Finding ROI for DFMA in Low Volume, High Mix Environments

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Abstract

The return on investment for DFMA in high-volume manufacturing environments is widely accepted. However, in many low-volume/high-mix shops, prototype houses, or design-to-order operations, common DFMA practices are perceived to provide an insufficient payback. Using the methodology of costing and return on investment (ROI), the authors lay out a case and process for identifying the principles to establish correct practices and appropriate DFMA choices to justify DFMA work in low-volume environments.

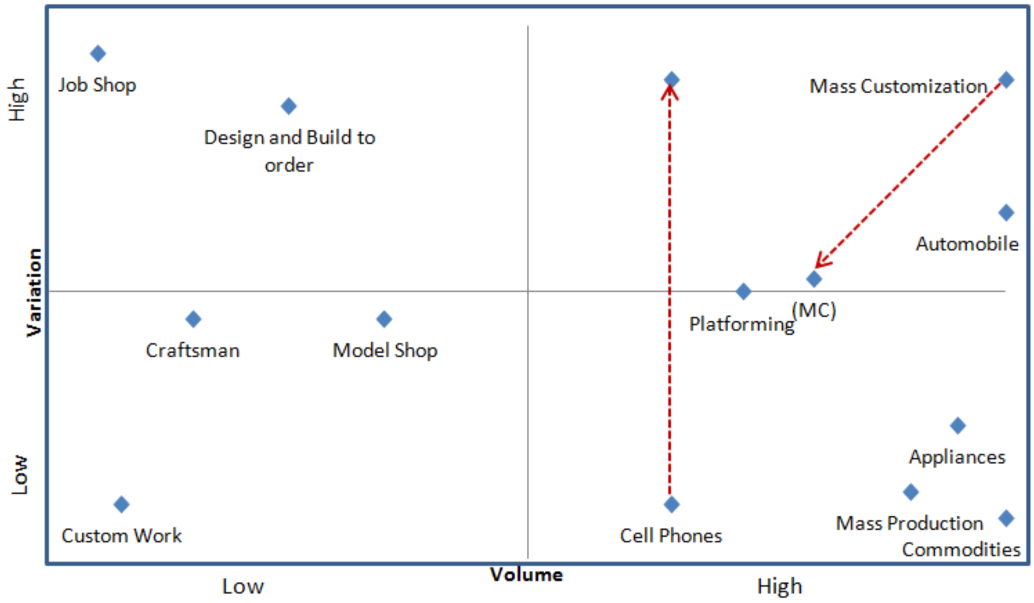
Introduction and Background

Since the early 1980's when the Boothroyd Dewhurst research and investigation into the DFMA approach began to go mainstream, the success stories have been astonishing (Geoffrey Boothroyd, 2011). Advantages have been accomplished through part count reduction, simplification, reduced manufacture and assembly time, and other savings to the company and customer. These successes have seemingly made the concept of performing DFMA work and concurrent engineering a moot point – why would anyone argue that the time and effort spent making a product more manufacturable wouldn't be worth it? From a business-model standpoint, the cheering comes loudest from those who live in a manufacturing-dominant world, where volumes are substantial and customer costs and value expectations are known. But for the design-to-order/engineer-to-order or prototype shop, many of these givens aren't so clear.

A literature review of DFMA principles and practices illuminates notable benefits for high-volume manufacturing businesses. Less emphasis has been placed on applications of DFMA for low-volume product runs. Yet industry trends show that the market is turning from more high-volume to low-volume and that product mix is expanding. (Sprovieri, 2004)

To better understand the differences between market types, we offer a typical 4-box model of market volume vs. mix (see Figure 1.)

Figure1. 4-box market representation



- **High Volume, Low and High Mix (HVHM, HVLM) –** The high-volume segments include commodities and mass-customization segments. The high-mix side is characterized by mass customization, where the market is often managed using platforming approaches, utilizing late-point identification strategies on the shop floor to drive efficiencies and profits. Strong manufacturability work is done on interfaces of components to keep costs in line by allowing a simple mix-and-match system of similar components. For example, PCs will work with any number of disk drives or other peripherals. The low mix, or more commodity segment, is the world of mass production, where speed and efficiency drive profits and variation is kept to a minimum. Cell phones are representative, but unusual example of HVLM. The dominant business model for high volume is to create production efficiencies to the extent possible to capture higher margins and, in some cases, provide the customer with a tailored product offering (mostly through third-party provided features). The customer chooses based on their sense of good value, where cost and quality are dominant characteristics, and product availability is just expected. These segments are consumer driven, where consumers are numerous.

