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PENNSTATE

Facilitators of Effective Design For Manufacturability

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Jim reported on the study that he and Gerry Susman have been conducting for the past year and half. The objective of the study is to identify policies, practices and methods that will encourage design and manufacturing personnel to work together effectively, thereby shortening the product development cycle and improving the quality of products and lowering their cost. The companies are Honeywell, McDonnell-Douglas, Caterpillar, Cleveland Pneumatic, British Tire and Rubber, Corning-Asahi, Digital Equipment, Boeing Helicopter, GE Astrospace, DuPont Electronics, DuPont Electronic Imaging, and Westinghouse. Each company offered two projects for analysis. One project is a "stretch" project in which the product or process technology being used is state-of-the-art or requires personnel to develop new knowledge or skills. A stretch project also might be one in which the magnitude of the differential on cost, quality, schedule or performance is significantly higher than that which was pursued in similar projects recently. The second project is a relatively routine enhancement of an existing product.

The companies used different terms to describe the relationship they were trying to encourage between design and manufacturing, e.g., simultaneous engineering, concurrent engineering, early manufacturing involvement, design to build. Also, different specialties within the manufacturing function may be involved in DFM activities. For example, materials people may want designers to use standard parts and processes and materials that are readily available. The quality assurance people may want designers to design products so that they are easier to inspect and test. Equipment services people may want to know as soon as possible if new machines need to be purchased. Methods people may want as few new manufacturing steps as possible resulting from the design. Manufacturing people may want fewer parts and parts that snap together easily. Finally, personnel people may prefer products that are designed so that existing skills can be used or that permit workers to be trained easily to perform the required tasks.

The projects varied in the design for manufacturability objectives they were trying to achieve. One objective was to design the product right the first time, that is, from the perspective of all the other functions that want to have input into the design process. This objective is conservative in that designing what is right probably reflects accommodation to existing factory capabilities. The benefits are derived from fewer mismatches between product characteristics and existing process capabilities that are due primarily to the designer's ignorance of existing factory capabilities. A second objective was to design products so that they have fewer parts or are easier to assemble or test. The benefits are derived from an improved product or process design rather than from avoidance of mismatches between the product design and existing factory capabilities. A third objective is to have the design and manufacturing phases overlap, perhaps, even to the point where the product and process design occur simultaneously.

Jim and Gerry visited each company twice during 1989. Senior function heads and program managers were interviewed during the first visit and a selected number of personnel with "hands-on" experience from each project were interviewed during the second visit. Three major clusters of policies, practices and methods used by the companies were identified during these interviews. These clusters are (a) integrative mechanisms that were implemented as organization-wide policies and practices, (b) group processes that encourage effective problem-solving among appropriate personnel, (c) codification and computerization of information relevant to designing products for ease of manufacturability.

Each cluster represents a composite of practices; no one company introduced all of them. The first cluster, integrative mechanisms, included parity in pay, facilities and educational requirements; manufacturing sign-off on drawings; strong project managers; project-based rewards; number of levels to a common report; top management support for DFM practices; rotation between functions; flexible budget allocation between project phases; co- location of project personnel. The second cluster, group processes, included low personnel turnover, percentage of time manufacturing personnel were assigned to the project; timing and frequency of opportunities for manufacturing

personnel to provide input on product design; group consensus on project goals; and integrative problem solving. The third cluster, codification and computerization of data, included existence of data on materials, costs, tolerances, etc. to support requests to modify a product design; existence of rules and guidelines for modifying products to meet DFM objectives; ease and speed of access to data, rules and guidelines.

Jim and Gerry hypothesize that the stronger the presence of these three clusters in a company, the greater the company's success in achieving DFM objectives in its new product development projects. They also hypothesized that effective group processes cannot be sustained without prior implementation of integrative mechanisms, and that integrative mechanisms and effective group processes together may contribute more to DFM success than will codification and computerization of data alone. They further hypothesized that codification and computerization of data will contribute marginally to DFM success unless accompanied by integrative mechanisms and effective group processes. Lastly, the magnitude of the impact of the three contributors will be greatest among projects with high technical risk and aggressive goals, thus increasing the differential between successful and unsuccessful projects of this type.

Jim and Gerry plan to rank the twenty-three projects according to the hypotheses presented above and evaluate them for degree of success at achieving DFM objectives. The stretch projects will be assessed separately from the routine product enhancement projects. Jim and Gerry are developing measures of DFM success that can be normalized across projects that are pursuing different DFM objectives. They will try to develop measures that assess DFM objectives directly, if this is possible, or they will assess final project success and assume that these measures reflect success at achieving DFM objectives. Measures of final project success include designing a product to meet performance and features specifications at targeted developmental or unit costs, as well as targeted product quality and schedule. A measure of success at transcending previously accepted trade-offs is the number of goals met/number of goals set and the sum of the gaps in goals/number of goals set.

