Evolving Trends: An Environmental Scan on Design For Manufacturing Techniques

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Abstract

Design for Manufacturing (DFM) is a proactive design methodology used by many designers and engineers to reduce and control manufacturing costs. Through the review of several periodicals, magazines, journals, textbooks, television newscasts, radio announcements, manager interviews conducted by the author (Manager A, B, & C), and websites, a trend may be established on "Design for Manufacturing" and manufacturing in general. Coded manager and company names were used for confidentiality reasons. The environmental scan presented highlights DFM and other manufacturing issues from 2002 through 2007. This study establishes a baseline for engineering technology scholars assessing DFM techniques in the next five or ten years.

Literature Review

El Wakil (1998) defines "Design for Manufacturing" as a relatively simple process involving design personnel initially considering the methods of manufacture during the design phase of a new product. In fact, design is considered one part of a three-part pyramid, with materials and manufacturing as the other two parts. Within this pyramid, a manufacturing system is brought into existence; a system constructed to deliver well-conceived ideas (inputs) into well-constructed products (outputs). The key to DFM is the intermingling of design and manufacturing technologies and capabilities in order to produce a product at the lowest possible cost with the highest possible quality as is accepted by the end-user; a.k.a. "The Customer." To further emphasize the role of the design engineer in facilitating DFM, the following paragraph from DeGarmo, Black, & Kohser (1997) provides insight:

> "The design engineer must, of course, know that certain manufacturing processes and operations exist that can manufacture the desired product. However, merely knowing that feasible processes exist is not sufficient. The designer must also know their limitations, relative costs, and process capabilities (accuracy, tolerance requirements, etc.) in order to design for manufacture. If maximum economy is to be achieved, the

> designer should be aware of the intimate relationship between design details and production operations (p. 1170)."

In the year 2007, there seems to have been little change in the DFM focus. Hudspeth (2007) states that engineers should design for specific manufacturing processes (considering components materials), design for ease of assembly and disassembly, and design for automation. In essence, keep components design simple and manufacturers will benefit from lower overall costs of product manufacture.

Design engineers must also pay attention to how manufactured parts are machined or modified as illustrated in the article "That's Really Tough (Callen, 2002)." Callen shares that many times a design engineer will construct a computerized part with computer aided drafting (CAD) software, without ever considering how the manufacturing engineer will machine the part on a computer-controlled lathe or mill. The article states that engineering drawings must contain complete product specifications in order to produce parts as the design engineer intended, to what manufacturing is capable of machining. Callen puts it quite succinctly in the following quote:

> "The tolerances specified by the designer to ensure that the individual parts can be assembled together significantly influence the processes used to manufacture a part. Often the designer establishes these tolerances without knowing the corresponding manufacturing implications. Rigid or exacting tolerances require specialized tooling and/or processes, which incur additional expense to product the part (p. 29)."

Whereas Callen supports the use of CAD in the workplace, Thilmany (2007) supports the use of CAD as well. Per Thilmany, "After a half-century of development, CAD continues to extend control over the design of ever-more challenging systems." The use of CAD is further enhanced through the use of photo-realistic modeling that an engineer is able to use to sell a product long before it is manufactured.

In the article "'Collar Joining' Method Makes Plastic-Metal Hybrids", Leaversuch (2002) highlights the development success of the company BASF AG, in Germany, in the fabrication of metal-to-plastic joining technology. This new technology is said to find a home in the automotive industry due to "cost, weight, and space savings (which are) not possible when plastic or metal are used alone (Leaversuch, 2002). The technology developed yields metal-to-plastic joints utilizing a pressed-in-place mechanical bond, which is comparable to molded hybrid (metal and plastic) assemblies. By working with manufacturing, the new joining technology became possible.

DFM tools are becoming more software-supported in 2007. This is evident in the 65-nm semiconductor industry. Through the use of Clear Shape Technologies' OutPerform and InShape DFM software tools, semiconductor manufacturers are able to create wafers with lower cost and greater precision. Per Santarini (2007), both software tools "bring process models of lithography, RET (resolution-enhancement technology), OPC, CMP (chemical-mechanical polishing), mask, etch, interconnect parasites, and transistor modeling to physical design and verification to help IC designers ensure that they are targeting can manufacture their designs."

DFM in Product Lifecycle Management

Product Lifecycle Management (PLM) also has its place in DFM. Elliot (2002) shares that "PLM plays a role in all product decision making, starting with "ideation," and that it incorporates CAD/CAM/CAE, PDM, as well as some elements of ERP, MRP II, financial analysis, and human resources management." The PLM approach is said to be a comprehensive management practice to include everything from design to product manufacture. PLM takes into account the capabilities of suppliers in supplying material and knowledge in the incorporation of their resources into the manufacturer's product.

Zimmermann (2002) shares that "document management systems are very important to business critical applications." The article states the importance of well-controlled documents (Word, Excel, emails) within a web-enabled ERP manufacturing enterprise. The case was made for reduced database libraries for manufacturing's use, which in effect makes it easier to scan and find importance documents. This article applies to DFM in that documents must be well controlled and available for designers and ultimately manufacturing engineers to do their jobs properly. For product information to be useful, it must be stored in set locations for all to view when needed; cryptic or hard-to-find information will cause errors to creep into the production system.

