DFMA: An Enabler of a Lean Enterprise

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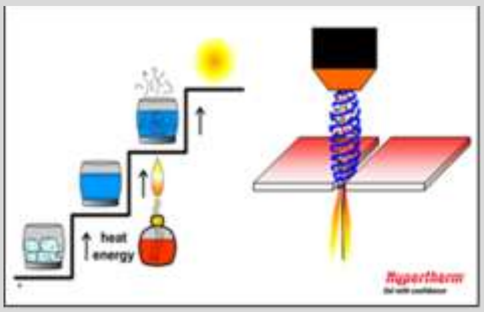
About Hypertherm

Hypertherm, Inc., located in Hanover, New Hampshire, is a company dedicated to providing the best industrial cutting solutions in our industry (www.hypertherm.com). The company was founded in 1968 by current Chairman of the Board Dick Couch and Dartmouth College Engineering Professor Emeritus Bob Dean when the pair discovered the potential to cut metal with speed, accuracy, and precision using a narrowly-focused plasma arc.



The conductive electric arc used for cutting is a result of adding energy to a gas to dissociate its molecules and ionize its atoms.

Our focus on technology remains strong with product offerings in several cutting-related markets: plasma arc, laser, and water jet cutting, as well as CNC motion control hardware/software and CAM software solutions. Nearly all our manufacturing is done in the United States while the company has a global sales and service presence in 93 countries. North American markets account for 45% of sales and exports to Europe, Asia, and South America account for the remaining 55%.

Executive Summary. Design for Manufacture and Assembly (DFMA) can help ensure we develop and integrate the best product designs into Lean supply chain and manufacturing operations. Desired outcomes include designs that require the minimum materials, time, space, and resources to provide value to customers. These outcomes are the definition of Lean. In this white paper we'll identify the key linkages between DFMA and Lean Enterprise, and explore what the benefits are.

Lean Enterprise Culture and Operational Excellence. In a time when novel industrial concepts are conceived at an ever-increasing pace it can be a challenge to maintain a constancy of purpose for improving products and services. At its core Lean[1] is the pursuit of delivering ever-increasing value to customers when they need it, and Lean Enterprise provides a vehicle for an organization to fully engage in that pursuit. This white paper is a collection of observations from one organization where we strive to align the enterprise to Lean thinking. Specifically, this article explores how DFMA is a key enabler of a Lean Enterprise.

Lean is creating the most value for the customer while minimizing resources, time, energy and effort. Resources include physical entities such as materials, labor, and space - as well as information, which is now often found in digital form. While Lean strives to minimize waste in any of these forms we will pay particular attention to information-based waste, in no small part because it can be hardest to identify and as a result can be so pervasive.

In a company that develops and sells products and services, there will be a collection of steps in the value creation process, also known as the 'value stream'. A Lean organization, or a Lean Enterprise, constantly evaluates which steps in the value stream deliver value to the customer and which are non-value added or waste. The value stream map in Figure 1 describes key process steps in value creation in the lower portion of the map. The upper part of the map captures some of the information flow paths -

clearly there are many. In addition, one or more digital databases provide information to those process steps. Customers generally do not value this information (i.e. do not want to pay for it) so a Lean Enterprise will strive to manage its processes with a minimum amount information related waste.