Design For Manufacturability: Examples From Japanese Companies

Inyong Ham
The Pennsylvania State University

Dr. Ham is Fanuc Professor of Industrial Engineering and has been at Penn State for over thirty years. He is Korean, but speaks fluent Japanese. He spent nine months in Japan on his last sabbatical leave, during which time he visited many major Japanese companies, research institutes and universities. The first part of his presentation concentrated on observations from his visits. The second part focused on conceptual design, a subject in which he has had a long-standing interest.

Dr. Ham made some preliminary remarks on Japanese and American views of their respective strengths and weaknesses in technological development. The Japanese still view the U.S. as superior in basic research and development, but view themselves as superior on applied research and development. They expect to excel in "opto-electronics" e.g., fiber optics, lasers, well into the twenty-first century; however, they expect continued tough competition from the U.S. in computers, life sciences and new materials.

Dr. Ham believes that the U.S. is misdirecting some of its cost reduction and quality improvement efforts, especially when directed towards phases that are late in the product development cycle. His examples included the development of a sophisticated five-axis spot welding robot for use on auto body designs that are too complex in the first place. A simpler robot could do a better job on a less complex auto body design. He thinks that U.S. companies should be concentrating more effort on reducing material costs (up to 65% of total costs in some industries), rather than on reducing direct labor costs by investing in robots (only 7% of total costs). He also thinks that the potential for cost reduction through improved product design is much greater than through improved assembly methods, but that they

can complement each other significantly. He showed data from Hitachi that support this claim. Hitachi reduced relative assembly cost by 80% between 1980 and 1987 due to improved product design and automation. Finally, he believes that just-in-time manufacturing, quality circles and life-time employment help only marginally. The real source of competitive advantage for many Japanese companies is their strong relationship with suppliers and the way they manage technology and educate and use their engineers.

Dr. Ham made a number of observations about his visit to Fanuc Ltd. They have 80% of the market for NC controls in Japan and 60% world-wide. Many of their former U.S. competitors now have formed joint ventures with them in the U.S. Dr. Inaba, the president, has a Ph.D. in engineering. The company has a basic research lab which employs only five people who are asked to think in terms of developing products for markets that are five to ten years in the future. No employees other than the president has access to the lab.

Fanuc does a thorough world-wide survey when considering developing new products. The selling price for new products is set at the earliest stage of design against a target of meeting a 30% profit rate. The production cost is thus determined by knowing both the selling price and profit margin. Product performance and quality, of course, are set as high as necessary to satisfy expected customer requirements. The project team that designs the product also designs the manufacturing system and follows the product into the factory and installs the system. The team is not relieved of its responsibility until the system has been successfully implemented.

Some interesting observations about the Fanuc culture are that personnel at all levels of the company rotate regularly between functions. Eighty percent of professional employees are engineers. There are no dividing walls between functions on any floors. Virtually every door and the few walls have the following slogan on them: Reliability Up, Low Cost, and Fewer Parts! The president expects most of the cost reduction ideas to be made during product development. While he does not deny that quality circles have some value, he expects Fanuc engineers to be able to identify most cost reduction opportunities well before blue-collar workers do.

Dr. Ham's next observations were on Sharp Electronics which is known for speedy introduction of new products at low prices. Two recent new products were the Wizard, a pocket-sized computer that can store up to 2000 names and addresses and a refrigerator with doors that can open from the left or right side. Particularly noteworthy is Sharp's matrix structure for special projects. A special "presidential team" is created for "gold badge" products. The head of such a team has the power to select the very best people from each function. The team has virtually an unlimited budget and power. The team leader follows the product into the plant and temporarily becomes the plant manager for the product. Rewards are high for successful projects. For example, in addition to cash bonuses, team members receive a one or two step promotion and the team leader receives a two step promotion.

Dr. Ham made some general observations about differences in the values and priorities of Japanese and American manufacturers. He noted the number of Japanese he sees at international machine tool trade shows in the United States, West Germany and Japan. He sees very few Americans at the latter two shows. He noted that German and Japanese companies have donated state-of-the-art machine tools to many of their universities, while American companies usually donate out-of-date, amortized equipment, if they donate at all. The rationale behind the gifts by many Japanese and German companies is that students familiar with their equipment will be more likely to recommend purchasing it after they are hired by industry. Japan has three times the number of engineers per capita than does the U.S. (although fewer in absolute number). About 80% of Japanese engineers stay on the shop floor, while less than 30% in the U.S. do so. Nearly all Japanese supervisors and plant managers have graduated from some type of technical college.