- **Low Volume, Low and High Mix (LVLM, LVHM)–** These business segments include design-to-order, build-to-order, job shop, and prototype houses--where high levels of design and execution adaptability are imperative. Customers value how quickly the business can provide a product of the customer's definition, with reasonable quality and cost as qualifiers (Mahoney, 1997). The non-recurring expenses (NRE) for the development time, rather than the product cost, tend to dominate the overall cost equation. In this case it is perceived that volume is not sufficient to amortize the costs of additional design effort to perfect the product. Many LVLM shops tend to drive their business toward LVHM work to mitigate the business risk associated with market swings (Sprovieri, 2004). Low volume segments of the market tend to be single-customer driven. Because LVLM markets are generally trending to LVHM, and HVHM market segments run into situations that look distinctly like LVHM (low volume options mixes), this paper will focus on the LVHM model and its challenges to utilizing DFMA.

Many LVHM companies obtain work through bid contracts, often because the specific customer's desired end-product doesn't have a clear solution, nor is it desired to have a mass production solution from the onset. Many times the customer wants something that is on the bleeding edge of technology to give them an advantage in their operations (The military is a customer group that comes to mind here.) Yet the solutions have a limited market, and these customers might not have an easy method to determine the value of their creation, even if follow-on contracts are probable. Oftentimes calculating value of immature technology is difficult because the technology has never before existed and its advantages are not completely understood. Additionally, new technology has little if any competition. The customers receive the economic benefits that competition would create only through the imperfect bidding process, not from actual marketplace competition.

Typically, containing contract costs is done by controlling the proposed development work scope to minimize the NRE portion of the bid and maximize the probability of winning the bid. In situations like this, the extra work costs required to perform DFMA can be perceived as prohibitive if value is not properly described to the DFMA-insensitive customer. Is DFMA appropriate in these environments? Necessary? Valuable?

In perceiving the appropriate time to perform DFMA, authors writing in *Product Design for Manufacture and Assembly* point out this low-volume conundrum. They maintain that even at low volumes doing it right the first time has intrinsic benefits, especially when the one-off prototype becomes the production model (Boothroyd, 2011). The reality is that there are environments where an anecdotal ROI (e.g. "Industry says that DFMA will save us 54%!") or intrinsic benefits of DFMA aren't rationale enough to satisfy the close scrutiny of costs on specific projects or bids. One must look further into the cost and benefits equations of DFMA.

The strategy for DFMA efforts in the low-volume environment must be about value--drive perceived value into the customer solution and simultaneously enable business value. Better ROI decisions for DFMA implementation and exploitation require a different look at this value creation from the paradigm of the LVHM business model reality. The customer in this segment is defining value as receiving delivery as a primary driver, with negotiated cost as a secondary driver. The business value is to hit a target cost (bid) and follow through according to promised schedule.

This paper will explore DFMA ROI based on the customer and business value propositions as stated in the LVHM segment above, although the method can be expanded to include any set of chosen values. Our focus will be on translating these values can to quantifiable measures of ROI, identifying and targeting the most impactful DFMA opportunities, selectively deploying DFMA tools to provide the best company ROI and customer value.

The ROI of DFMA

Companies need to have a profit-based rationale for any method or technology, and this holds true for the use of DFMA as well. For the decision-making model for DFMA deployment we will use **return on investment** (ROI)--utilizing resources to generate valuable output for the company in a cost effective way. The basic definition we will use for ROI is:

$$ROI = \frac{Benefits - Costs}{Costs} \qquad \text{(Eq. 1)}$$

Benefits can be revenues or other characteristics that represent gain. In this paper we use ROI because of its simplicity and applicability. However, net present value (NPV) or internal rate of return (IRR) equations can be substituted for the ROI equation to provide the level of detail required.

If we use the words benefits and costs in a different way we can say

$$\frac{Benefits}{Costs} = Value \qquad \text{(Eq. 2)}$$

a common definition in the world of Value Analysis. Combining Equations 1 and 2 shows that

$$ROI = Value - 1 \qquad \text{(Eq. 3)}$$

This only works if benefits and costs have the same units; benefits must be monetized. Accomplishing this is the subject of Value Analysis and Value Engineering, and will be left to those texts (See (Mudge, 1971).) Recognizing the close relationship of value and ROI now directs us toward identifying high-value propositions that will provide a high ROI.

To develop value propositions we must determine benefit and cost categories and look for ways to drive the benefits higher and the costs lower. Consequently, we must determine what the benefit and cost drivers are and how DFMA work can help.

What is an acceptable ROI?

In prototype, job shop, and design-to-order environments, DFM costs show directly in the bid, often as direct labor costs in NRE. This extra cost must have a benefit associated with it to offset a potential perceived reduction in value to the customer. Theoretically, when one looks at the value and ROI equations, value is still provided even when the ROI is zero! Since in LVHM businesses there are few products to amortize development efforts across, DFMA work can have a much lower ROI than many of the HV business examples that the industry is used to seeing. Yet even negotiating an acceptable target for DFM to have an ROI of zero (costs equal benefits) is theoretically reasonable! An ROI of zero for DFMA work doesn't harm the customer or company financially, still provides neutral value, and still allows for the team to provide intrinsic benefits. We don't want to calculate the ROI with a painstakingly high degree of accuracy (nor incur the overhead costs to do so), so the team should provide for a bit of slop in the calculations and volunteer to provide at least an ROI of one. That also protects the team from some execution uncertainty. Whatever the negotiated ROI, the intrinsic opportunities to provide the customer with a better product or the team with winning bid is enormous. This is what can be used to drive the DFMA design practices into even one-off products.