The need for knowledge in PLM is no less important in 2007, although the focus has shifted somewhat. Manufacturers are now more focused upon designing "green" products – products that utilize materials that utilized minimal resources for development, are non-hazardous, and can be recycled / reused. Per Stackpole (2007), manufacturers use PLM methodologies to achieve "sustainable design goals" that incorporate "green." In essence, "green" manufacturers have an eye upon sustainability, keep up with data management, and control the use of materials available for use in the design of a product. Design for modularity is another new important element within the green revolution. With "design for modularity", product designers consider how existing products may be upgraded easily through the swapping out of an outdated component or assembly with an updated component or assembly. Vorster (2007) supports "design for modularity" by sharing that successful manufacturers understand their PLM costs and design accordingly.

DFM in Contract & Collaboration Manufacturing Management

Companies who utilize Contract Manufacturing (CM) must also consider the impact of DFM in their manufacturing systems. IBM is yet another vendor providing CM "to design, test, certification, prototyping and manufacturing for chips, cards, boards and systems (Assembly, 2002)." By offering CM, IBM has initiated a service to aid in the DFM realm for high technology companies. CM isn't anything new to the manufacturing world, but one can infer from this article that many companies need to have a highly competent vendor supply technical knowledge and component design & manufacturing services. Naturally for DFM to be of any value in this scenario, IBM must be well in tune with the manufacturing capabilities of their customers, as should any in-house or out-of-house vendor.

In the article "Collaboration Eases Product Development (Teague, 2002)", the author shares the benefits of early collaboration with vendors, customers and internal company colleagues. In essence, collaboration early on in product design yields great benefits in reducing manufacturing and customer concerns down the road. One of the companies mentioned in the article is Graco (Minneapolis, MN), a manufacturer of fluid handling equipment, who practices Internet collaboration so that "They don't have to worry about the time associated with other media." The key of the collaboration is best said in the following quote by Bill Hasbrook, an engineer of Phoenix Gold, (Teague, 2002): "By collaborating with vendors and internal departments, we found out early and didn't have to tweak designs repeatedly, we knew the end result before we made the parts."

Customer Relationship Management (CRM) and Supply Chain Management (SCM) also have a part in DFM, as pointed out by Dennis Van Bodegom (2002). Manufacturers are admonished to consider not only design and manufacturing engineering activities for product creation, but to evaluate product development through "sourcing, procurement, sales, distribution, and maintenance – until retirement of the product."

In every human endeavor, work must be performed to develop a system that can interface with other systems; computer chip design is no exception. In the article "Platform-based Design: A Choice, Not a Panacea (Goering, 2002)" reference is made to how important it is for designers to have a solid understanding of how their chips will interface with other chips on a standardized platform. Naturally this concept fits neatly in with DFM. For reference, ARM's PrimeXsys chip is to include "peripherals, a choice of operating systems and software, and hardware development tools (Goering, 2002)." The computer chip manufacturing industry appears to be heading to a one-chip-fits-all type structure; one requiring that its designers are in touch with a myriad of operation possibilities.
In the article "Contract Manufacturing On The Rise (Weber, 2002)", it is interesting to note that contract manufacturers seem to supply product niche for companies who wish to streamline their organizations in personnel and manufacturing facilities, plus create a healthier bottom line. By outsourcing, these same companies have in effect off-loaded the headaches and hurdles of managing manufacturing… or have they? In the article, the following is mentioned about contract manufacturers:

> "Contract manufacturers are at their most efficient when running at high volumes, with minimal engineering changes. But, when demand for a new product is 'lumpy,' or when bugs are still cropping up requiring more frequent engineering changes, contract manufacturers run into difficulty. For this reason, many OEMs are retaining new product production in-house, until both the design and the demand for a new product have stabilized (Weber, 2002)."

It would appear from Weber's article, that contract manufacturing is relegated to high volume, low-change type products. Trading your in-house talent for out-of-house vendors may not be the wisest thing to do.

On another note, Weber's article (2002) highlights the many problems that a manufacturing engineer might have in dealing with a contract manufacturer. In essence, "You are losing control of manufacturing, rampant changes engineering changes during the first stages of manufacturing can be more difficult to implement. If you are a small company, you may not get the attention that you require from the Electronics Manufacturing Services (EMS) staff, as you would from your own manufacturing staff (Weber, 2002)." By this statement, and many others in the article, It appears that Design for Manufacturing could be quite complicated to actuate.

Contract & collaboration manufacturing management issues are not much different in 2007 than they were in 2002 – with the exception of product safety and outsourcing risk. In the case of product safety, imported product inspection efforts have increased due to recent imports of contaminated pet food from China and products painted with lead-based paint in Asia (Mongelluzzo, 2007). While the United States cannot inspect all imported products, a risk-based approach is being considered by demanding that offshore suppliers document their processes and materials used through conventional paper records and through video recordings of their operations. On the risk-based side of the equation, manufacturers must be sure that suppliers are chosen who are trustworthy and reliable (Chatterjee, 2007).

DFM Application to the United States Outsourcing Dilemma

The disturbing, yet true, commentary of "Working Together is the Answer (Lessiter, 2002)" brings home another aspect of Design for Manufacturing, the aspect of working together with non-American suppliers. The article points out the need to have a clear understanding of what American companies are giving up in creating alliances with foreign businesses for components – compromises may include:

1. First, as part suppliers move offshore, domestic part suppliers will be forced to either change the way they do business, switch to a new product line, or go out of business.
2. Second, American companies who purchase offshore components are setting themselves up for possible headaches in obtaining on-the-fly, and quick, componentry revisions; domestically, changes can usually be done rather quickly without the worry of customs holding a shipment.
3. Third, the product liability of offshore components could be in question, with possible disastrous results if the offshore supplier does not maintain consistency in component manufacture and materials.
4. Fourth, as American jobs move overseas, who will be left domestically to develop new technologies in our country? Once the jobs are lost, engineering and technological talent can be hard to re-establish on American soil.