The final segment of Dr. Ham's presentation was devoted to product design. He believes that American design engineers tend to overspecify tolerances and do not realize the cost implications of doing so. Their ignorance is partly due to not taking manufacturing-related courses in college. They also may set tolerances too tight because they believe that an allowance is necessary to assure that manufacturing personnel will make a good part. Machining costs increase exponentially as tolerances tighten. Manufacturing personnel often know that their equipment cannot meet the tolerances that designers set. Rather than argue, they may simply lower the tolerances on the drawings and meet whatever tolerances they can. Dr. Ham estimates that production costs can be reduced by 30% simply by

setting tolerances at levels that are sufficient for producing good parts. Another contributor to setting inappropriate tolerances is the poor quality of data-bases. Many design engineers still look up tolerances in handbooks. A common data-base that can store and readily retrieve engineering and manufacturing data is badly needed by American industry.

The Use of A Multi-Functional Team To Develop A New Electronic Connector

Dan Bertoncini
Du Pont Electronics

Dan was the product engineer on a project that was formed to develop an electronic connector. An electronic connector bridges two electronic devices such as two computer boards. It can have more than one-hundred contact points, each of which must make a reliable contact between two boards from fifty to two-hundred times over the life of the connector. A connector consists of metal strips that are formed and plated with precious metals, and a housing which is formed by plastic injection molding. These two main parts are assembled by customized assembly machines, although some thought is being given currently to purchasing standard-based machines with interchangeable tooling.

EISA is a standard for PC connectors set by a consortium of nine computer companies that want to offer equipment that permits use of existing PC boards. IBM has introduced the PS2 line of computers which do not permit use of existing boards. The PS2 requires purchasers to buy new boards because it uses a microchannel architecture that is different from that used in the previous generation of machines. The consortium set specifications for connectors in April 1988 and asked DuPont and its competitors to submit samples by August 1988. DuPont thus had only four months to develop a product that usually takes twelve months to develop. DuPont had to meet this deadline if it was to have any chance at achieving an acceptable market share for the product.

Management put a cross-functional team together immediately consisting of product engineering, marketing, manufacturing engineering and quality assurance. Manufacturing was asked to lead the team. The project was given high priority. Although the work loads of project members were adjusted somewhat, only one person was assigned full-time to the project. Everyone worked together from the start of the concept phase. The product engineer developed an initial concept and modified it based on feedback from the other team members. Everyone had responsibility for the concept and participated fully in design reviews. They met their cost target very early in the project by incorporating suggestions from manufacturing personnel on ways to simplify the manufacturing process. Another target was to meet a process capability index that was twice as wide as normal, 2.0 versus 1.3. The team developed and implemented the entire manufacturing process, including documentation, tooling and delivery of samples.

Dan credited a lot of their success to the use of the Product Protocol which is now required for use on all new development projects. This is a structured procedure with four phases, each of which is followed by a management review. If the review is successful, management will authorize money and permit the project to proceed to the next phase. Marketing leads the Business Proposal phase (Phase 1) during which return on investment and sales projections are developed and a rough product concept is reviewed. Engineering leads the Design Feasibility phase (Phase 2) during which a preliminary design is developed and tested for ability to meet specifications. Manufacturing leads the Manufacturing Feasibility phase (Phase 3) during which preproduction tools are made and utilized. Manufacturing takes responsibility for Phase 4 which is manufacturing scale-up and full production.

Dan indicated that activities during Phases 2 and 3 were highly overlapped with much simultaneous activity occurring. Four design iterations occurred during the design feasibility phase. The design reviews were critical to making the needed modifications for manufacturability. Tools were being designed and built from preliminary

drawings. Prototypes that were being made in parallel provided feedback for modification of the product design. Some outcomes of team interaction were that the product and production process were kept simple and were designed to minimize the possibility of defects. Qualification samples were ready in the targeted four month time frame. The customer qualified the product within nine months.

Dan commented that teamwork was facilitated by bringing everyone into the project at the concept phase, by having clear responsibilities for everyone and giving them the authority to make decisions without having to check with a superior. The short duration of the project assured cooperation because there was so little time for conflict or for turnover of personnel to occur. The Product Protocol had the effect of assuring that all team members participated in making decisions and were committed to them. Co-location played no part in this project. In fact, everyone was scattered geographically all over Pennsylvania. They initially met once a week, then less often.