Finding monetized benefits in DFMA work

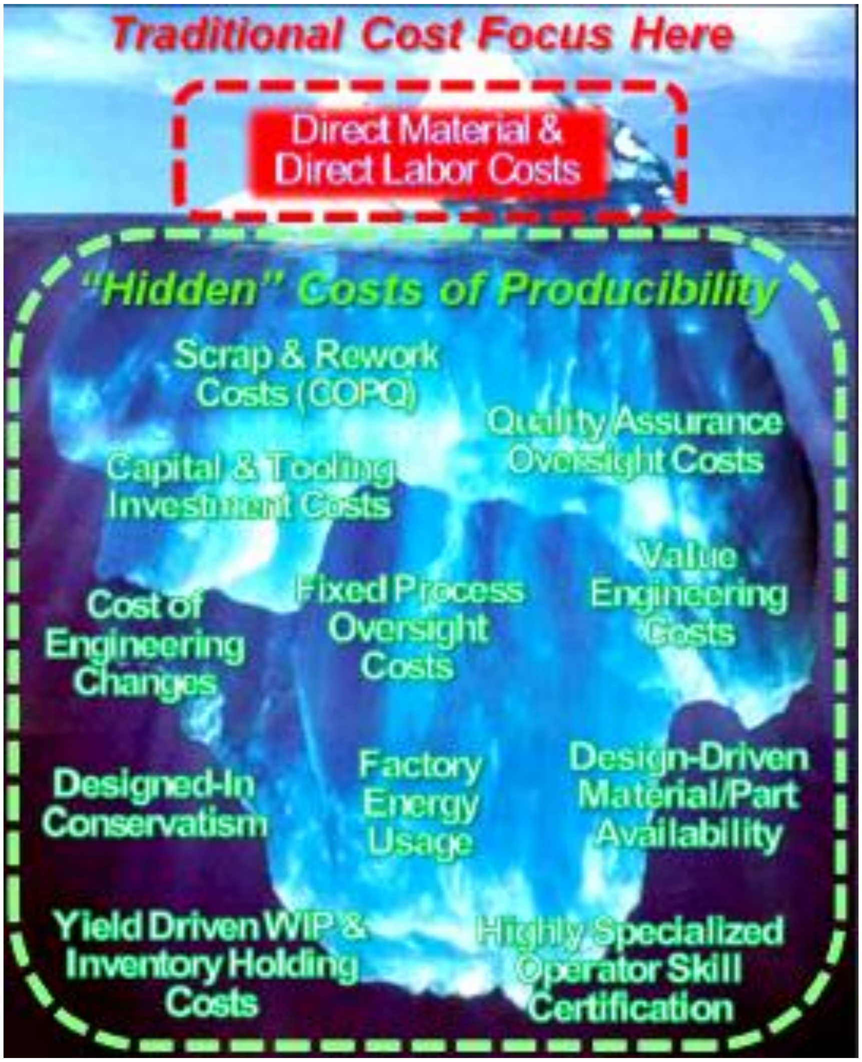
The business must have a way to identify or model the monetary value of both benefits and costs. The labor and material costs are easily identified, but the costs that are avoided (negative benefits reduced) because of good DFMA can easily hide beneath the surface of day-to-day operations.
Some of these savings include

- shortened development cycle,
- reduction in engineering change orders,

- reduction in defects and associated rework, and
- reduction in lead time (late delivery).

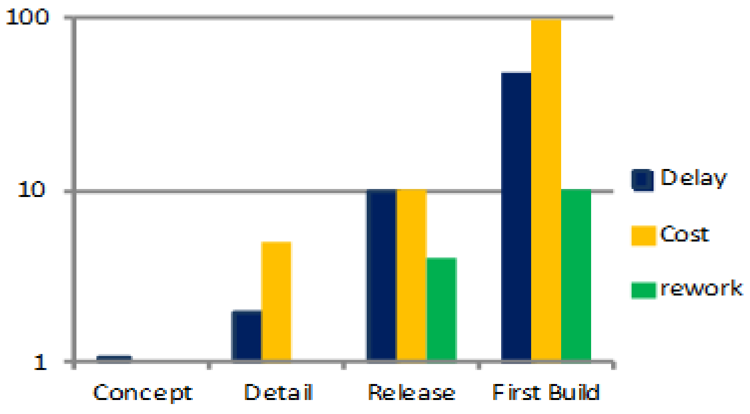
By employing DFMA efforts, the goal is to attack and reduce the many hidden costs associated with products that are the result of low producibility (see figure 2). Too often, prototype houses consider these hidden costs to be just another part of low-volume production. However, if a business can find a way to identify these costs, they can use lessons learned to improve subsequent designs (i.e. avoid the repetitive mistakes on the next contract). Producibility mistakes have a large impact on product costs and benefits (figure 3), and these mistakes can have a greater effect the longer they persist within the design and execution cycles. DFMA is the tool to identify and target these mistakes early.