As an addendum to how design talent is squandered, the article also alludes to how American manufacturers typically use domestic suppliers to design and perfect a component, only to procure manufacturing of the component offshore; this too will eventually move all design functions offshore as well. While companies still need to look for the cheapest component for their products, due diligence is still needed to work with domestic suppliers to purchase domestic components that are competitively priced to that of their mirror-imaged (copied) overseas competitor. Design For Manufacture requires that designers and engineers utilize all resources to develop the lowest possible cost product that interfaces optimally with all aspects of the product as well as how it was manufactured in the first place. Hopefully these procedures can remain in effect in American companies, but to read this article, many offshore suppliers are taking away business from domestic metal-casting companies, a trend that appears to be increasing (this is true in 2007, as it was in 2002), not decreasing. Therefore, one can surmise that DFM can lead American companies to Design components For Foreign Manufacturing (DFFM), not American manufacturing.

It is interesting that in 2007 outsourced products are taking on a much greater scrutiny due to non-manufacturing compliance on the part of offshore suppliers. Case in point, Mattel Incorporated. Mattel Inc. is currently recalling "magnetic toys manufactured between January 2002 and January 31, 2007, including certain dolls, figures, play sets and accessories that may release small, powerful magnets (Tennessee Tribune, 2007)." This recall affects over 18.2 million magnetic toys! Part of the Mattel recall is due to the lead-based paint issue as well, since contracted offshore manufacturers used non-approved paint with ultra-high levels of lead.

On the flipside of offshore manufacturing, Wernle (2007) shares "if the dollar (U.S.) keeping slumping against the Euro, the United States could become the next Mexico – a low-cost manufacturing haven for European automakers and suppliers." This is statement is supported by the movement of BMW X3 car manufacturing from Graz, Austria, to Spartanburg, South Carolina; Daimler-Chrysler increase of plant capacity in Vance, Alabama; and Volkswagen's consideration of moving automobile manufacturing to America if the U.S. dollar remains weak in comparison to the Euro. This too is very interesting and could change the U.S. manufacturing landscape.

DFM: Engineering Pre-requisites

Womack (2002) believes that successful lean manufacturing techniques and processes requires a shift from "the focus of the manufacturing engineer from individual machines and their utilization, to the flow of the product through the total process." By inference, this appears to be in sync with Design for Manufacturing in that each manufacturing engineer, or design engineer, should have a good understanding of the individual and composite operations taking place in their product's manufacturing facility. Through diligence in reducing labor and capital equipment expenditures, by understanding and applying lean manufacturing principles, both the manufacturing and design engineering staff will further actuate DFM methodologies.

"Designers need to have a manufacturing background on processes and machine capability in order to bring about positive impact for a manufacturing environment utilizing Design for Manufacturing principles (Manager A, 2002)." As a manufacturing engineering manager for The A Company, Manager A (2002) has had a lot of exposure to design implementation errors on a first hand basis, noting that “designers seem to get lost in their world and sometimes fail to investigate what is really possible in the production environment. Plus, often these same designers possess reluctance to change anything in a product’s design to make products more manufacturable.” Per Manager A (2002), “In order to meet production goals, tolerances and machined features must be reasonable and obtainable with limited funds. The goals of manufacturing should always be low cost, quality, and productivity.” Manager A also stressed that design engineering department staff personnel should be located at the site of manufacturing to gain a better idea of what is, and isn’t, possible on the product manufacturing lines. Another key element of sustaining DFM on the manufacturing level, is the timely, and often, sharing of information between manufacturing and design engineers, shared Manager A (2002).

The need to maintain a close design-to-production link is also of great concern to the Tool & Engineering Co. of Warren MI. At the Tool & Engineering Co, precision part-holding and dimensional-checking fixtures are manufactured for the automotive industry utilizing very close tolerances and dimensions for the fixtures they manufacture. Each fixture manufactured is required to hold 1/10th of the tolerance allowed on the stamped-metal part that a fixture will hold, as needed by various exacting customers. The need for design engineers and designers to have a perfect understanding of thermal expansion coefficients, geometrical dimensioning and tolerancing (GD&T), and machining center capabilities is a must, as shared within the article (Destefani & Olexa, 2002).

In the article “Industrial Diamonds Gather Strength (Lerner, 2002)”, the case for DFM is very evident in that the unique properties of diamonds must be well understood for the manufacture of inexpensive synthetic diamonds for industrial use. For reference, synthetic yellow diamonds can be grown up to about 3 carats, at about half the cost of natural yellow diamonds. White (colorless) diamonds cannot be synthesized at the present time without compromising strength of the diamond. It is quite interesting that scientists can “combine a solution of carbon and metal, and use a 1,000-ton press to generate a pressure of 50 tons/cm^2 and an electric current to the heat the solution to 1,400^{o}C, to create industrial grade diamonds (Lerner, 2002).”

Manager B (2002), Production Manager for Company B, states, “Design engineers must be intimately familiar with manufacturing processes and the products being manufactured. Designing new products requires that design engineers have a firm grasp of part and processes standardization methods.” Manager B also shared that “Design for Manufacturing requires that industrial and manufacturing engineers continue to improve processes in the future, which will reduce cost on an ongoing basis, over time, as new technologies are developed.”

