Holistic Consideration of Best Practices in Product Design, Quality, and Manufacturing Process Improvement through Design for Value

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Division: Manufacturing

Abstract

Manufacturers in the US have compartmentalized their product design and process improvement teams which has hindered the generation of synergy between the two groups that can substantially improve a company's overall profitability.

Companies have pursued initiatives to improve the product design process through concurrent engineering (CE), design for manufacturing and assembly (DFMA), design for X (DFX), and geometric dimensioning and tolerancing (GD&T). These have been primarily implemented by a company's product design team. Process improvement initiatives like Lean manufacturing, theory of constraints (TOC), etc., are pursued by manufacturing teams in a company.

However, the product designers and manufacturing personnel pursue their improvement initiatives independent of each other in a typical manufacturing company. This leads to islands of excellence, which might result in some gains but dreadfully fail to achieve the true promise of these initiatives if these were implemented in a holistic fashion throughout a company under top management leadership.

We have also observed that the mindset in industry of keeping product, manufacturing, and quality initiatives separate and mutually exclusive is also reflected in academia, where manufacturing engineering and manufacturing engineering technology programs at universities in the U.S. teach product design ideas, manufacturing practices and quality concepts as independent notions. This hampers students' ability to make the strong connection between these concepts that is necessary if they are to lead companies which will use these best practices as strategic tools for their business operations to realize quantum improvements in their processes and productivity.

In this paper, taking the above into consideration, the authors propose a new manufacturing mentality that we coin as "design for value" or DFV. We define DFV in the context of best practices in product design, manufacturing processes and quality, and promote DFV as a top management initiative rather than an initiative to be pursued by product design engineers, manufacturing personnel or quality assurance teams. The paper also elaborates on how the concept of DFV can be introduced to manufacturing engineering and manufacturing engineering technology students through appropriate curricula.

Introduction

It is estimated that around 70% of the cost of a manufactured product is locked in at the product design stage as shown in Figure 1, and it is estimated that around 80% of chronic quality problems in manufacturing can be traced to issues in product design. Clearly the importance of product design on efficient manufacturing and high quality products cannot be overstated.

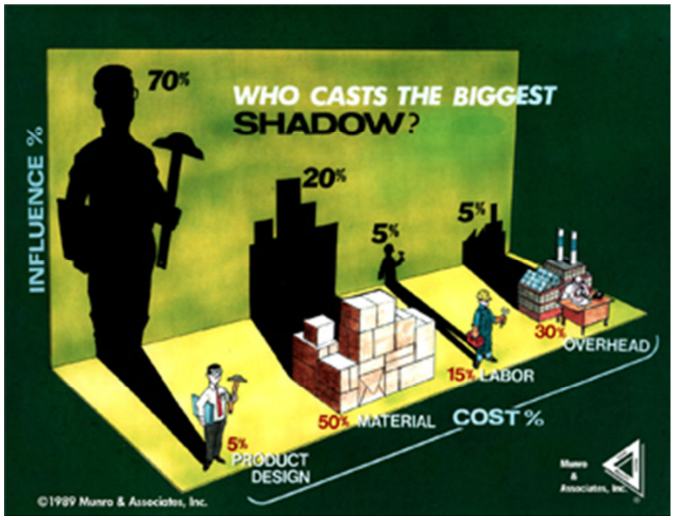

Figure 1. Who Casts the Biggest Shadow? (Munro, 1989)

However, product design and quality are not given the importance that we feel they deserve in industry. The evidence that product design and quality are being deprioritized in manufacturing can be found in the fact that the body of knowledge for the Certified Manufacturing Technologist (CMfgT) and the Certified Manufacturing Engineer (CMfgE) certifications administered by the Society of Manufacturing Engineers, includes topics on design and quality as only 20% of the core content (SME, 2012). Also, SME's Certified Professional Engineering Manager's (CPEM) body of knowledge that is made up of 8 domains that cover 44 areas of manufacturing expertise only includes 5% body of knowledge on design and quality specialties (SME, 2012).