Figure 2. Hidden Costs of Producibility



(National Defense Industrial Association, 2013)

Figure 3. Relative costs associated with mistakes



Knowing how to identify and calculate cost drivers is key to the ROI

One of the ways to identify cost drivers is to understand where and how costs are enumerated within the contract model. A generic example of a cost model is shown below (Table 1):

Table 1. DTO Product Costing/Bid Example

1	Materials				$ 5000
2	Material Overhead (OH) (%)		10%		500
3	Labor (RE)				3850
4		Manufacturing Labor	50 hrs	1000	
5		Mfg Labor OH (%)	250%	2500	
6		Support Labor	10 hrs	200	
7		Support Labor OH (%)	75%	150	
8	Other Direct Costs	(e.g. shipping)			200
9	Hardware Costs				**$9550**
10	Development non-recurring engineering (NRE)				11350
11		Engineering	500 hrs	5000	
12		Engineering OH (%)	75%	3750	
13		Development Mat'ls		200	
14		Prog MGMT	160 hrs	1600	
15		Prog MGMT OH (%)	50%	800	
16	Product Cost				**$20900**
17	G&A (%)		15%		3135
18	Total Product Cost				24035
19	Margin		15%		3605
20	Bid Price				**$27,640**

In this example, it can be seen that the cost of the product bid to the customer (line 20) is really much greater than the hardware costs alone (line 9). This must be true for the sale to make business sense. The margin shown (line 18) is the profit that the company receives for their effort, while all other items are really the costs associated with that firm being able to cover expenses. When DFMA efforts are being bid into a proposal like this, they would show up under the hours bid in line 11 as a cost. Line 13 is an engineering development material line, which covers non-deliverable materials used in the development process to test concepts.

This example shows roll-up method of costing a product for bidding purposes, but with a bit of algebra this analysis can be inverted to create a price-to-win model. In this model, the final bid price is predetermined, then assumptions are made concerning needed margins, overheads, and percentages of material and labor allowed. The result would be the calculation of a target number for material costs, labor costs, and development costs. This inverted method is also called a target-costing approach.

Target costing can be used effectively when there is a discrepancy between a rolled up bid and the price to win. DFMA costs and outcomes (benefits) can be inserted here to show how this gap can be eliminated. For the purposes of this analysis, time and money invested in performing the DFMA work will be defined as costs in the NRE area (lines 11-13), and the benefits (both positive and negative) of the DFMA work will show up as lower material, labor, and support costs (lines 1-2,4-7). By exploring the cost structure we will enumerate the potential benefits in terms of costs:

<u>Line 1 and 2 Materials</u>

DFMA and part-count reduction can yield savings in material costs and overhead. In a low-volume environment, prioritizing the DFMA done on parts is critical to accomplishing high ROI.

<u>Line 3 (incl. Line 4-7) – Build Labor</u>

DFMA is valuable here in identifying challenging assemblies and ways to minimize the actual labor within the product. In a customer-focused strategy, saving the customer money or not going over budget is a positive benefit worth at least the cost of the savings. Saving money creates return customers! By performing DFMA, assembly complexity can be discovered and defect predictions can be made. Removing defects is never guaranteed, so expected avoidance should be used. This can be calculated as follows:

$$Expected\ Defect\ Reduction = Qty\ Defects\ Eliminated * (1 - probability\ of\ recurrence)$$

Or (Eq. 4)

$$E(DR) = DE * (1 - P_{Recurrence}) \qquad \text{(Eq. 4a)}$$

For every defect there should be a defect cost-value assigned based on lessons learned from company history. This can be done by averaging the cost of defects within an environment. Most shops don't have a good method for doing this, but it isn't difficult to create a rough model. For example, when a defect is detected, track time, labor, and materials required to get back on track. Do this for a short period of time and tabulate the results (see Table 2.)

