sabbatical in 1986-87. Most of the companies were devoting increasing time and attention to managing the design/manufacturing interface. The reasons were the speed with which new technology is being developed, new and more sophisticated products being introduced, product life cycles shortened, and mass markets fragmenting into specialty niches. These trends place a high premium on the rapid development of high quality products.

2. Mike summarized what he saw as the major problems companies were facing in managing the design/manufacturing interface. These problems included lack of a common data base by which design and manufacturing can communicate with each other, lack of rewards for designing products right the first time, failure of manufacturing to communicate what they want from design, uncertainty about how to reward, train and maintain professional engineers.

3. The companies were pursuing four different strategies to better manage their design/manufacturing interface. The first strategy is to improve communication via CAD/CAE systems and to develop a common data base between the design and manufacturing functions. Manufacturing wanted to include data on preferred materials, process capabilities and costs. The second strategy is parts simplification by which the number of parts per product is reduced, modular designs used, etc. The third strategy is to establish new relationships between the functions, such as early involvement of manufacturing in design, co-location, cross-functional teams, rotation between functions. The fourth strategy is to upgrade the status of manufacturing by establishing parity in pay, creating manufacturing research centers, and nurturing a culture that values and rewards cooperation between all levels and functions.

Design for Manufacturing: Facilitators and Barriers

James W. Dean, Jr.
Gerald I. Susman
Penn State University

The first part of the talk was an overview of the DFM project currently being undertaken by Penn State and twelve companies, in both defense and commercial industries. Two product development efforts are being investigated in each firm, and data collection is scheduled to last about one year. The research questions to be addressed are:

- What approaches to DFM are best suited to the various organizational contexts of product development efforts?
- What are the most common barriers to DFM, and how are companies trying to overcome them?
- What methods do companies use to measure DFM performance, and what are the advantages and disadvantages of various measures?

The research framework used in the study is based on the premise that the organizational context of the DFM process will influence and constrain both the process itself and its effectiveness. In addition, the nature of the DFM process itself will substantially impact the outcome of the product development effort. Criteria of effectiveness include costs (development, unit, and life-cycle), quality (designing within capabilities, use of standard parts), and lead-time (development, ramp-up). Number of engineering change notices and rework as a percentage of total labor costs are also being tried in some firms.

Characteristics of the organizational context include strategic consensus, an articulated link between DFM goals and strategy, and a reward system and set of design methodologies that support this link. Status differences and data base incompatability between functions are two important contextual barriers. Finally, cross–functional training and experience can increase people's ability to work in a multifunction setting.

In an effective DFM process, information is exchanged continuously in both directions, and issues are resolved at the lowest level possible. Commitment is to project rather than functional goals, and there is mutual respect and trust between functions.

Effectiveness also depends on choosing the correct organizational approach to DFM. Approaches vary from such low–impact approaches as manufacturing sign–off and the establishment of an integrator or liaison position, to higher–impact approaches which include cross–functional teams and the establishment of a product–process design department. In general, higher–impact approaches are called for when technical risk (product and/or process) are high, and project goals (cost, quality, and/or schedule compression) are aggressive.

QUESTIONNAIRE SUMMARY

This questionnaire is part of a Penn State research project to understand how jobs and human resource practices are changing in response to advances in manufacturing technology. Below is a summary of the responses from the forum participants.

1. Please put a check next to any of the following manufacturing technologies that are in use in your plant(s). (Percent of checks out of 20 total responses.)

   70% a. manufacturing resource planning (MRP II)
   95% b. computer-aided design/engineering (CAD/CAE)
   70% c. numerical control
   75% d. computer numerical control (CNC)
   45% e. direct numerical control (DNC)
   40% f. flexible manufacturing systems (FMS)
   75% g. robots
   75% h. automated materials handling
   85% i. computer-aided testing/inspection
   50% j. computer-aided process planning (CAPP)

2. Considering the changes in manufacturing technology in your plant(s), which jobs are being affected the most? (Please circle the number.)

		Average	Not At All	Some Extent	Great Deal
a.	machine operator	1.45	0	1	2
b.	technician	1.40	0	1	2
c.	test/inspection	1.45	0	1	2
d.	maintenance	1.45	0	1	2
e.	materials handling	1.45	0	1	2
f.	production control	1.65	0	1	2
g.	first-level supervisor	1.60	0	1	2
h.	other:				
	design engineer	1.50	0	1	2
	management	2.00	0	1	2
	______		0	1	2
	______		0	1	2

SUMMARY OF WRITTEN COMMENTS
HUMAN RESOURCES QUESTIONNAIRE

1. What specific changes in these jobs (listed on previous page) do you see (e.g., responsibilities, skills needed)?

- job combinations due to additional responsibilities
- broader responsibilities
- more interpersonal and "high tech" skills needed, more information management, more work, faster–paced
- production personnel taking direct responsibility for quality assurance, increasing need for technical skills, especially in electronics
- corporate pressure to reduce layers of supervision and push decision–making and control to lowest possible levels, leads to broadened realm of responsibility, all employees "owning" the process, promotes employee contribution, substantially reduces the difference between "worker" and "manager," so maintenance operator, line operator, as well as support staff and supervisors all see/feel the changes over time.
- operators will run cells and FMS instead of stand–alone machines; planners responsible for all phases of manufacturing, right through production cycle; inspection/materials will become more of an audit function
- teams working with consulting firm to "redefine" functions and responsibilities of all hourly, technicians, and salaried managers
- flexibility, ability to learn quickly, need more thinkers, good written and oral communication skills
- more effort directed towards manufacturing systems engineering, with an interdisciplinary team of experts; more emphasis on production control to improve quality; testing and inspection will become more complex, thus a move toward increased process control; more involvement in the process, issues and problem–solving at lower levels; formation of quality councils to discuss and resolve management and people issues
- managing day–to–day responsibility at point closest to the work
- use of high–performance work systems/self–managed work groups
- need better understanding of manufacturing requirements; more direct communication with manufacturing personnel; additional design inputs required
- responsibility for performance goals, need problem–solving skills, low–level people are dealing with suppliers
- responsibility for written and oral communication, and self–improvement

2. In order to deal with changes in technology and jobs, what changes in human resource management practices have you seen in your plant(s), (e.g., selection, training, rewards, appraisal)?

A. Selection

- a different light
- more difficult to qualify for job, more based on ability than seniority
- operators – tied in with the union (?)
- work redesign teams dealing with all HRM issues

B. Training/Retraining/Education

- more important than selection
- need to teach decision–making skills to people further down the hierarchy, and explain how their function adds value
- more computer skills, better understanding of organizational goals
- more in–house training and training via community resources
- computer user training; training is increasing to emphasize total responsibility, i.e., team approach, JIT concepts and added technical skills as appropriate
- very comprehensive program is being organized and started; includes technical upgrades for operators which will take several months; APICS courses for managers
- work redesign teams dealing with HRM issues
- more training for shop operators especially associated with computers and software technology
- substantial capability–building –– use of SPC, teamwork, and leadership skills
- pre–management classes to bring out changes in style/methods; total quality training, establishing the concept of vendor–customer relations

C. Rewards

- offering a lot of incentives
- moving toward total compensation which includes individual and team performance awards
- using performance management techniques to change thinking and behaviors

D. Appraisal

- input from both parties
- moving from ladder ranking to bonding for performance
- responsibility for performance goals