



The Design Engineer's Guide for Total Product Cost Using DFA

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Introduction

Design engineers are typically tasked with three major goals as part of a product development project. Those three goals are product function; ensure it does what it's supposed to do for the customer, the target completion date or ever important time-to-market launch, and of course the product manufacturing cost target. All three are always a challenge for any project, but hitting the cost target seems to be the odd man out more often than not; speaking through experience. The Design for Assembly (DFA) software by Boothroyd Dewhurst, Inc. (BDI) is a product development tool that the design engineer can use to assist in hitting that cost target. The experienced DFA user will tell you that DFA can assist with all three of the major project goals, and it's been proven it can. However, this review will focus on how the DFA software can be the essential guide for all aspects of cost for the design engineer during product development. Use of DFA on early design concepts will be stressed, but what will also be examined is how to use DFA analysis data on existing product baselines, for cost reduction, and application in competitive benchmarking projects. Custom operations in the software will be reviewed and example products and projects will show how the DFA data helps make design decisions during product development. Once the total product cost is understood, the Total Cost of Ownership (TCO) analysis will expand on the topic of overall cost and take things a step further by understanding hidden costs when determining where to build products or purchase parts. TCO is an analysis used for strategic sourcing decisions and commonly calculated in excel, but once entered into the DFA software as a custom operation it can be a tool the design engineer can use as well. Additional topics covered will be time studies of product assemblies, how to segue from DFA to Design for Manufacture (DFM) analysis, and some finance basics for engineers. All of these topics to be covered are to understand how DFA can be a core costing tool for the design engineer.

Product Cost Breakdown

BDI's DFMA software is used for product simplification and cost improvement by many companies. Their software can help determine what the cost drivers are in products. Figure 1 shows a pie chart that represents BDI's experience over the last 30 years with regard to the typical product cost breakdown at final assembly of most manufactured products. At last year's DFMA forum, Dynisco showed an average cost breakdown of several products that had very similar percentages for piece part costs (materials), labor, and overhead. Using the minimum part criteria questions in the DFA software, the design engineer will traditionally focus on the seventy-plus percent of the cost tied to the product materials. Additionally, DFA estimates the labor time required to assemble the product and how to minimize this time as well.

This means the design engineer is focusing on, let's assume an average of 75% of the total product cost. What about the remaining 25% in overhead? In laymen's terms, overhead is tied to the overall cost of running the business. In the language of the engineer, that 25% of overhead is "what the bean counters spread across the products like peanut butter, the cost of doing business." Translation; the accountants in your company's finance department will calculate the overhead rate at the building site where your products are manufactured and apply to the products. The overhead rate calculation is typically shown as a percentage. An example overhead rate is 500%, but this percentage could be higher or lower and will vary at each company itself. Engineers don't really need to understand how the overhead calculation is derived, but should understand that the overhead applied to the product they design is a function of its labor time and cost. So the materials, labor, and overhead have one thing in common for sure . . . they are all tied to the design of the product. Let's understand how.

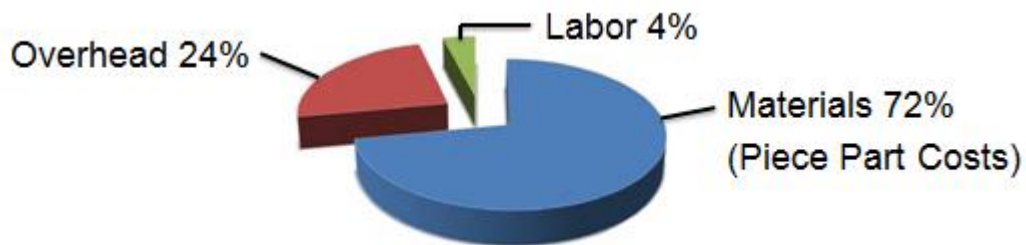


Figure 1 – Boothroyd Dewhurst's typical average cost per product breakdown. Dynisco products have a similar average percentage breakdown for manufacturing costs.

DFA Analysis

DFA is commonly used to target the material and labor costs, but can also be used to understand how the overhead is calculated and applied to the product. DFA can guide engineers to understand how materials, labor, and overhead costs are tied to their design decisions, because it's the design decisions that determine the total cost. To understand the impact to total cost from design decisions, engineers will need to understand how to interpret and apply the data derived from a DFA analysis on a product design.