Table 2. Example of tally sheet for determining defect costs

Work-station	Error Type	Cost to rectify defects						
		Material $	Labor hrs	Burdened Labor $ (x2) (Calc)	Support hrs	Burdened Support $ (x2) (Calc)	Total Labor $	Schedule days delayed
A	ASSY	0	.5		0			.5
A	ASSY	0	2.5		0			1
B	MACH	250	5		0			3
A	COMPONENT	5	.5		2			10
C	MACH	20	1		10			5
A	HANDLING	.5	.25		0			0
totals		275.5	9.75		12			18.5
Grand Avgs		45.9	1.6	$224	2	$140	$364	3.2
Defect SubGroup Avgs								
Assy Avg		0	1.5	$210	0	$0	$210	.75
Mach Avg		135	3	$420	5	$350	$770	4
Component Avg		5	.5	$70	2	$140	$210	10
Handling Avg		.5	.25	$35	0	$0	$35	0

By straight averaging or group averaging (types of defects) a defect cost can be obtained. Also realize that there is an opportunity cost associated with tying up labor resources in rework. The company not only had to pay more for this product to fix it, but could not employ those resources on another project or task. Thus the labor cost for the defect is at least double the cost of labor. Eliminating defect costs is a positive benefit. The total benefit here might need to be adjusted with a probability of occurrence percentage. Thus calculating the benefit of defect avoidance would look something like this:

$$Benefit_{Defect\ Redux} = \sum E(DR)i * \ Avg\ Cost\ Defect_{type}i \qquad \text{(Eq. 5)}$$

The benefit of defect reduction also lowers the risk to a program in variances to cost targets. This helps in subsequent bidding (less variance means more confidence in a bid) in both costs and lead times.

A significant benefit of Defect Reduction is minimization to lead time changes – a primary customer value in the LVHM environment! Most companies do not have a lead time cost model, but a penalty clause for late delivery is a common feature of many contracts. A straight-line model of days slipped due to defects can be tracked and modeled from Table 2, and the cost of a day slip can be roughly calculated.

$$Cost_{\ LT\ Delay} = \sum E(DR)_i * Days\ Slipped_{avg/defect} * \$Penalty_{Daily} \qquad \text{(Eq.6)}$$

Identifying these lead time costs (negative benefits) and utilizing DFMA principles to minimize these has highly visible value and good ROI.

Line 10 (incl. lines 11-14) Development (NRE)

This is where costs are accumulated against the DFMA ROI. In this case estimates of the hours and materials needed to perform the DFMA and realize the projected benefits are used. The strategy needs to be in how to get the most DFMA result with the smallest invested time. Optimizing and targeting the DFMA efforts is critical in making a difference in this area. So we will explore the ways of getting the biggest DFMA bang for the buck. It is tempting to spend time on improving DFMA until the product is perfect; however, it is important to remember that the goal is to have a positive ROI and stop when the return is good. “You’ll be tempted to do more, but don’t. That’s not where the money is (Shipulski, 2010).” (This is under the premise that you can identify the DFM made changes from a baseline concept to the current edition. Oftentimes in concurrent engineering, these trade-offs are discussed and made in models informally and seamlessly, so tracking the before and after will be challenging. Once a track record is established, this tracking will become easier or even go away.)

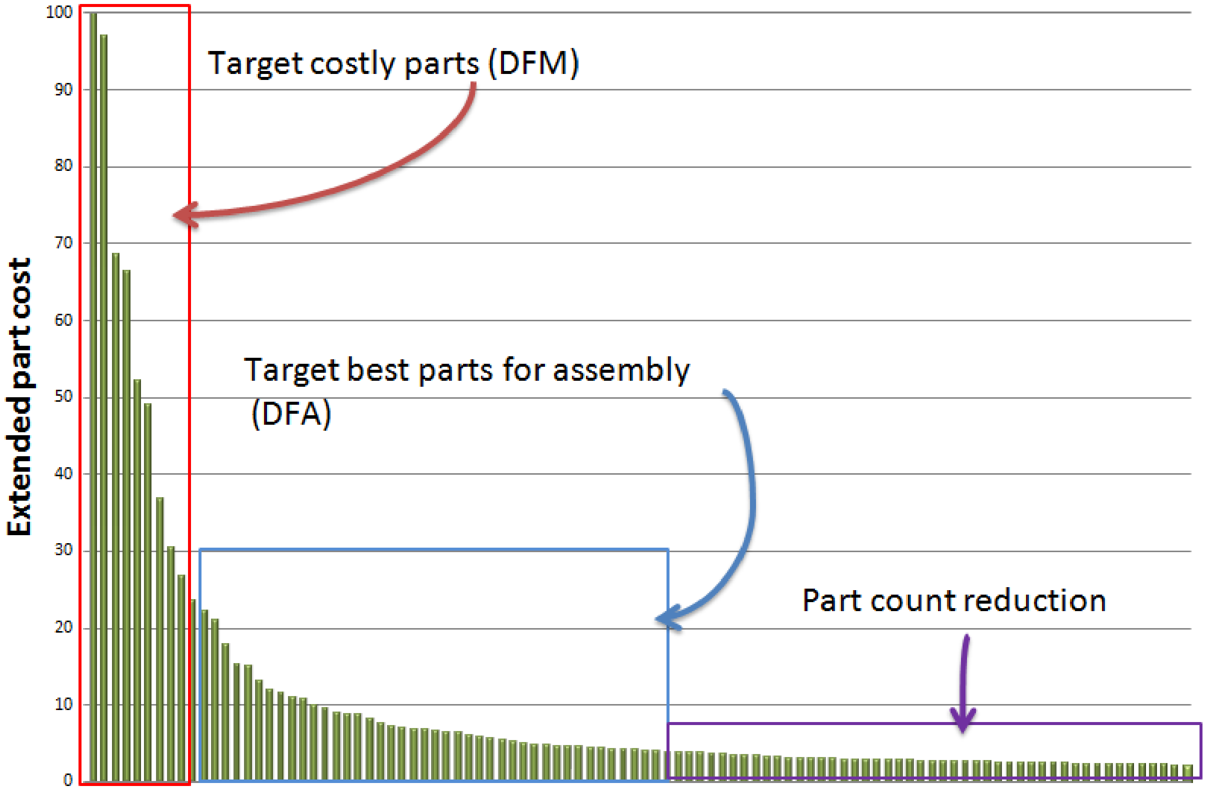
Process of Developing the Acceptable ROI for DFMA