Background

The book, *The Goal* (Goldratt, 1986) which hit the manufacturing community like a ton of bricks to awaken it to the fact that a manufacturing operation exists only to make money, and that all systems, processes and metrics employed by management are the means to the goal rather than the end goal, we believe underplayed the importance of product design and quality in achieving the ultimate goal.

Engineering and technology curricula at universities picked up this book as required reading to teach the manufacturing concept of drum-buffer-rope (DBR) as a stand-alone best practice for manufacturing scheduling on the shop floor as shown in Figure 2. Students, although clear on how to implement DBR on the shop floor, missed on what effect product design and quality can have on manufacturing scheduling. This might have created manufacturing managers and engineers who have clusters of knowledge, but who are deficient in understanding the holistic effort needed to achieve long-term success for the manufacturing companies that hire them.

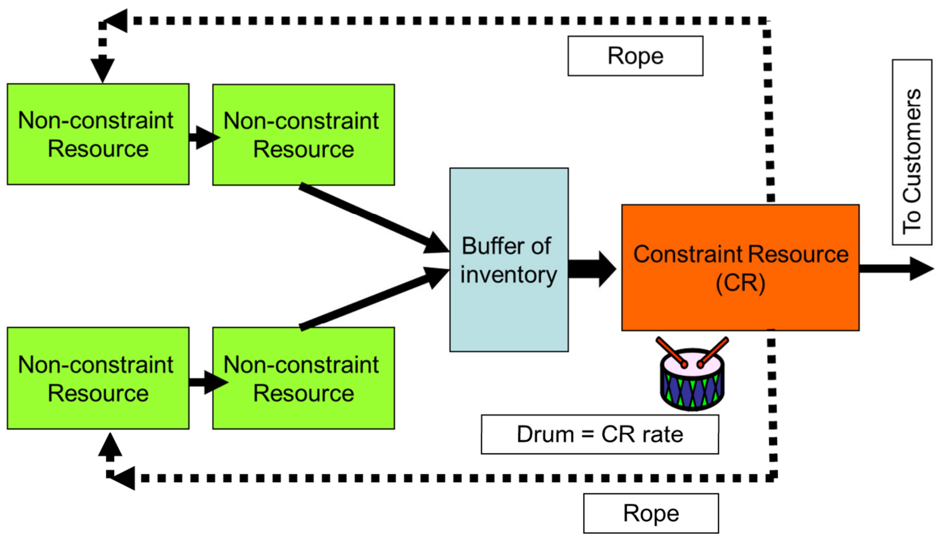

Figure 2. Drum-Buffer-Rope Concept in Theory of Constraints

In describing the Toyota Production System (TPS), Taichi Ohno the creator of TPS, that was responsible for the Toyota Motor Company's stellar rise to be the largest automobile company in the world, defined three pillars of TPS as: 1) just in time (JIT) production and assembly, 2) Autonomation, which is the concept of using automation with a human touch to stop the process if the process is producing out of spec product, and 3) pull manufacturing strategy for manufacturing scheduling where the product is moved to the next operation only if the downstream operation requires it (Ohno, 1988).

Ohno further stated that JIT is only possible if supported by quality, inventory accuracy, and level production. This clarification however is lost by many who attempt to imitate Toyota to replicate its success in cutting out all waste of resources that customers are not ready to pay for in a manufacturing company's cost structure. Toyota using its Poke-yoke (mistake proofing) philosophy, does not allow a component to move on to the next stage of processing unless it has been positively identified as acceptable. Along with Poke-yoke, Toyota uses two more quality philosophies of self-inspection and next operation inspection to ensure that no substandard component stops the manufacturing and assembly processes.

The Machine that Changed the World (Womack, 1990), which is the final report of the 5-million dollar, 5-year study conducted by Professors Womack, Roos and Jones on behalf of the U.S. government to identify why the big three automobile manufacturers in the U.S. cannot compete with their Japanese counterparts, is credited with initiating the Lean revolution in American production by documenting TPS.