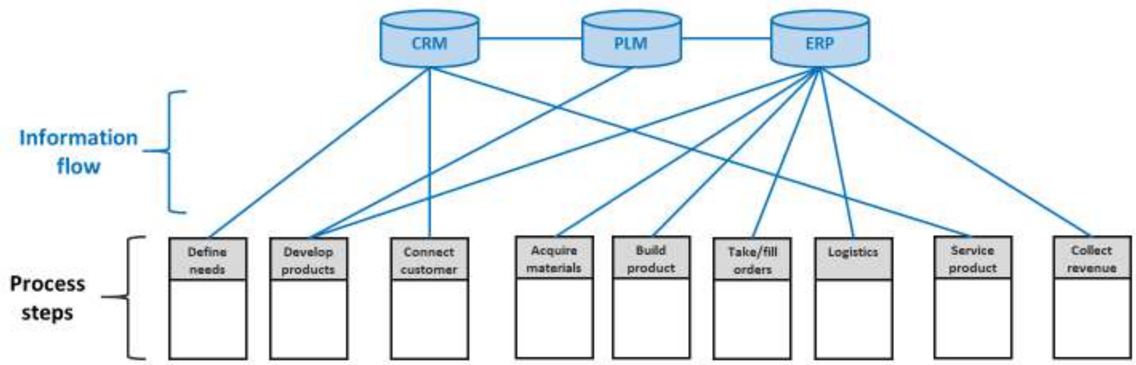


Figure 1. Value stream map of customer value creation.

Labor and material cost savings achieved over the life cycle of a product represent the collaborations of both the design and operations teams. As we'll discuss in this paper, the design community cannot be successful without the input of the operations team. Likewise, the operations community needs the design team to carefully consider design choices such that parts count, along with material and labor costs, are reduced without adverse impact on function.

Hypertherm has long leveraged an advantageous position with a technology-based product protected by strong intellectual property, a value proposition clearly perceived by customers, and a relatively low labor-to-material cost ratio. However, mounting global competitive pressure, increasingly at-risk market share, and continued infiltration from alternative technologies (such as fiber laser) simply mean that the company cannot be complacent. While Lean manufacturing improvements are essential to continued profitability, those alone will not provide enough defense. Design improvements reducing parts count, executed through DFMA methodology, are critical to avoid waste before it is engineered into the product. Our strategy at Hypertherm is to use DFMA integrated into each product development cycle to produce step change improvements in material costs and operating expenses. In between product development cycles operations teams employ Lean principles to lower operating expenses and reduce material costs. We also appreciate the impact that DFMA has on waste rooted in the transactional and information-based processes that manage that data related to each and every part and process step related to a product.

In what ways might information and transaction-based waste be identified in a product? The traditional 7 wastes often referenced in Lean manufacturing include

- Transportation
- Inventory
- Motion
- Waiting
- Over production
- Over processing
- Defects

If Lean aims to create value for the customer while using the minimum of materials, labor, space, and information then one or more of these wastes can affect the value creation process. For example, a design that lacks simplicity, is overly complex, and has more parts than necessary …

- Creates more raw materials and work in process inventory
- Increases the probability of assembly defects
- Contributes to transport, motion, and over processing, all of which increase labor
- Consumes excessive space both in production and the warehouse

It's worth looking at several examples of how design decisions can either contribute to a Lean environment or undermine it. For example, DFA activity often focuses on parts count reduction. In this example of a DFA project, parts count dropped from 721 in the original design to 533 in the new design. A cross-functional team of design and manufacturing engineers, assemblers, technicians, and leaders removed 188 parts from the product – a 26% reduction.

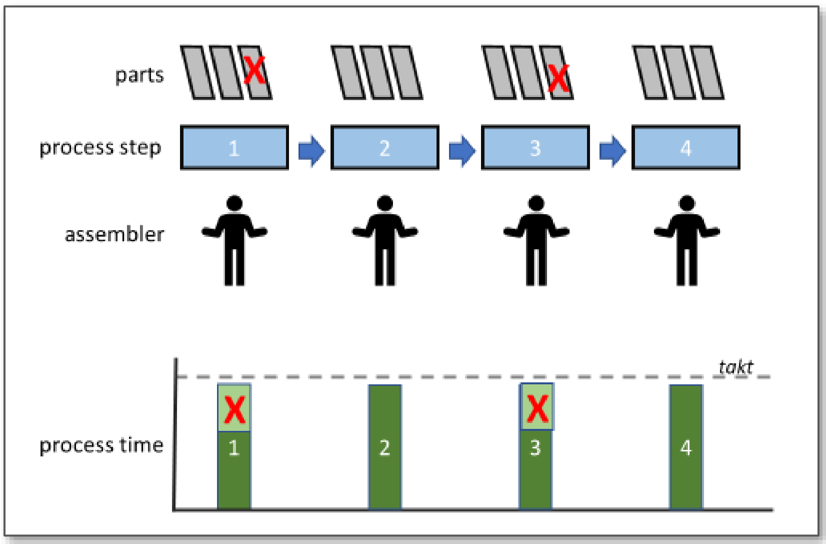


Figure 2. Effect of reducing parts count on work cell process time balance.