1. Determine a starting cost
    a. Bid cost--if you have an obligation to meet a bid, this is the place to start.
    b. Price to win (target cost)--market analysis may dictate a starting point.
    c. Historical data--previous products of similar design and/or complexity can be used as a baseline.
2. High level DFMA analysis
    a. Determine priorities—find the best impact opportunities.
    b. Determine best DFMA tools to use to capture an opportunity.
        i. Eliminate unnecessary parts (DFA).
        ii. Reduce the cost of the most expensive parts (DFM).
    c. Gaps in material and labor costs are opportunities for DFMA.
3. Estimation
    a. Determine level of cost impact DFMA can have.
        i. Reduced material costs
        ii. Reduction in labor
        iii. Shortened delivery times
        iv. Reduction of rework loop, and corresponding increase in factory capacity
    b. Determine the cost of DFMA effort.
4. Determine the impact
    a. Rerun the bid model to show improvement.
    b. Run the simple ROI model to show the result of the investment.
    c. At the point where the bid model is acceptable and the ROI of the effort is acceptable, a path forward has been identified.

Selective Deployment

By looking at the cost roll-up potential of a product and project, the DFM expert must know where to go hunting. The rule of thumb is always to look for where the costs are largest. The most opportunity is found where there is much to reduce. Utilizing a costed bill of materials is a great way to identify these target opportunities quickly (see Figure 4.) Using the Pareto principle, sort the parts and assembly costs in largest to smallest. Typically the top 10-15% of the parts will provide 85-90% of the material costs. DFMA alternatives to lower these part costs are warranted but are often ineffectual because the low volume of parts does not provide for many alternative, low-cost process opportunities. These part costs are driven either by setup times or capital cost constraints, so alternate processes don't usually drive costs down significantly. On the other hand, if designs are adapted to allow for generally available tooling and "LEGO®" strategies of standardization, economies of scale using existing standard processes can be a benefit.

Figure 4. Part cost Pareto



We have identified three areas where DFMA principles can be applied profitably in a low-volume production environment. These areas are platforming, the use of common parts, and combination of functions of parts. The examples given are biased toward aerospace but are applicable to a variety of industries.

One of the most conspicuous examples of platforming is found in the auto industry. Many manufacturers will use the same base to build a variety of different models--a vehicle has common systems installed and is only differentiated late in the build process. How could this idea be applied to a low-volume shop? Many low-volume operations have multiple varieties of a product that can benefit from late process identification.