A constant theme has been developing in several of the latest article reviews and personal interviews conducted, that is, the subject of engineer training. To further investigate how training affects engineers practicing Design for Manufacturing, an article entitled “Proper Engineer Training is Cost-Efficient (2002)” by Edward J. Vinarcik was reviewed. Mr. Vinarcik shared an example of how a transportation company prepared product design engineers over a five-year period using DFM:

Year 1 – Focus on CAD and dimensioning skills.
Year 2 – Manufacturing methods training.
Year 3 – Materials and product function.
Year 4 – Validation testing methods.
Year 5 – Project management and financial management.

Within this five-year training effort, the following core areas are studied: "Solid modeling, basic Geometric Dimensioning & Tolerancing (GD&T), linear stack-ups, CAD assemblies, design revision tracking, choosing functional datum's, and basic gauging (Vinarcik, 2002)." All told, the time to train one product engineer was roughly 760 man-hours, at a cost of $7,000 per year / $35,000 total. That is a substantial investment in one person in order to meet DFM! But if one considers the cost of dealing with product redesigns and production problems if an engineer is not properly trained, then the investment is probably well worth it.

Design and manufacturing engineers also have to contend with industrial robots that have unique operating characteristics. Molnar & Borchelt (2002) contend that although manufacturing hasn't obtained technology comparable to what is presented in science fiction, robots still exhibit "impressive strength, lightning fast speed, and painstaking attention to detail." The article authors also shared that new technologies in "high-volume robotic sensors, ultra-low cost robotic controls, and adaptive logic and learning capabilities" will increase the functionality and use of industrial robots. From this article, one can infer an even greater need for engineers, both in design and manufacturing, to understand the capabilities of their machining and processes. And if one considers the "adaptive logic and learning capabilities" of the next generation of robots, then engineers will have to adjust themselves to understanding the present and future state of industrial robotic equipment.

Manager C, General Manager for a manufacturing plant in the Midwest, stated that "most companies don't think that production, design engineers and manufacturing engineers are working closely together (2002)." "The problem that usually surfaces when the resultant product isn't the same as was initially projected when it was first designed by the product engineering department personnel", according to Manager C. In essence, we sometimes miss practicing proper Design for Manufacturing methods, due to customer imposed issues that must be dealt with. Manager C also shared the following:

> "At our company, we lack continuity in DFM practices due to our assimilation of several different product lines into one plant. Which means we are destined to work with what we were handed with, that is until time is available to optimize our design and manufacturing processes. Also, with design engineers being approximately 500 miles away from our plant, only communicating by phones and email, we will probably continue to experience difficulty in implementing DFM effectively. As an auxiliary to DFM, the biggest problem for many companies, ours included, is that they do not have a full understanding of their manufacturing capabilities. Failure to understand what you are capable of can highly affect manufacturing due to tolerance stack-ups, which may not be found until a quality control audit is performed or customer complaints start coming in (Manager C, 2002)."

Design for Manufacturing is still needed in the semiconductor industry, as shared by Maliniak (DFM Remains, 2007) in relation to reduced process variations and the need to improve processes. DFM analysis tools need to "incorporate fab data on lithography, reticle-enhancement technology, optical-proximity correction, CMP, masks and etching." Along with the need to practice sound DFM in wafer production, Maliniak states that DFM must be heavily used in the design portion as well – insuring great success in overall cost reductions and usage of fabrication technologies (Down Come The Walls, 2007). No other articles could be found for 2007 that changed the DFM environmental scan's finding in 2002.

DFM & Cellular Manufacturing

Design for Manufacturing also should be considered in the product assembly and fabrication areas of a manufacturing plant. In the article, The Perils and Profits of Assembly Cells (Sprovieri, 2002), a case is made for the benefits of cellular manufacturing over that of typical process-based assembly methods. The article consists of an interview conducted by Assembly Magazine to four panelists who have been involved in cellular manufacturing setups in four large corporations (Stryker Howmedica Osteonics, Solutions Group at Ingersoll-Rand, Boeing Military Aircraft and Missile Systems, and Lockheed Martin Naval Electronics and Surveillance Systems). Each panelist shared the pros of investing in cellular manufacturing, predominately in reduced processing costs, quick machine setup times, immediate product turn-around times for shipping products to customers, and reduced part inventories. The applicability of DFM for cellular manufacturing would probably consist in the need, once again, for design and manufacturing engineers to have a firm grasp of the products and in understanding the capabilities and limitations of cellular manufacturing.

A. Blanton Godfrey (2002) states that many manufacturing plants can double their profits, without increasing sales, by simply reducing waste within manufacturing operations. Godfrey's contention is that many plants fail to realize the amount of waste in redundant tasks and scrap creation that permeates most facilities. This article is also in tune with the Design for Manufacturing process in that design engineers also must consider the possible redundant tasks and scrap that may be created from a less-than-perfect design. DFM must go further than "can we make it on the plant line?" DFM must also consider all possible ways in which production could deviate from the intended manufacturing method.

Literature for cellular manufacturing in 2007 has been sparse. One article by Alhourani & Seifoddini (2007) illustrated improved methodology in identification and utilization of machine-part families for cellular manufacturing line setup. While cellular manufacturing seems to have lost interest on the part of many manufacturers and educators in journal article submissions, while the plethora of articles in lean manufacturing and Six Sigma have increased substantially.