Management gave their effort strong support and encouraged the selection of exceptional performers with good interpersonal skills. The team members never had to wait for approval of funds and were lucky in being able to get quick turnaround from shop personnel as well as vendors. There were few other development projects against which to compete for shop resources during the four months and their vendors seemed eager to have their business and were very accommodative. A strong plus is that Dan had manufacturing experience before going into product design. He sought consensus from team members and assumed that if it were not forthcoming that something was wrong with the design and needed modification. The team members received a monetary reward at the completion of a successful project.

Black & Decker's Total Quality Management Initiative

Rick Tancreto
Black & Decker

Black and Decker saw superior quality as one of its most effective weapons for dealing with foreign and domestic competition. They developed their total quality program (TQP) from ideas they gained from visits to companies like Xerox, Corning, Jostens, IBM, Milliken and Florida Power and Light. Their intention was to borrow ideas from such companies, but weave the ideas into a unique program of their own. They were not interested in a packaged program. A steering committee made up of seventeen senior managers from two major domestic divisions, U.S. Power and U.S. Accessories, guided their program. Seven thousand people work for these two divisions which have combined revenues of approximately $700 million. This committee, which included two division presidents and the vice presidents and directors of all the functions, developed a charter and provided the strategy, direction and resources for the TQP initiative.

The Steering Committee developed a major policy statement and communicated it to ninety managers (mainly direct reports) at a day-long meeting. They also developed five guiding principles. The ninety managers, in turn, developed ten action steps based on site visits they made to the companies identified above. The five principles are (a) customer focus, which means more than manufacturing a quality product, but also providing proper invoicing and other indicators of error-free shipping; (b) total involvement, that is, everyone is responsible for quality, not just the Quality Control and Quality Assurance departments; (c) prevention is more valuable than being able to put out fires; (d) continuous improvement means that the ultimate objective is zero deviation from the customer's requirement. All action should be guided toward reaching that objective; (e) measurement of the cost of quality should be undertaken to provide everyone with data that they can use to take corrective action and provide a basis for rewarding the achievement of goals.

The ten action steps developed by the ninety managers are:

1. Every department was encouraged to identify internal customers, ask them for feedback on their outputs, and identify the key activities that are linked to these outputs.

2. The cost of not doing things right the first time was estimated. A 1988 study of two hundred employees led them to the conclusion that 25% of total sales were expended on rework, scrap, recalls, returns, etc. That amounts to $25,000 per employee or more than the average annual salary per employee.

3. A TIPS (Today's Improvement Proposal) program was developed which requests that employees identify on a form what they think prevents things from being done right the first time. Employees must receive feedback on their suggestions within five days. Seventy-five percent of suggestions can be handled by the employee's immediate supervisor. They can respond with yes, no or assign the suggestion to a team for study. A no answer must be reviewed by the next higher level of management.

4. Corrective action teams (CATs) were initiated. These are problem-solving teams that seek the root causes of problems so that when the problems are solved they stay solved.

5. Each department was encouraged to set goals and measures for performance and display two or three of them so as to encourage a bit of friendly competition between departments. Rick said that the companies they visited varied on whether they thought this practice was a good one. Black and Decker thought use of this practice was consistent with their culture.

6. Ten quality "pulse points" were developed by which progress on quality could be measured, e.g., on-time deliveries, warranty rates. These should be measures that every department can use for comparisons purposes.

7. The TQP further developed its structure of committees. The steering committee provided overall direction. Next came quality improvement teams (QIT) each of which is headed by the vice president of a function and his immediate reports. Each QIT focuses on implementing the ten action steps. Next came the corrective action committees (CATs). Finally came the TQP team made up of six managers who have responsibility for developing a training program which will be delivered by sixty managers.

8. All managers and nonmanagers will attend a two day training program; one-day will be devoted to raising awareness about TQP and the other day to introducing problem-solving skills. Managers will receive an additional seven days devoted to statistical process controls, how to implement the ten action steps, etc. The training will take about eighteen months to complete. About one-hundred managers have been trained thus far.

9. A number of mechanisms have been developed to facilitate communication about TQP throughout the company. The president has held fifteen conferences to which five thousand employees were invited. This typically occurred by shutting down a plant for two or three hours and having employees assemble for a meeting. Also, the steering committee holds quarterly review meetings with the QITs to report on what they are doing. The committee reviews any roadblocks which they can help remove.

10. An indication of how serious the quality initiative is at Black and Decker is that the president is being held accountable primarily for quality indices rather than financial indices. Rick believes that about 60-70% of people are now committed to TQP.