In describing Toyota's TPS, and best practices of other Japanese automobile manufacturers, it was identified that product design plays key role in the success of these companies through the pursuance of simultaneous or concurrent engineering and Lean design.

Womack et al observed that the intent of Lean design in Japanese companies is to shorten the time to market for new products, but readers failed to make the connection that product design can have a significant influence on process improvement initiatives, which might have given the Japanese a substantial lead that the big-three are finding hard to catch up to.

Some researchers and practitioners have identified other product improvement initiatives like concurrent engineering (CE), that for a time became the predominant design philosophy in product design and manufacturing process development along with service and disposal (recycling) of products (Rehg & Kraeber, 2005). With the wave of CE, other best practices and tools to support it were developed like design for manufacturing and assembly (DFMA), design for maintenance, design for recycle, and design for X, where multiple considerations were given during the product design phase.

Although TPS and CE focus mainly on the technical aspects of product and process design, Monden has documented that Toyota was successful in using these product development strategies without much fanfare for achieving the real goal of profit (Monden, 1993). This they seem to have achieved to do by determining their production cost at the design stage, and not on the manufacturing floor. This was their key to establishing the vital link between product design and profitability.

Monden also defined cost as a target, not as a result of product design, thus giving rise to the concept of value engineering and target costing (or market pricing) as a core concept of design. Monden articulated the futility of coming to the sales price of a product by first collecting the manufacturing cost and then adding on a profit percentage.

In target costing, the market price of a product is determined by what the market will bear based on the perceived value of a product, and the target manufacturing cost is determined by subtracting the desired profit from the market price. Hence, only through cost reduction can profit in the marketplace be improved.

The concept of target costing or market pricing however has failed to impress up on manufacturing personnel to make the connection that only by giving product design the necessary importance, firms will be able to have a steady grasp on their costs and quality to survive and thrive in the global marketplace.

Defining Design for Value

With the above discussion, it is evident that a new paradigm that connects the value provided to customers with product design, quality attributes and manufacturing initiatives is essential if firms are to use these as a universal medium to excel in the international marketplace of today. Also, such a new paradigm will enable educators to stress the importance of holistically understanding product design, quality and manufacturing for students of manufacturing engineering and manufacturing technology.

Only by giving a top-level importance to product design, quality and manufacturing processes will our students be able to lead their companies into every-widening thought and action to provide exceptional value to their customers. We hence define design for value (DFV) as follows:

1. **DFV is a top management initiative:** Design for value is a product design, product quality and manufacturing process paradigm which is promoted and implemented by the chief executive officer (CEO) working with the top management team in a manufacturing business. Design engineers, quality assurance personnel and manufacturing executives deal with DFV's concepts, but the ownership of the paradigm and its successful implementation is the responsibility of top management.

2. **DFV provides value to the customer:** Someone has to pay for all efforts that are expended by a manufacturing company. It is always the final customer who pays for the product who covers all the activities that were performed. DFV requires that all personnel working in an organization understand this, and constantly keep in mind the need to perform only activities that the customer thinks are valuable, and is ready to pay for. Actions and time put into efforts that the customers do not feel are valuable are wasted resources and tasks that the manufacturing company should target to eliminate. Top management constantly promoting a culture of "always being customer task oriented" is essential in practicing DFV.

3. **Key player in DFV is the product design team.** In a DFV environment, top management should constantly remind its product design team that their input is paramount in how their company produces quality products without any wasted resources that provide exceptional value to their customers. Also, it is essential for top management to articulate to the product design team that although their work is the most important in creating a quality value product for the customer, the product is brought to life only by the manufacturing personnel and hence they should make every effort to make manufacturing flow smoothly.

4. **DFV determines tolerance using tolerance analysis.** Designers have a tendency to arbitrarily assign tolerances to critical components in products. Using scatter plots (Bhote, 2000) tolerances can be decided on critical components that are close enough to achieve the functional requirement and at the same time are not too restrictive to unnecessarily increase the manufacturing cost. An example of

how this can be done using Shainin' s Red X and Green Y ideas (Bhote, 2000) is shown in Figure 3.