The process starts by entering a product bill of material into the DFA software. From there the DFA user will structure the product assembly to the best of their knowledge. This requires putting the parts, subassemblies, and additional operations in order of assembly. From there the DFA questions on minimum part criteria are answered. These minimum part criteria questions (see Figure 2) are the DFA theory/philosophy that is the catalyst for engineers (and others, DFA analysis is best conducted as a multi-disciplined group) to generate the discussions that come up with the ideas on how to combine

parts for function or eliminate them all together from the product assembly. Handling and insertion difficulty questions are answered as well, all while in the background the DFA software is estimating assembly time based on the size of each part, subassembly, and overall product assembly. DFA is creating a virtual product assembly cell and routing estimate for the user based on all of the analysis inputs. Once completed, there are many ways to export analysis results out of DFA. Important product data such as total part count, the number of parts that meet the minimum part criteria, labor time and cost, total product and life cycle cost, suggestions for redesign, and DFA index (assembly efficiency) can be viewed in a variety of ways. The goal with DFA is to minimize the total number of parts, improve ease of assembly, and also minimize product cost. Numerous case studies on BDI's DFMA software application have shown improvements to quality, reliability, and time-to-market, just to name a few attributes, which are positive byproducts of the process.

It is also important to understand the product state during a DFA analysis. One state can be defined as the next generation design or refresh design of an existing product line or sometimes considered a clean sheet design, a completely new product developed by a company. Existing products are another product state that is common application for DFA. Product life cycles can vary too. Consumer products are typically low, say a couple years. Industrial products that Dynisco and Roper companies produce are niche market products that can sometimes have very long life cycles; ten plus years or even longer. This is an opportunity to apply DFA to the product to sustain its health for performance and manufacturing costs from both customer and company perspectives. A third area of DFA application is toward the competitive benchmarking process. To understand DFA application in these areas, an example product will be used. Assume a product existed that had the following cost breakdown; Materials \$700, Labor \$50, and Overhead \$250. So the example product's total cost is \$1000 to manufacture. The next section will explore how DFA is used to design out cost and reduce labor time.

Cost of Goods Sold

The cost of goods sold (COGS) is fundamentally what the first few sections have been about. The COGS can be defined as direct costs attributable to the production of the goods sold or delivery of services provided by a company. And the COGS are the material, labor, and overhead of the product. How would the \$700 of material costs be reduced by applying DFA? Once the costed bill of material of the example product is entered into DFA, the cost for each individual part would be entered into the piece part cost

input box in the software. All the parts and their costs are now in the software ready for analysis. From there, the user answers the DFA minimum part criteria questions on each part.

First, the function of the part is questioned. Is the part's sole function in the assembly to fasten or connect other parts? If the answer is yes, then the part is automatically considered a candidate for elimination. If the answer is no, then the user moves to the minimum part criteria questions (see Figure 2). One suggested guideline in DFA is that each assembly has only 1 base part. Typically, the first part in the product assembly (or subassembly being analyzed) is designated as the base part. The base part is defined as the part that all other parts can be assembled to, is always a required part, and "meets the minimum part criteria." For each part added to the assembly after the base part, the DFA user then answers the following three questions in relation to all other parts before it in the assembly; 1. Does the part move relative to all other items? 2. Must the part be a different material? 3. Does the part have to be separate to allow assembly? If the part meets the criteria of one of these three questions, the appropriate radio button is selected and this part is categorized as a part that also meets the minimum part criteria. If a part is not considered a fastener or connector and does not meet the minimum part criteria, then the last radio button is selected for no fundamental reason the part exists and DFA categorizes it as a Category 1 candidate for elimination. This means it's a candidate for elimination "other" than a fastener or connector and this author refers to these parts as "the others." These other parts, the category 1's, are parts that DFA is guiding the user towards focusing on for combining with the theoretically required parts for function or eliminating them all together. Why?

Because more than likely category 1 parts are designed and manufactured parts that carry more weight in terms of cost than fasteners or connectors. Parts that fasten or connect are category 2 candidates for elimination, such as screws or a small mounting bracket, for example. Meaning, there's larger opportunity to reduce cost with category 1 parts. These "other" parts are also parts that may have function originally designed into them or at least intended, but do not meet the minimum part criteria questions. This is not to slight the design engineer's efforts; DFA just provides a different way to look at the part design. This is the essence or heart of DFA though, the minimum part criteria questions. If you've never asked yourself these questions while designing parts and assemblies in a product, it definitely takes some practice, but through asking these DFA questions, they become the catalyst for ideation in the design process. It makes the engineer ask how the design can be simplified, while maintaining the same function. As the ideas are generated for redesign, this is the time to segue to the DFM software. DFA can be used to quickly analyze the redesign ideas of the assembly and DFM can be

used in parallel to understand what different materials and manufacturing options can be used to produce parts. This one-two punch with DFA and DFM, reduce the number of parts in the assembly and then understand and minimize the cost of the individual parts, will lead to the largest impact to reducing the overall product cost. So that would be the approach to cost reducing the largest percentage of product cost pie chart, the \$700 or 70% of cost in the example product.