The plan is to focus their implementation efforts towards functions, with a natural carry-over to cross-functional problem-solving. Rick thinks that TIPS may be the most difficult action step to implement. CATs will convene on company time or their members will be paid for overtime. While SPC is being well received on the shop floor, there is still a need to develop basic data as well as better math and reading skills. The sixty managers assigned to provide the training for a two year period are considered to be "high potential" managers. This raises the prestige and importance of TQP within the company.

Managing The Transition Between Design And Manufacturing

Joe Di Tommaso
Westinghouse Corporation

The Westinghouse Electronics Systems Group in Baltimore, Maryland contributes approximately three billion dollars a year to the corporation's twelve billion total. ESG's business is 90% defense and includes radar, electronic warfare products, missile launchers, etc. It is now seeking commercial applications for its products as defense spending is winding down, e.g., radar for commercial aviation and for drug interdiction. One of Westinghouse's major past successes has been radar for the F16. This radar costs less today than it did in 1984 and has a 300% improvement in reliability, e.g., mean hours between maintenance.

The current challenge is to develop radar for the Advanced Tactical Fighter (ATF). Getting the ATF contract is viewed as essential by senior management. Two teams are competing for the contract. Westinghouse is part of the team that includes Northrop and McDonnell-Douglas. The other team includes Boeing, Lockheed and General Dynamics. The competition is taking place during the demonstration and validation (DemVal) phase, which will end with a flying test and an award of a contract to one of the two teams to proceed with full-scale development.

The Westinghouse contribution to the development of the radar is called the complex vector processor (CVP) which is a digital signal processor. The CVP must be produced on three boards. Each board must have a circuit density of over 300 circuits which will require 12,000 solder connections per board. That, in turn, will require the use of VHSIC chips which have 132 leads per chip with 20 mil. spacing between each lead. By contrast, F16 boards have 120 circuits per board with 50 mil. spacing and 3500 to 4000 solders per board.

The CVP is too complex to expect to build it right the first time. However, the number of engineering changes can be reduced and those that remain can be identified and corrected earlier in the DemVal phase, mainly by designing the product and process in parallel. The organizational mechanisms that Westinghouse developed to facilitate concurrent engineering are called Producibility Assurance Centers (PAC) and Technical Assurance Centers (TAC). Each is a dedicated facility located adjacent to each other. One pair of PACs and TACs exists for circuit boards (used for this project) and another exists for microwave modules. Westinghouse has invested six million dollars of its own money in the PACs and TACs which it cannot pass on to DoD. It expects to recover the investment by attracting more business as a result of developing superior products.

PACs and TACs are made up mostly of the same personnel, e.g., process engineers, manufacturing engineers, quality control, etc. A PAC has fifteen to twenty persons, while a TAC has twenty-plus persons. Function heads assign these personnel; but the ATF program is headed by a strong program manager. Process engineering leads the PAC, while manufacturing engineering leads the TAC. These personnel simply switch objectives and leadership when they move from the PAC to the TAC. The objective of the PAC is to demonstrate the feasibility of making a functioning board. PAC personnel work with electrical and mechanical engineers during the conceptual design phase. Once a conceptual design exists, the PACs work on product/process development. The TAC is responsible for transforming the process developed in the PAC into one that is repeatable and cost efficient for producing a high volume product. The TAC contains all of the equipment that Westinghouse has at its College Station Texas plant where the boards will be produced in high volume, if Westinghouse wins the contract to undertake the subsequent development phases.

It takes time to develop a high volume production process for a product as complex as the CVP. Since the TAC is a dedicated development facility, there is no need to interrupt the production of any mature high volume products in order to test the new process and proceed along the learning curve. Personnel from College Station are invited by the TACs to observe the process and provide inputs as it develops. Workers in Baltimore and in College Station may provide inputs as well. The TAC was instrumental in learning early that the circuit boards would be very difficult to make in high volume with 20 mil. spacings. The spacings were changed to 25 mil. with no compromise in product

performance. The TAC also worked closely with its vendors who also were struggling to learn how to make products with such demanding specifications. The TAC also developed two new robots for assembling high density boards. The robots will be moved to College Station, if and when the production volume justifies their use.

PACs and TACs are an effective organizational solution to developing new products and processes concurrently. Perhaps some day CAD will develop to the point where some of the information exchanged within and between PACs and TACs can substitute for them. In the meantime, PACs and TACs permit the kind of dialogue and problem-solving between product, process and manufacturing engineers that is needed for developing such complex products and for producing them efficiently in high volume.