Figure 5. Platforming example

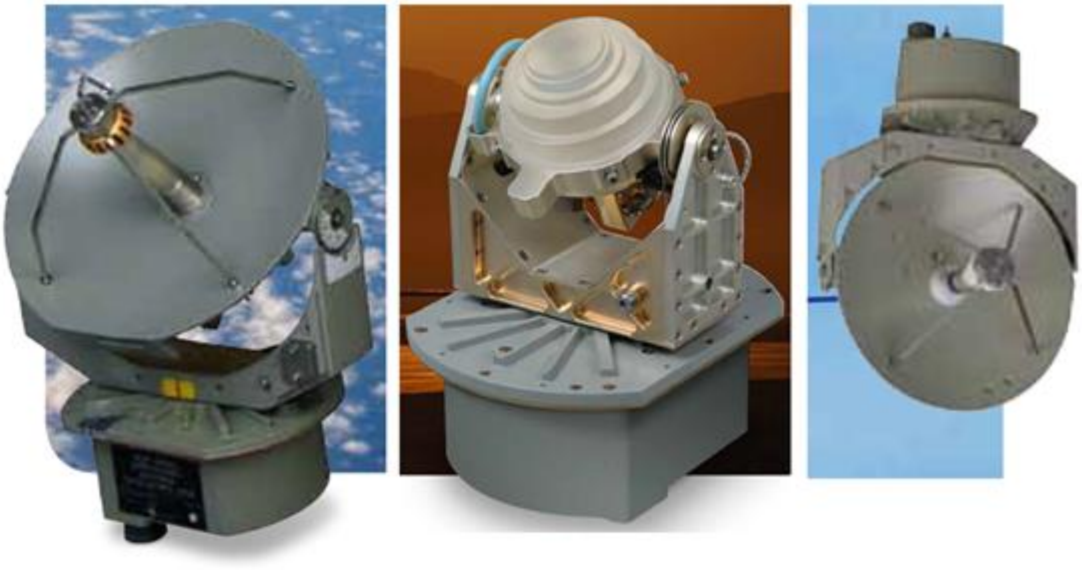


*image courtesy www.l-3com.com

For example, although any of the antennas in Figure 5 may be built in low volumes, all three could use a similar base with unique parts added later in the process.

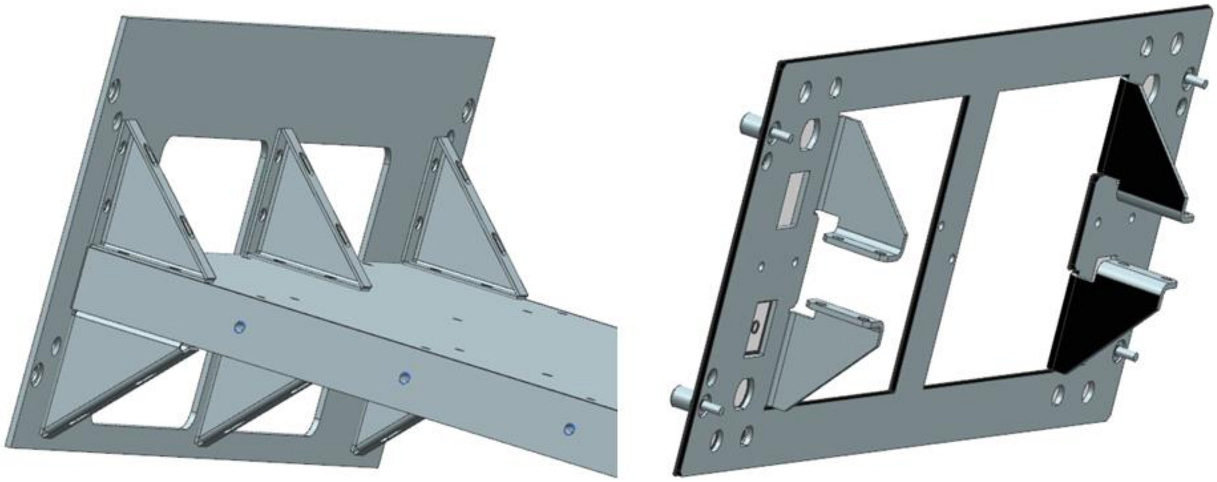
If grouping of product families is not an option, it is worthwhile to look inside an assembly for common parts. What are the subassemblies that can be assembled as platform parts and then go into the finished product? One example is an optical system for a planetarium that has the same mechanical parts for three colored lasers that are combined to make an image. The mechanical parts can be built in larger quantities and then the unique glass parts are inserted at the end.

Platforming can also be used to simplify new product development. For example, when designing a new product that needs a heat exchanger, perform a search to find which of your other products use heat exchangers and see if you can repurpose that subsystem. Even better, if you can buy the subassembly you need, both manufacture and assembly time are offloaded.

Using common parts is similar to platforming but applied on a component level rather than a subassembly level. One simple but easily missed method is to use a single size of fastener with a captive washer whenever possible--part count is reduced and so is the likelihood of making a mistake (Shipulski, 2010). Additionally, if hardware is standardized, the number of tools necessary to assemble the product is reduced.

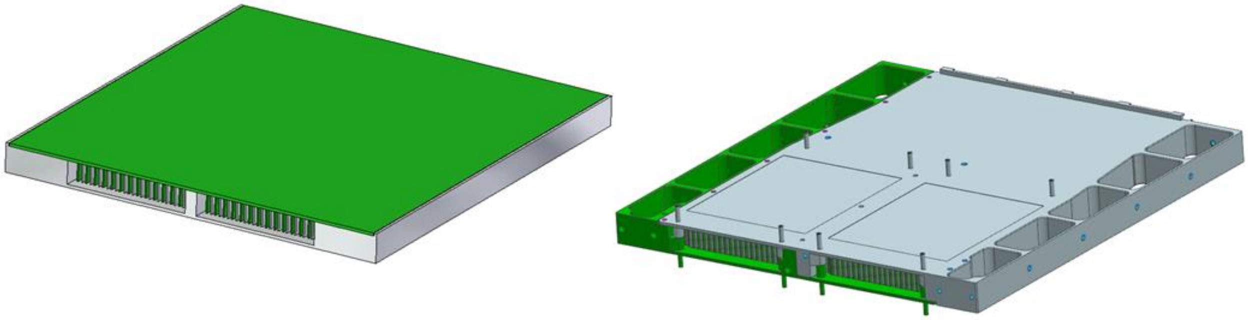
Combining functions of parts is another quick way to improve DFMA in an assembly. This practice can be as simple as making a sheet metal faceplate with folded tabs that eliminates the need for brackets and their associated hardware (see Figure 6.) Even on low-volume runs this type of improvement is worthwhile as it reduces part count and ensures that the parts are assembled correctly.