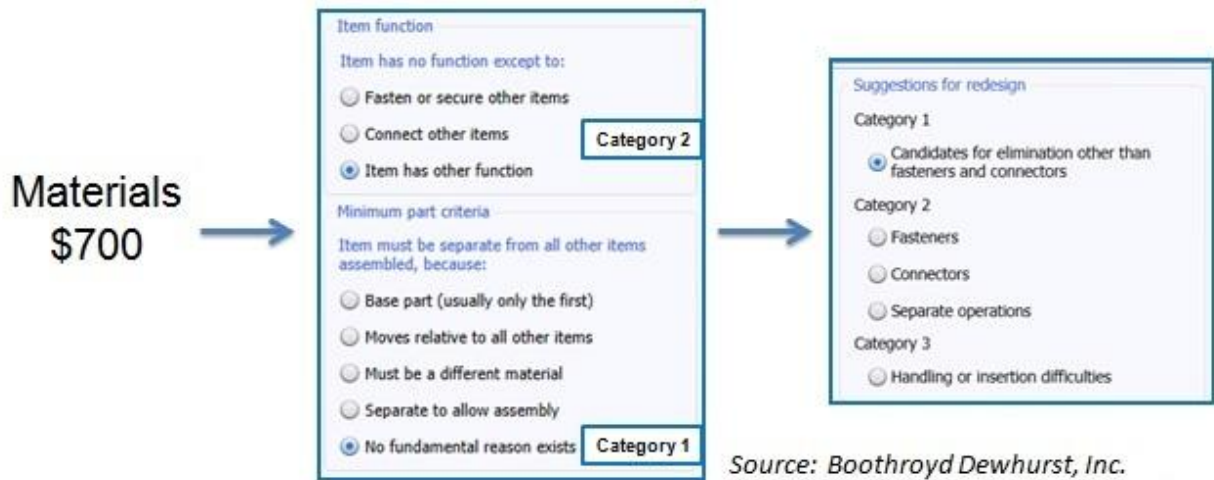


Figure 2 – Screen shots of minimum part criteria questions and suggestions for redesign in DFA.

The next target to try to cost reduce through simplification on the \$1000 example product is the \$50 of labor cost or 5% of the total cost. This \$50 is calculated from what's called the direct labor rate. This is defined as the average salary of the workers who assemble or "touch" the parts. For the example product a Direct Labor rate of \$25/hr will be used. So if the assembly time is 2 hours, then to calculate the labor costs of the product, it is just \$25 multiplied by 2 that equal \$50 of labor cost. So easy to see that the lower the labor time, the lower the labor costs will be in the product.

All parts are going to contribute to assembly time in some way and some will take more time than others. DFA provides time estimates (or time penalties) for each part depending on how the questions on handling and insertion are answered. So the DFA user will want to look for parts that significantly contribute to the total labor time. Again going to the suggestions for redesign tab in DFA, the user can simply click on the radio button for category 1, 2, and 3 parts and DFA will highlight the parts in the assembly in order to see the total labor time for each part. You can also export the suggestions for redesign report and all candidates for elimination will be shown. From there it's a matter of determining which parts provide the biggest opportunity. Also worth noting, if the user focuses on combining category 1 parts with required parts or eliminating these designed parts all together, they will more than likely reduce the number of category 2 parts as well, again speaking through experience. That's not to

say the user should stop there, but follow through on trying to eliminate fasteners, connectors, separate assembly operations and try to minimize handling and insertion difficulties on any parts they can to reduce assembly time. That's important to consider as there is still \$250 or 25% in overhead costs to investigate on the \$1000 example product that directly relates to the product labor time.