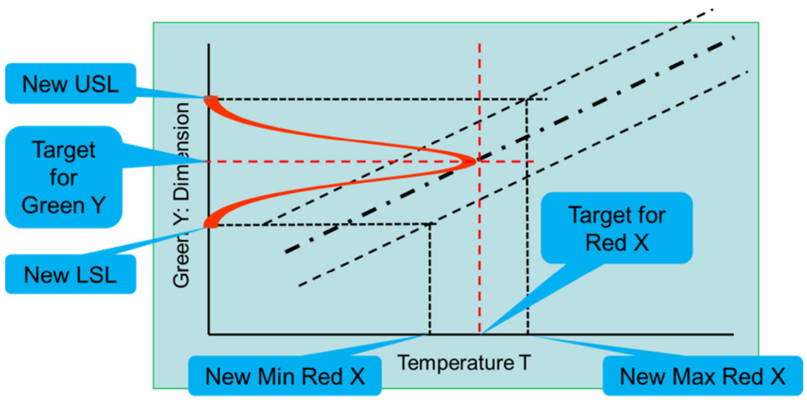

Figure 3. Utilizing Shainin Techniques to Determine Critical Product Tolerances

5. **DFV uses geometric dimensioning and tolerancing (GD&T).** In DFV, product design communicates quality requirements to manufacturing using geometric dimensioning and tolerancing (GD&T). This is done through the use of zero tolerancing at the maximum material condition (MMC) or the virtual condition (Mehta, 2012). This concept allows the maximum tolerance that is available to be offered to manufacturing so that they do not waste time in coming back to product design to seek for some additional tolerance if a component is out of size. This also allows a common tolerance to be made available between the size and geometric tolerance, like it would happen in an assembly situation. Figure 4 shows a product with a zero tolerance at the MMC.

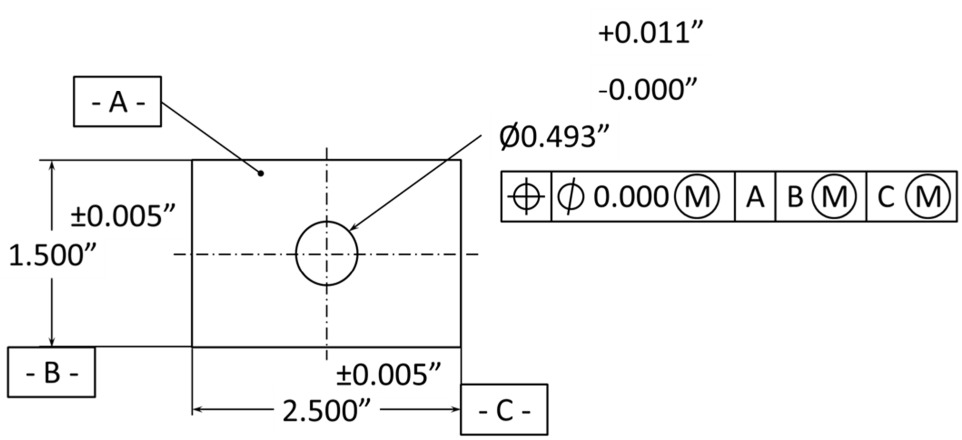

Figure 4. Applying Zero Tolerance at the Maximum Material Condition

6. **DFV requires the application of design for manufacturing and assembly (DFMA).** DFMA is not just a toolbox to reduce internal labor and material costs by 20 – 50% (Shipulski, 2009), but it is also a methodology/process to lower costs while maintaining design requirements and product integrity. The underlying principle in DFMA combines two principles: design for manufacturing and design for assembly. DFMA requires that any design process consider production factors from the beginning of the product design phase. It must be performed as part of the design process, using concurrent engineering methods, to optimize product design to accommodate the manufacturing and assembly process, thus facilitating quality, minimizing cost, and maximizing profit (Rehg & Kraeber, 2005). However, DFMA in DFV should not be thought of as a product design function, but a management initiative to be doggedly pursued by the top management team.