DFM & The Assembly Line

Design for Manufacturing is also undergoing a massive overhaul at the automaker Ford. In the article "Flexible Production Is Key Goal at Ford (Weber, 2002)", Anne Stevens, Vice-President of North American vehicle operations, outlines plans to convert many of Ford's present mass-producing manufacturing lines to a more customizable type of assembly line approach, one with machinery that can be easily changed for different automobile models without interrupting the flow of product down the assembly line. This new type of assembly approach has been brought about by a consumer shift to only purchase automobiles with personal tastes factored in. Ford has met this challenge by "making transformation to flexible manufacturing with plants, processes and people (Webber, 2002)." By the discussions given in this article, Ford design and manufacturing engineers will have to be even more in tune with Design for Manufacturing to meet Ford's strategic plan. This trend in DFM dictates more flexibility, in essence thinking out of the box to meet consumer demands.

In the article "The Proof Is in the Picking (Weber, 2002)", the author points out the need for pick-to-light systems for production assembly of products. Using pick-to-light electronics consists of part bins that have been retrofitted with infrared sensors to detect when a person has inserted their hand to obtain a part for assembly onto a product. When coupled with many part bins, the pick-to-light technology makes it possible to eliminate bills-of-material at the assembly person's workstation. And by linking the part bin sensors to a computer, assembly personnel can be notified by buzzer, or light, if they have went into the bin too many times for parts, or not enough. This technology is another example of Design for Manufacturing; design engineers seeing the need for optimized floor assembly, and manufacturing engineers making it happen.

Solectron (2002), a high-volume electronics manufacturing solution provider to industry, provides a service they call "New Product Introduction (NPI)." With NPI, Solectron provides Design for Manufacturing services for products such as "functional characteristics, physical layout, component engineering, design verification, materials leveraging, manufacturability, testability, prototyping and development." Solectron also claims that "engineers get "real" feedback on the design for manufacturability readiness of a product – and allows them to give the manufacturing facility valuable – and cost-saving – information to ensure the volume production goes smoothly."

By positioning the company to fully investigate the capabilities of their client company, as well as considering their own manufacturing capabilities, it would seem that Solectron has applied the principles of Design for Manufacturing quite well.
In tandem with Ford's 2002 emphasis upon customizable assembly lines, 2007 developments in "on machine" component measurements have added another facet of product manufacturing streamlining. The "on machine" measurement method spoken of is called multidimensional shape inspection process control (MSIPC). MSIPC makes it possible to reduce the total number of design-to-finished part steps; net effect: reduced cycle time and improved profit margins. The traditional-versus-MSIPC process flow is as follows (Mundra, 2007):

Traditional	**MSIPC**
1. Design part with 3D CAD	1. Design part with 3D CAD
2. Create part program / transfer to machine	2. Create part program / transfer to machine
3. Start working cycle	3. Start working cycle
4. Remove part from machine	4. Check part on machine
5. Check part on CMM	5. Finish part machining
6. Reload part on machine	6. Check finished part on machine
7. Finish part machining	
8. Remove part from machine	
9. Check finished part on CMM	

Waurzyniak (2007) supports the lean-automation ideology that lean manufacturing plus automation equals waste reduction and increased return on investment. In the article "Automation in Lean Manufacturing", Mr. Waurzyniak states that many companies practicing lean are missing out by not including robotized automation in their operations. Waurzniak claims that "there are machinists and toolmakers that spend 60% of their time loading and unloading the equipment, and very little time programming the equipment to do the job." By using robots to augment human part processing, and other processes that could be automated, a company's Overall Equipment Effectiveness (OEE) return on investment can be greatly enhanced. The key is to look for processes where human capital is being wasted. Complementary to this article, Weber (Ten Forces, 2007) states that on October 15, 1990, the term "lean manufacturing" was coined in the newly published book called "The Machine That Changed the World." Further evidence that lean manufacturing, and DFM as a subcomponent of Lean, is here with us for a while.

DFM: A Forecast

Anthony Theodorou (2002), of Aristotechnics, Inc., forecasts the following trends for corporations (all involving Design for Manufacturing):

- All types of systems will have to be sophisticated, pre-engineered, and pre-manufactured. This will allow people with few or no skills or tools to do the work.
- The demand for "do-it-yourself" products will increase.
- End users will be willing to pay higher prices for components that offer greater manufactured value in terms of timesavings and lower skill requirements.

Russ Olexa (2002), Senior Editor of Manufacturing Engineering, shares the lean manufacturing (and Design for Manufacturing) triumphs of the Lockheed Martin Pike county operations in Troy Alabama. Lockheed manufactures weapons for the military, weapons, which historically have been costly due to cost overruns and minimal manufacturing planning. By implementing lean manufacturing principles, Lockheed has been able to "convert to single-piece flow manufacturing and getting the waste out of a process, and removing all the extraneous material collected in the manufacturing environment over the years (Olexa, 2002)." The link from lean manufacturing-to-Design for Manufacturing comes into play when one considers that Lockheed also spends a large amount of time with customers, vendors, and tooling engineers to prepare production for the most manufacturing-friendly operation possible, to quote the editor:

> "Lockheed even hired a staff engineer to develop specialized equipment or tools that help reduce waste during missile assembly. For instance, he might design a multifunction tool rather than using one tool for one function. This saves steps and the time that would have been consumed obtaining multiple tools (Olexa, 2002)."