As parts are eliminated from a product (**inventory** reduction) and the design is simplified several opportunities emerge (Figure 2). The space required to store parts is reduced, fewer tools are required, process steps can be moved closer together, and the footprint of the value stream is reduced, along with **transportation** and **motion**. The assembly cycle time will drop as well. It is unlikely that it will drop uniformly across all the process steps so sound Lean practices will be needed to re-balance the work content equally across the process steps to fully capitalize on the process time improvements. Or, in the example in Figure 2, the team may decide to consolidate four process steps into three, thereby freeing one assembler to be redeployed to another role in the team.

The material cost savings and direct labor cost avoided result in an increase in EBIT (Figure 3). However, the impact of the eliminated parts reaches far beyond the material and direct labor savings.

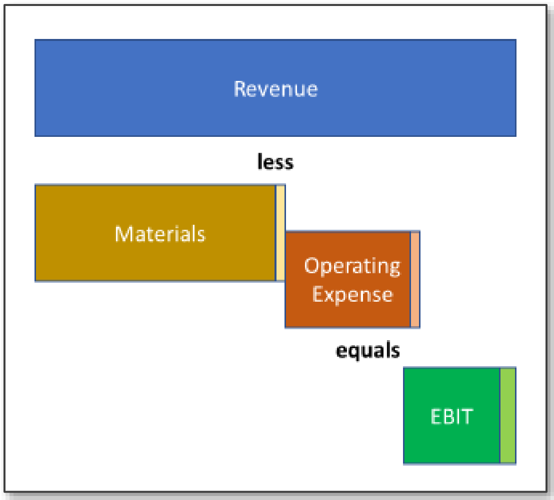


Figure 3. Earnings (EBIT) = Revenue – Materials – Operating Expense; (reduction in materials and OE / increase EBIT shown in lighter shade)

Referencing the often-cited Department of Defense paper "Reduce Program Costs Through Parts Management"[2] as a starting point, we can look at the impact of indirect costs on a commercial business (as compared to direct costs that are related to physical handling of the part during manufacturing).

There are some considerations: First, expenses in a commercial organization related to part maintenance do not likely approach the same level as DoD complexity or expenses. Second, not every part that is removed from a design results in it being fully eliminated (i.e. reducing fastener count from 10 to 5 does not eliminate the part entirely) so there are some fraction of parts that, while reduced in number, may still require maintaining documentation. Third, not every part requires the same rigor in research or support (for instance, supplier qualification or tooling). The table in Figure 4 lists the main types of activities related to parts maintenance that contribute to costs. At Hypertherm, these are all significant contributors to costs, and represent waste that is associated with unnecessary parts.

Activity
Engineering and design time Including create and maintain part-related documentation
Supplier qualification and part qualification (e.g. PPAP – production part approval process)
Manufacturing locator planning and maintenance
Tooling and manufacturing documentation
Procurement related cost (initial and recurring)
Inventory carrying costs

Figure 4. Indirect activities and costs impacted by parts count.

While the DoD report cites an average lifecycle cost of $20,000 per part, a rough estimates the expected indirect costs per part at Hypertherm may be about half that over the product life cycle given the lesser degree of complexity of the commercial business compared to DoD. Given the example above of reducing parts count by 188 the estimated *indirect* life cycle cost avoidance is significant.

A further example of the impact of DFMA comes from printed circuit board design. In collaboration with the PCB supplier, the circuit board layout and design were adjusted to better integrate with an automated assembly process.