Finance Basics and Overhead

Let's first breakdown some finance basics to arm the design engineer with the understanding of how overhead is applied to the product. The goal at any business is to be as healthy and profitable as possible. Operating profit is a metric used to define this. The operating profit calculation is the total company revenue, the products and services they sell, minus the COGS and the Selling, General, & Administration (SG&A) costs. The COGS have previously been defined so let's now define SG&A. SG&A is the costs of selling, the salaries of people in different departments such as engineering, supply chain, finance, IT, the executives' salaries, and lastly, things like the engineering project budgets are included. So from the design engineer's perspective, can they impact SG&A costs in their role? The answer is no. Understand what SG&A is, but it's not going to be required in any engineering analysis.

What is important to the engineer is the equation that is left after disregarding SG&A costs. The product gross margin is defined as the company revenue minus the COGS and that's where the engineer has the opportunity to make an impact. And that brings us full circle because the engineer can greatly influence the materials, labor, and overhead of the product in the design. The last piece of the puzzle, or pie chart, is to define what overhead is, and how it's calculated. Overhead costs are the rent of the company building; the utilities (gas/electric/phones); the maintenance, repair, and operations of keeping things running daily; shipping/freight costs; and some companies may categorize bin items like screws, nuts, and washers into overhead costs. All of these items will be rolled up and calculated into the previously mentioned overhead rate. Back to our product example, a 500% overhead rate is used and now we need to understand how it is calculated and applied to the product.

If the product assembly takes 2 hours at a direct labor rate of \$25/hr, the \$50 dollars in labor is multiplied by the overhead rate of 500% to calculate the overhead costs applied to the product. In this case, the \$50 in labor cost is simply multiplied by a factor of five which equals \$250 in overhead costs applied to our product. That's how we get to the \$1000 total cost. The takeaway here is that any improvement made to the labor time will reduce the labor AND overhead costs applied to the product.

To capture this in a DFA analysis, all that is required is to build a custom operation to calculate the overhead. DFA has an Operations Library that allows the user to create custom operations such as this. Creating these operations is a matter of entering in the formula for the desired outputs. This will not be shown in detail, but we'll see how it is shown in DFA for use. For overhead we're creating inputs for the DFA user to enter that are total assembly time and overhead rate. Figure 3 shows the overhead operation for the \$1000 example product. DFA already has a couple variables of the equation already in the analysis. Those two variables are the total estimated assembly time and the direct labor rate. DFA is estimating the time based on the inputs of part size and handling and insertion difficulties. The direct labor rate is entered in the top line of a DFA analysis in the assembly data input area of the project definition. This DFA custom operation is a suggested way of understanding the product overhead and 100% of the total product costs. It's a simple calculation that does not add to the DFA assembly time, but does add overhead into the process costs. When exporting data out of DFA, this overhead cost line can be separated for clarification so that the engineer can have a full estimated breakdown of material, labor, and overhead cost. With this overhead operation in place, the engineer can compare redesigns at 100% cost and even product costs at different build sites that might have different direct labor and overhead rates.

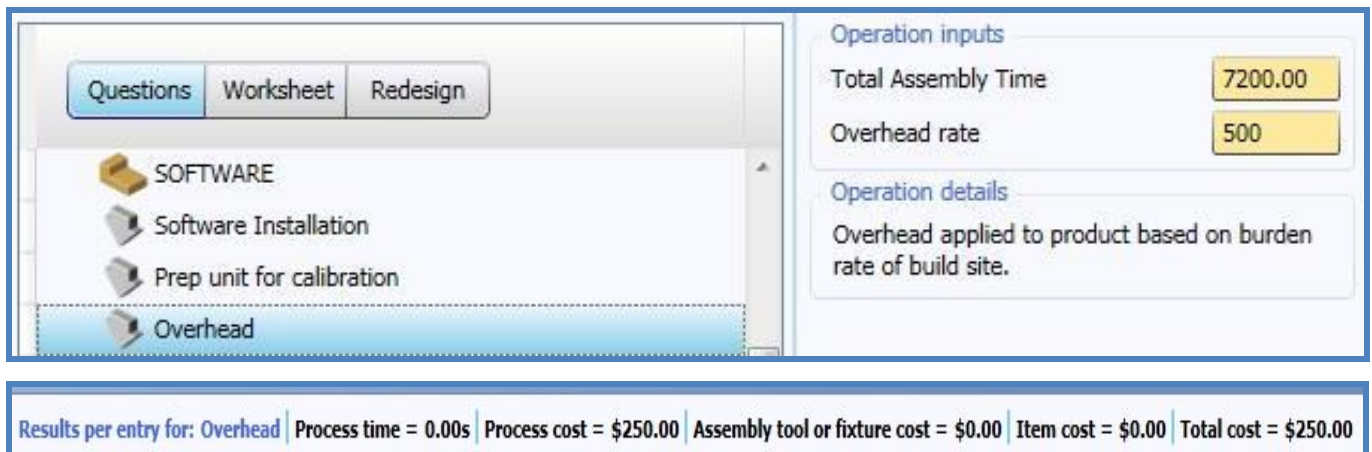


Figure 3 – Custom operation for overhead calculation in DFA.