Danford (2007) cites from a Lean Enterprise Institute (LEI) survey that middle management is the number one obstacle to lean manufacturing (aka, lean production) success. With many believing that DFM is a subcomponent of lean manufacturing, this does not bode well for many companies who wish to practice continuous improvement programs within their facilities. In the LEI survey the obstacles to lean manufacturing success included: 36 percent (middle management opposition), 31 percent (lack of implementation skills), and 28 percent (employee resistance).

While lean manufacturing and DFM may be facing problems, the use of lead-free solder is yet another story. Through governmental regulation, electronic component manufacturers have been forced to change… or else. In the case of lead-free solder selection and implementation in domestic and offshore supplier facilities, DFM teams have been successful in finding different types of solder alloys which do not use lead as a primary ingredient (Prasad, 2007).

DFM: Knowledge Accounting

Knowledge Accounting (KA) software is another key component of implementing effective and efficient design-for-manufacturing processes. W. Bradley Holtz (2002) states that many companies suffer irreplaceable knowledge losses when an experienced employee leaves a company – in summary, they "take their knowledge, experience, decision-making skills, and tricks of the trade." The Machine Design article written by Holtz lists the positive aspects of the KA software entitled "Kollabnet" by the Kollabnet, Inc. Company. The software captures knowledge and experience during the product development phase of a new project. The key to the KA software is its ability to help an engineer "document critical parameters, links, and relationships (Holtz, 2002)." Furthermore, as shared by the article's author, the software "Kollabnet" creates "A DesignMap (a map or chart of requirements and their relationships) can show all the pieces (DesignBlocks) of the design, and identify exactly the upstream and downstream impact of any change." By using Kollabnet, as purported by the software company, design and manufacturing engineers should be able to create a knowledge base to help keep historical design decisions and ongoing process changes in check and available for all to use – which would definitely aid Design for Manufacturing issues in most manufacturing facilities. To get an idea of how academia supports design-for-manufacturing efforts, three university websites were viewed (see DFM in Education section).

In 2002, Knowledge Accounting was listed in several articles. Unfortunately in 2007, no article on KA could be found. After scanning for quite some time on KA, the researcher shifted to

Knowledge Management (KM) and discovered that too proved to be sparse in article resources, albeit except for one article: "Unlock The Knowledge Base." Within this article, Persson (2007) relates the need to maximize on knowledge currently in a company's workforce. Persson claims that the knowledge maximization comes about as a company adopts the latest technologies within operations, and the manner in which it is dispersed to its customer base. For employees, work on breaking down intra-company barriers in technology, culture, and geography. For customers, explore and implement Voice Over IP (VOIP) and web conferencing. In essence, keep your customers involved and demonstrate that your company's service is second to none.

DFM in Education

Within the curriculum of the University of Wisconsin (2002), a course entitled "MIE 7550 – Product Design and Development" is used to bring about understanding on the part of new aspiring engineers to understand the role of correct design practice coupled with the fundamentals of Design for Manufacturing. Four basic outcomes are expected and consist of:

1. Development of problem solving skills and decision-making.
2. Gaining knowledge and practice from the latest methodologies on product design and development.
3. Preparation for advanced analysis.
4. Understanding of economic analysis methods.

The MIE 7550 course is also broken down into the following components, which further illustrates the need for engineers and others to have a firm grasp of design, Design for Manufacturing and overall design impact considerations:

1. Development Processes and Organizations
2. Product Planning
3. Identifying Customer Needs
4. Product Specifications
5. Concept Generation
6. Product Architecture
7. Industrial Design
8. Design for Manufacturing
9. Prototyping
10. Product Development Economics
11. Project Management

Another interesting angle to preparing college graduates for the real world exists at the University of Washington in their Industrial Design course (2002). In the Industrial Design curriculum, students encounter three years of fine art studies in the following areas that are preparatory to obtaining an understanding of Design for Manufacturing. The main topical areas covered are listed below to help the reader get a better idea of what is involved in Industrial Design – Topical Areas:

1. **Design Theory** - Ethics of design, organizational principles of design, elements of 3D design, design with history.
2. **Design Practice** – Introduction to woodworking, rapid sketching, model-making and rapid prototyping, ideation, scenario building, research methods and testing, design evolution, introduction to design presentation, design implementation, design collaboration.
3. **Materials and Manufacturing** – Manufacturing processes, casting and molding, manufacturing materials, design in multiples, design for industry.
4. **Design Technology** – 2D computer design, 3D CAD, web development, design presentation.
5. **Ecological Design** – Product Lifecycle, design for life, design for disassembly, recycle-ability and reuse, product take-back, material reduction, material impacts, re-evaluating use.
6. **Design Practice** – Furniture design, advanced research methods, human factors design, form development, advanced sketching and rendering, advanced model-making, design presentation for competition.
7. **Design Issues** – Recent trends in design, opportunities from industry, professional design management.
8. **Degree Project** – Self-management, professional mentoring, advanced research and documentation, portfolio.