1. Place all components on one side of the board (prior designs had components of both sides to minimize board size)
2. Place components in an orthogonal orientation to better enable automation
3. Adjust spacing between components to allow pick/place automation and eliminate manual component placements
4. Use standard component footprints and pad sizing, eliminating large pads for easier conform coat
5. Change interface connectors to a design compatible with to enable a reflow solder process and eliminate secondary manual assembly steps.

While relatively straightforward, these design changes significantly improved the manufacturability of the boards. In addition to assembly cycle time reductions, the process yield has increased. At Hypertherm, a critical benefit has been the improved and more predictable flow in the power supply assembly value stream. Far fewer boards fail at functional test and thus fewer machines require trouble shooting and repair/rework. Over time, our confidence in the board fabrication process reached a level where that data showed such a low degree of failures that it no longer made economic sense to have a functional test step outside of the assembled product. Now, functional test is accomplished through an integrated product test step during the assembly process itself. The costs of the prior functional test itself, as well as the cost to design, fabricate, and maintain the test fixtures and equipment, and the management of the functional test data itself is avoided. Finally, from a business metric perspective, the reliability of the machines in use at customer sites is higher and warranty costs have dropped by 34%.

The 'classic' seven wastes associated with Lean were listed earlier in this white paper. The eighth waste that is also often included with this list is the waste of human intellect. When we fail to engage workers in improvement opportunities we fail to capitalize on the insights and wisdom that production workers glean from day-to-day work in the assembly process. The term 'engagement' is often used to describe how much ownership an associate feels for the process or product in which they have a role. A Lean Enterprise is more likely to have a highly engaged workforce because Lean promotes a culture that relies on the input of a broad range of associates for identifying and implementing improvement. A 2014 study[3] by the Work Place Research Foundation (now Employee Motivation and Performance Assessment) reported that increasing investment employee engagement by 10% has the potential to increase profits by $2,400 per employee, per year. The same study also found that highly engaged employees are 38% more likely to have above-average productivity. In simple terms, increasing engagement increases profitability.

Many companies ask their associates and employees to participate in surveys to attempt to get a quantitative measure of engagement in the workplace. Hypertherm is no different in that regard, employing 60-odd question survey every 18 months along with quarterly 'check-ins' with a handful of related questions. The value in the survey results is two-fold: first, year-over-year comparisons can reveal trends within an organization. Second, benchmarks against similar organizations can provide an indication of 'what is possible.'

How can engagement be improved as a step towards realizing higher profitability? Quite frankly, it is likely that any sort of cross-functional kaizen improvement or problem solving project will contribute because it pulls associates out of their day-to-day activities and creates an environment where they are interacting with different individuals, thereby breaking down ‘silos’. DFMA, in particular when carried out within a cross-functional workshop setting, is particularly effective because it checks the key boxes of relevancy (improving a design/product), working with different people (design engineers, manufacturing engineers, technicians, assemblers, operators, supply chain, marketing), and impact (realizing a quantitative, material increase in profitability).

We can capitalize on higher levels of engagement as well as focusing on specific types of themes. An engagement survey question that we have used for years is ‘…I am encouraged to come up with new and better ways of doing things.’ Certainly asking an assembler or machine operator to contribute their ideas for product improvement, gleaned from hundreds of hours of producing the product, will be viewed as positive. While an absolute measurement of engagement is challenging it is clear to us that cross functional workshops help with devising design and process improvements as well as maintaining high levels of engagement that contribute to profitability.

Business impact. Since rejuvenation of DFMA efforts at Hypertherm there have been four significant product launches since 2016. The long (12-24+ month) product development cycles mean it takes time for the investment in DFMA to begin to show in business results, underscoring the importance of constancy of purpose in an organization. As mentioned previously, Lean has been a part of the culture at Hypertherm since late 1990’s. It’s not possible, or at least not worth the extensive accounting effort, to fully separate the impact of Lean, DFMA, and other continuous improvement initiatives. Further, a major theme of this white paper has been to describe how these efforts are inter-related and integrated.