Total Product Cost Example

DFA can be that tool for the engineer to capture total product cost. It's important to understand how this tool can help and what is actually happening to the costs if DFA is applied. To understand that, we'll create some sample results on the \$1000 example product. Figure 4 shows the before and after cost

results for materials, labor, and overhead on the product. These results are interpreted differently based on the type of project or what was referred to earlier as the product state.

Let's first examine the results if this product was a new product design, the next generation product or refresh design. The before cost would be considered the costs for the first concept analyzed with DFA. Assuming the imaginary company that builds this project has been using DFMA tools for some time and is established with the initiative, let's also assume the design went through a few iterations of DFA analysis and redesigns to arrive at the "after" cost results. Material costs were reduced by 50%, an obtainable goal with DFA. Labor costs were just as successful as the labor time was reduced by an hour. Overhead applied to the product is also reduced due to the reduction in labor time now that we know the calculation. Which design would be more desirable to go to launch with? That's easy, the one with the \$500 manufacturing costs. This is the classic example of applying DFA early in the design process. An example of cost avoidance, taking cost out before going to production.

<u>Example Product - Before</u>			→	<u>After - DFA Application</u>		
Materials	\$700			Materials	\$350	
Labor	\$50	2.0 hrs		Labor	\$25	1.0 hr
<u>Overhead</u>	<u>\$250</u>	<u>500%</u>		<u>Overhead</u>	<u>\$125</u>	<u>500%</u>
	\$1000				\$500	

Figure 4 – \$1000 example product before and after DFA is applied to identify the impact to total cost.

What if the product in Figure 4 was an existing product? The results are interpreted slightly different. The reduction of materials cost is still a cost savings for the company. The product gross margin is improved from the reduction in materials cost. We've reduced the labor and overhead costs applied to a product in production on the shop floor present day, but is this a cost savings for the company in terms of labor and overhead cost? The answer is no. Unless there is a reduction in headcount there is not a cost savings. The costs applied to the product are lower, but the company still has a fixed amount of labor and overhead costs company wide. What has been accomplished is that opportunity has been created; there is now an increase to the capacity in manufacturing. More products can be assembled if volumes increase or additional product were introduced to the shop floor. This can be a particular concept for the design engineer to embrace and this author has had long discussion on the topic with members from manufacturing and finance. The best way to summarize this study on total product cost

was summed up by Dynisco's Vice President of Finance. He stated, "our goal is to have all our products go together as easy as possible." DFA application is one of the tools that can help a company meet that goal.

One last topic to review on the custom overhead operation in DFA is towards competitive benchmarking. Dynisco has shown their practices with competitive benchmarking at previous DFMA forums and the DFMA software has been a critical tool used in that process. DFA is used to analyze the product tear down of the competitor's product assembly. Together with DFM should-costs on the individual parts combined with the estimated labor time in DFA, the competitor product's materials and labor costs can be estimated. Competitors have overhead too though and the custom operation for overhead in DFA can capture that and provide an estimate. Therefore, if the competitor's actual sell price might be known and the cost model from DFA estimated 100% of the COGS, then the competitor's product gross margin can be estimated. This is powerful data to have to get a good understanding of how competitor products hold up to yours.

Total Cost of Ownership

The review thus far has consisted of capturing total product cost with DFA. TCO is another costing tool that can also be added to DFA with a custom operation to understand direct and indirect costs of building products at different manufacturing sites within a company. Typically a strategic sourcing decisions tool, Dynisco uses TCO to do just that and analyze the optimal build site for a product.

TCO was first presented at the DFMA Forum in 2011 by Harry Moser of the Reshoring Initiative. Dynisco's President, John Biagioni, then presented on TCO at the following DFMA Forum in 2012. Both gentlemen shared their versions of a TCO excel spreadsheet they both deploy. Both TCO spreadsheets are similar in that they take into account risk factors for building products at various sites or different countries. Additional inputs on product data and other areas that impact costs to support and build the product are factored into the calculation.