While the courses above prepares a younger person for product design and manufacture, learning DFM topics requires an adult to (Sheppard, 2007):

- Move from a dependent personality to a self-directed one
- Use their growing experiences as a catalyst for learning
- Use their knowledge immediately, it is not stored for future use
- Motivate themselves from within

The underlying concept of these principles further demonstrates the need for adults in manufacturing to have an immediate outlet for the learning experienced on the job. Performance-Based Training (PBT) is appropriate for this type of situation. With PBT, companies encourage learners to take the next step and become Leader-Teachers, who in turn train and teach Peer-Teachers. Once a company embraces this philosophy, employees no longer "attend" training sessions; they experience learning. This translates into "Individual Performance and Business Results" per Frattali (2007). In 2007/2008, little has changed in the University of Washington's Industrial Design curriculum with focus upon Design + Society, Issues in Design Theory, and a Capstone Design Project (2008).

DFM Cost Cutting & Value-Added Issues

Hegland's (2002) article, "DFMA Cuts Costs Up Front", shares the need for not only having a thorough understanding of Design for Manufacturing techniques, but also for Design For Assembly (DFA) methods as well. By combining the two methodologies, the new resultant methodology becomes Design for Manufacturing Assembly (DFMA). DFMA brings in "predictive cost estimating while early design decisions are being made (Hegland, 2002)." Per the author, DFMA also minimizes product costs by reducing part counts, implementing the best assembly process, reducing assembly time, and by cutting part costs by as much as possible. Four elements were also pointed out to be things to consider in design: quality (conformance to requirements), cost (internal – cost structure, external – price), timing (internal – how long it takes to develop, external – when it is available to the public), and function (what the customer gets). Hegland (2002) also shares the following regarding the need for early and accurate cost information in the design process – the information:

1. Serves to unify the development teams around project objectives.
2. Provides understanding of financial objectives.
3. Forces concurrent development.
4. Allows early understanding of project viability.
5. Provides focus of cost discrepancy to targets.
6. Provides timely information in evaluation of design alternatives among solution sets, and optimization within a solution set.

DFMA also adds value by:

1. Providing insight into issues usually considered much later in the process.
2. Improves product quality and reduces costs.
3. Allows teams to build and retain management support.
4. Reduces time-to-market and overhead costs.
5. Provides a ripe environment for innovation and quantified brainstorming.

In 2007, the latest buzzword in product manufacturing circles was Manufacturing 2.0 (Mfg2.0). With Mfg2.0, everything is about collaboration and enhanced communication. Companies adopt Mfg2.0 to increase business efficiency, competition is requiring it, to solve problems, on the advice of a business partner or employees, and to take advantage of bundled services. Per Kenney (2007), fundamental elements and definitions within Mfg2.0 are as follows:

- **Blogs** – Interactive online journals
- **Collective Intelligence** – Any system that attempts to tap the expertise of a group
- **Mashups** – Aggregation of content from different online sources to create a new application or service
- **Podcasts** – Audio or video recordings available over the Internet
- **RSS** (Really Simple Syndication) – A method of pushing Internet content to subscribers
- **Social Networking** – Online communities that allow members to learn about each other's skills, talents, and knowledge
- **Web Services** – Systems that automatically communicate to pass information or conduct transactions over the Internet, such as online inventory updates
- **Web Widgets** – Scripted online tools that present an easily accessible way of viewing and performing independent tasks on one web page
- **Wikis** – Systems that allow users to add and edit content for collaborative publishing

Little has changed from 2002 to 2007 in this regard, to optimize on value-added activities in manufacturing and services, companies should (Sabbatis, 2007) focus on:

1. Leveraging unique staff knowledge and expertise to provide high-value to clients
2. Creating a collaborative culture, that encourages sharing and learning
3. Deploying technology solutions that help eliminate repeatable processes, capture knowledge, enhance client communications, and attract & retain the most talented people

2002-to-2007 Conclusions

From the literature, interviews, and various sources, the following summary of information highlights the status and trends of Design for Manufacturing in industry and manufacturing in general. While it is hard to predict how industry will continue to react to DFM efforts in manufacturing in the next five or ten years, it appears safe to assume that DFM will continue to have a place in manufacturing for some time to come. Here are the 2002 and 2007 issues, in a comparison format:

<table>
<tr><th>2002</th><th>2007</th></tr>
<tr><td>DFM will remain to be mixed with various design and manufacturing technologies to obtain the lowest cost at the highest quality</td><td>No change - DFM remains mixed with various design and manufacturing methodologies (Hudspeth, 2007)</td></tr>
<tr><td>DFM will be correctly applied by knowledgeable designers and engineers utilizing known "limitations, relative costs, and process capabilities (accuracy, tolerance requirements, etc…) in order to design for manufacture (DeGarmo, Black, & Kohser, 1997)"</td><td rowspan="2">Both remain to be a work-in-progress as designers and engineers practice the art and science of product design toward optimized manufacturing; addendum, CAD usage in continuing to grow in usage as companies automate and CAD-generated photo-realistic designs are used for product sales brochures (Thilmany, 2007)</td></tr>
<tr><td>Designers and engineers will continue to be admonished to be intimately involved with manufacturing processes and capabilities in order to correctly specify drawing tolerances that manufacturing can inexpensively manufacture</td></tr>
<tr><td>Product Lifecycle Management (PLM) will take on a greater role in DFM; helping designers and engineers in better implementation of DFM principles. This is also true of web-enabled companies seeking to obtain more customers and make more profit (Elliot, 2002)</td><td>PLM is just as important today as it was in 2002. In fact, PLM helps support "green" initiatives and design for modularity (Stackpole, 2007; Vorster, 2007)</td></tr>
<tr><td>Many companies such as IBM will emerge to offer Contract Manufacturing (CM) services to aide other firms who develop products, yet choose not to manufacture their own products. In the opinion of managers interviewed, this trend will further alienate designers and engineers from fully understanding the capabilities of manufacturing, and result in reduced DFM and optimized manufacturing taking place (Assembly, 2002)</td><td rowspan="2">Contract Manufacturing still holds a major role in 2007 global manufacturing. While IBM may still hold a considerable presence in Contract Manufacturing, no articles were found listing IBM's participation. Contract Manufacturing & Collaboration issues were more focused upon tenuous relationships between global suppliers provided lead-based painted products, undermining needed levels of trustworthiness and reliability on the part of vendors (Mongelluzzo, 2007; Chatterjee, 2007)</td></tr>
<tr><td>DFM proponents will push further for increased levels of interaction between vendors, customers and internal company colleagues</td></tr>
</table>