A relevant example is based on a new product launched in late 2016 for which we now have several full years of sales history. Analyzing revenue, materials cost, and operating expense over a 6 year period that includes the product being replaced overlapped with the new product being introduced we see an EBIT increase of 30% post new-product. Best estimates attribute about 60% of the EBIT improvement to Lean, about 30% to DFMA material and labor cost avoidance, and about 10% to various indirect factors (information-based) discussed above. To further illustrate, some of the Lean improvements - such as rebalancing work content across process steps to achieve cycle time gains – were enabled by DFMA-driven part count reduction and design simplification.

With four recent DFMA-influenced products launched and several more in the latter stages of the development pipeline we anticipate continued positive trends. The graphs in Figure 5 – which are for the whole company level - represent this ‘work in progress’ – that is, a company that is growing and is on a learning curve. The data points plotted on the graph for %material/revenue, %operating expense/revenue, and %EBIT/revenue are company-wide in that these include all business units and support functions (i.e. direct and indirect labor, as well as all other operating expenses). There are positive trends in materials cost, operating expense, and EBIT since 2016 as indicated by the large green arrows. As additional products launch over the coming years we will check back to see if these trends continue. At Hypertherm the business results we have seen with Lean, and DFMA as a key enabler of Lean, have more than convinced us to continue to integrate these methodologies into our product development and operational strategies.

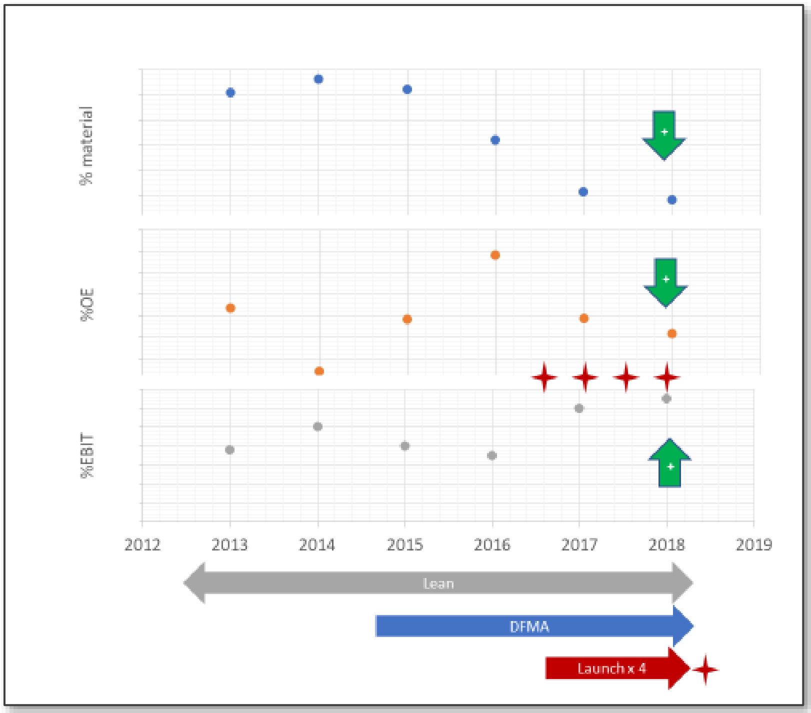


Figure 5. Business impact of Lean, DFMA, and other continuous improvement initiatives over 6 year period on material costs, operating expense, and EBIT. DFMA workshops began in 2014, four major product launches have occurred since 2016.

In summary, there are three key learnings that we hope product designers, developers, and manufacturers can take advantage of. First, DFMA with of its emphasis on product simplification and parts count reduction, is an enabler of many forms of waste reduction. Benefits of DFMA alone are important but the combined value of DFMA and Lean has the potential to be several times greater. Second, not all forms of waste are immediately visible and easily identified. To be truly successful with a combined DFMA and Lean effort all associates must learn how to spot the different forms of waste and act on eliminating them. Third, a workshop-based approach to DFMA that leverages a cross-functional team in early in each product development cycle will enhance engagement and deliver the most benefit.

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