   Through DFMA, cost is decreased in the supply chain by reducing waste in areas like engineering and design time, fewer suppliers to source, fewer purchasing transactions, less inventory to manage and handle, etc. However, the design engineering community had been isolated from Lean initiatives (on the manufacturing shop floor,) and therefore, part count reduction efforts have not been (a) part of the lean equation (Shipulski, 2009)

Suggestions for Including DFV in the Curricula:

We believe DFV is a top management initiative and hence although its parts can be taught in various courses, the overarching holistic concept should be introduced and well seeded into students' minds in the capstone experience. DFV's ideas on providing nothing but true value to the customer can be introduced to students in product design and manufacturing systems courses. Courses with titles like engineering product design, design for manufacturing, lean manufacturing, six-sigma and manufacturing processes would be ideal to introduce the customer value proposition to students.

The concept of manufacturing as the true satisfier of the customers' needs should also be introduced in courses like product design, lean manufacturing, and manufacturing processes. Tolerance analysis for determining the true tolerance to assign to key components can be tackled in quality assurance or quality control courses. Also, another good place if available for this idea can be a course in design of experiments.

Use of geometric dimensioning and tolerancing (GD&T) in DFV can be introduced in basic engineering drawing or CAD classes, along with a mention in the manufacturing processes or manufacturing systems classes. The concept of zero tolerancing at the maximum material condition (MMC) or the virtual condition is a little difficult for manufacturing personnel and students to grasp as it calls out a zero tolerance inferring a perfect process. Naturally, this is not the case, and once understood it has been observed that manufacturing personnel zero tolerance at MMC as it makes life easy on the shop floor. Application of design for manufacturing and assembly (DFMA) concepts can be tackled in introductory courses in product design or manufacturing processes and systems.

Conclusions

Leaving product design, quality and manufacturing management to individual department managers in a company is a sure recipe for sub-optimization of these important functions in a company leading to mediocre performance. Only through the adoption of a top-level initiative like design for value (DFV) where top management takes the responsibility for effective communication between product design, quality and manufacturing can a company be successful over the long haul in the global markets of today.

It behooves top management to not only embrace the proposed paradigm of DFV, but they should well learn details of DFV as elaborated above if they are to achieve the true promise of DFV.

In the educational context, it is incumbent upon institutions and personnel who provide manufacturing engineering and manufacturing technology education to the manufacturing leaders of tomorrow to provide a clear understanding of DFV, and how DFV can provide for a strong manufacturing base for our country for tomorrow.

References

Munro and Associates Website. (1989). *Who has the Biggest Shadow?* Downloaded from the web from: http://www.munroassoc.com.

SME Website. (2012). *Certification Body of Knowledge.* Dowloaded from the web from: http://www.sme.org/sme-certification.aspx.

Goldratt, E. M. & Cox, J. (1986). *The goal: A process of ongoing improvement*. New York: North River Press.

Mehta, M. (2010). *Theory of Constraints (TOC) and Lean—A Synergistic Winning Combination*. Presentation at the Operational Excellence Conference of the Institute of Industrial Engineers (IIE).

Monden, Y. (1993). *The Toyota management system: Linking the seven key functional areas*. Cambridge, Mass: Productivity Press.

Ohno, T. (1988). *Toyota production system: Beyond large-scale production*. Cambridge, Mass: Productivity Press.

Mehta, M. (2012). *Japan's Double Barrel Manufacturing Weapon for Superior Product Quality*. Conference presentation at the 2012 Engineering Lean Six-Sigma Conference hosted by the Institute of Industrial Engineers.

Bhote, K. and Bhote, A. (2000). *World Class Quality: Using Design of Experiments to Make it Happen*, Published by AMACOM - American Management Association, NY.

Rehg, J. & Kraebber, H. (2005). *Computer Integrated Manufacturing, 3e.* Upper Saddle River, NJ: Pearson Prentice Hall.

Shipulski, M. (2009). *Resurrecting Manufacturing*. Industrial Engineer. Volume *41*(7), 24-28.