<table>
<tr><th>2002</th><th>2007</th></tr>
<tr><td>Environmental variables appear to consist of designer and engineer labor availability, adequate funding for DFM in industry, understanding in DFM practices, the technology level in a given corporation or plant, knowledge of tooling capabilities, knowledge of the actual demonstrated abilities of employee workforce capabilities, and understanding in products manufactured</td><td>No articles were found that addressed this issue</td></tr>
<tr><td>Customer Relationship Management (CRM) and Supply Chain Management (SCM) are also being directed to be included in DFM activities. The integration of all three components brings together elements of "product creation, sourcing, procurement, sales, distribution and maintenance (Bodegom, 2002)"</td><td rowspan="2">Some argue that CRM, SCM, DFA, and DFM have become a subcomponent of Lean Manufacturing (Danford, 2007)</td></tr>
<tr><td>DFM will continue to be regarded as a sub-component of lean manufacturing. The link between the two methodologies will continue to integrate and merge</td></tr>
<tr><td>With the widespread migration of American manufacturing operations to offshore countries, or Mexico, a substantial amount of DFM work will be conducted and controlled from American corporate centers. With this workforce relocation effort will come greater distancing of what can be done in remote locations. In time, one could forecast that foreign operations will eventually take on their own original design and DFM activities. This is seen as the greatest element of social change in American industry. One that is already in motion and required little forecasting (Lessiter, 2002)</td><td>No change - DFM and manufacturing remain in an "outsourcing frenzy", in spite of increased safety and risk issues (Tennessee Tribune, 2007)</td></tr>
</table>

<table>
<tr><th>2002</th><th>2007</th></tr>
<tr><td>Designers and engineers will be expected to have extensive manufacturing backgrounds before conducting design activities (Manager A, 2002). Plus, many managers feel that design personnel should work at the same location that manufacturing occurs</td><td rowspan="2">No change here, "manufacturers are dealing with highly complex and diversified manufacturing pressures due to competitive pressures" … domestically and globally (Waurzyniak, 2007)</td></tr>
<tr><td>With frequent corporate downsizings, reorganizations and mergers, DFM will more than likely take a back seat to manufacturing optimization. In the interview with Manager C (2002), Manager C pointed out that many plants take whatever product lines they are handed – with very little knowledge of the product they are now to begin building. Therefore, once again, the key to increased and successful implementation of DFM would appear to rest in understanding product and manufacturing capabilities</td></tr>
<tr><td>Another trend for DFM is its merging into Knowledge Accounting (KA) software. Through electronic documentation, DFM practices and past knowledge could become more widely used by less experienced plant personnel (Holtz, 2002)</td><td>Knowledge Accounting seems to have been replaced by Knowledge Management. Persson (2007) presents a good case on Knowledge Management that appears to mimic Knowledge Accounting</td></tr>
<tr><td>Universities will continue to tailor their curriculums to include DFM principles, plus take on more "real world" topic matter to better prepare their students for workforce positions. This trend of focused-education may continue as state and federal grant and support dollars decrease. Thus in effect, universities and college virtually have no choice but to align their course offerings to be more in line with what industry wants for their workforce</td><td>Education is under substantial pressure to conform to the latest pedogies and technologies for adult learners (Shepherd, 2007). Performance-Based Training may help (Frattali, 2007)</td></tr>
</table>

2002	2007
Although cost reductions and workflow rates were never quantitatively stated in any of the articles reviewed, the trend for increased DFM application would still be expected. One could also surmise that the cost figures have been left out of the articles due to the difficulty of objectively and qualitatively determining the cost impact of choosing one design feature over its alternative. And since designers and engineers are trained to always choose the least expensive manner of manufacturing anyway, then what would there have been to compare in terms of cost? Design For Manufacturing would appear to be good old common manufacturing and design engineering common sense – correctly applied	While cost reductions and workflow rates are still important in manufacturing, only one article was found with cost information supporting the need to keep out a watchful eye (Vorster, 2007)
The role of Design For Manufacturing is an increasing one in relation to the Strategic Planning of Technological Processes. As industry strives to further reduce product costs, more emphasis will be placed on DFM to help eliminate waste (lean manufacturing), realize Design For Assembly (make it easy to build with little chance of building errors) on production lines, and create an environment well implemented in tailor-made least-expensive technological processes	Lean Manufacturing, Six Sigma, and Automation appear to be the leading role models for reducing wastes and costs in 2007 (Waurzyniak, 2007). Followed briskly on its heals by Manufacturing 2.0's technological enhancements (Kenney, 2007) and using value-added methodologies with talented / experienced staff, collaborative company culture, and appropriate technologies (Sabbatis, 2007)

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