Figure 6. Combination of functions--brackets vs. folded tabs



Many articles extol the virtues of reducing part count to improve DFMA. One method that we did not find in the literature is the search for symmetry. Normally we think of symmetry as mirror images; however rotational symmetry is a fruitful source of improvement that is frequently overlooked. A heatsink, for example, can be made with one finned part and a cover, or it can be made from two identical parts with fins that mesh together (see Figure 7.) By making a subassembly from two identical parts rather than two separate parts, the non-recurring costs for one part are eliminated, and the non-recurring costs for the other part are cut in half as they are now amortized across twice as many parts. The benefits gained from combination of function have a worthwhile return, even when volumes are low.

Figure 7. Reduction of part count through symmetry



A literature search (Dewhurst, 2011) will turn up recommendations for to reduce part count, and/or combine part functions by asking questions such as these:

1. Do the parts move relative to each other?
2. Must they be made of different materials?
3. We would add--is there any symmetry--mirror symmetry or rotational symmetry?

After platforming, the use of common parts, and combination of part functions have been used the remaining BOM parts (refer to Figure 4) are usually so low in cost impact that designing to lower those part costs provides negligible impact. However, eliminating any of those low cost parts does provide value in that it is leveraged through the system in reducing assembly time and defect cost potential. Consequently, part count reduction is a prime DFM Strategy in this environment.

Designs that eliminate mistakes in the assembly process can also provide significant cost impact. This can be analyzed through the use of DFMA assembly tools. Challenging constructions can be used to predict defects or their reduction potential. If defect records are kept by a company, this is another source of data to drive decisions.

In a prototyping and design-to-order environment, controlling piece part costs is challenging to provide impact. However, if we compare the average costs of defects in our example environment (table 2) to the cost of the example program (table 1), or to the cost of the hardware parts (recurring cost in program) we have the following (see Table 3):

Table 3. Defect costs

	Defect Cost	Lead Time Penalty (assume $50/day)	Total Cost of a Defect	Hardware Cost/ % impacts	Program Cost/ % impacts
Hardware Cost				$9,950	
Program Cost					$27,376
Grand Avg	$364	$160	$524	5%	2%
Assy Avg	$210	$38	$248	2%	1%
Mach Avg	$770	$200	$970	10%	4%
Component Avg	$210	$500	$710	7%	3%

As can be seen by this example, the cost of a defect can have a significant impact on the recurring cost of a product or program. Multiple defects have additive impacts. With this simplified model the percentages are high, but in more highly modeled systems defects costs can be significantly higher. With low margins this can significantly impact program health. Understanding these costs in a company's environment and utilizing this to identify the best DFM efforts for the project can help drive a good ROI. Utilizing the defect costs break-outs as shown in the example problem, targeting areas that exhibit high defect costs would make sense (in this case, machining and component failure).

Summary

Developing DFMA ROI that will win opportunities to help business in low volume markets can be accomplished by the following

1. Identify the key customer and business value proposition areas that will provide a win-win scenario.
2. Understand what the cost equation of the business is and what drives profitability.
    a. Understand the business contract model and what drives customer satisfaction as well as profit.
    b. Negotiate the ROI threshold that is seen as value-add (suggested to be at least 1).
3. Identify what the benefits to DFMA will provide the company within its cost context.
    a. Identify the impactful opportunities where effort should be spent (Pareto rule).
    b. Focus on the cost drivers, mainly
        i. High cost materials,

        ii. High cost operations,
        iii. Part elimination to reduce complexity and assembly mistake opportunities.
    c. Understand and quantify the cost of defects (mistakes) and the value of their elimination.
4. Implement selective deployment of DFMA tools to target impactful improvements.
    a. Target top areas of cost impact with appropriate DFM tools/strategies.
    b. Don't oversell a fix. Use expected defect reduction since these are soft costs.
    c. Minimize the DFMA costs by generating common solution principles from past successes.

So how does this method answer the questions: Is DFMA appropriate in these environments? Necessary? Valuable? We have shown that by employing certain DFMA tools we can generate specific value even in the low-volume arena. The work here shows that if cost is an important consideration in the development arena, DFMA can and does provide value to the customer. Through a paradigm shift that the worst the customer has to deal with is a net zero harm, one can say that all DFMA work must do is pay for itself. Most DFMA work provides benefit beyond that threshold, especially when a streamlined, targeted approach to DFMA is employed.

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