Dynisco's VAVE group built a custom operation in DFA based on the Biagioni TCO spreadsheet. By doing this, DFA can be used to compare total product cost and indirect costs of different build sites. This gives the design engineer that ability to run predictive cost models in DFA of the product depending on location and compare. The design engineer can make assumptions and enter inputs just as they do with

any DFA or DFM analysis to model costs to help in the decision process of where to build. TCO is another suggested area of where the design engineer can expand on their engineering toolsets.

The required TCO inputs into DFA, based on Biagioni's spreadsheet, are shown in Figure 5. Examples of the risk factors are inflation, quality, currency differences, and IP transfer. First, all the risk factors are assigned a weight of impact. There are seventeen factors and the one assigned with the value of 17 carries the greatest weight. The weights are assigned and then a probability of occurrence for each risk factor is assigned. While this may seem time consuming, the reason for entering in the inputs in this manner is because things can change. TCO allows the analysis to be rerun in at a later date if things do change, say 6 months to a year later to revisit the analysis and compare cost models.

After the risks are entered, the TCO formula in the DFA custom operation (Figure 6) will calculate an overall risk factor for the analysis. The overall risk factor is calculated into a Risk Factor TCO cost based on the overall costs of the product. Product data inputs such as estimated yearly volume, lead time, and total product cost are then entered. Total product cost can be taken directly from the DFA analysis. Estimated transportation costs are entered next followed by the remaining TCO inputs. Cost of poor quality, build site profit, and inventory carrying costs are entered as percentages and calculated into costs per product unit. Reoccurring costs are factored in next. Examples of reoccurring costs are sending engineers to the build site to support the product or travel costs. If a product is built overseas, the travel expenses can quickly add up for 3 or 4 visits per year. Lastly, examples of transition, or one-time set up costs, are costs to develop the production cell or any tooling and equipment required to assemble the product. Without getting into the formula detail, all of the TCO inputs are calculated into a TCO cost per unit to capture the indirect or "hidden" costs of moving products to different build sites.

- Enter remaining TCO Inputs

Product Data	
Yearly Volume	300
Lead Time, wks	12
Total Product Cost, \$	2165.88
Total Landed Cost	
Transportation Cost, \$	500.00
Total Cost of Ownership	
Cost of Poor Quality, %	10
Cost of Poor Quality per unit, \$	266.59
Profit at Build Site, %	10
Profit at Build Site per unit, \$	293.25
Inventory Carrying Cost, %	10
Inventory Carrying Cost per unit, \$	74.44
Recurring Cost, \$	20000.00
Recurring Cost per unit, \$	66.67
One Time/Transition Cost, \$	5000.00
One Time Cost per unit, \$	16.67
Risk Factor, %	8.3
Risk Unit, \$	280.53
TCO per unit, \$	1498.139

- Risk factors per build site

- Rank risk factors with a 1 thru 17 weight
- Probability of occurrence 0-100%

Risk Factor - Weight (1-17) and Probability	
Inflation, weight, #	17
Inflation, probability, %	10
Labor, weight, #	16
Labor, probability, %	10
Energy/Fuel, weight, #	15
Energy/Fuel, probability, %	10
Business Continuity, weight, #	14
Business Continuity, probability, %	10
Health/Pandemic, weight, #	6
Health/Pandemic, probability, %	10
Infrastructure, weight, #	13
Infrastructure, probability, %	10
Quality (recipe loss), weight, #	7
Quality (recipe loss), probability, %	10
Customer Perception, weight, #	10
Customer Perception, probability, %	50

Currency, weight, #	11
Currency, probability, %	25
IP Transfer, weight, #	1
IP Transfer, probability, %	25
People, weight, #	2
People, probability, %	25
Culture, weight, #	3
Culture, probability, %	25
Language, weight, #	4
Language, probability, %	25
Skill, weight, #	5
Skill, probability, %	25
Financial & Legal, weight, #	9
Financial & Legal, probability, %	25
Service Level, weight, #	12
Service Level, probability, %	25
Trust/Corruption, weight, #	8
Trust/Corruption, probability, %	25

Figure 5 – Custom operation for TCO calculation in DFA showing risk factor inputs and product inputs.

Build Site #1 | Build Site #2 | Build Site #3

Questions | Worksheet | Redesign

- CABLE TIES, CLEAR, 5
- Route wire/cable
- Tie wrap
- PLATE
- SCREW, 6-32 X 3/8 LG
- WASHER, 6 FLAT PLATE
- TOUCHSCREEN
- Record Touchscreen Serial Number
- CABLE ASSY, PLATFORM
- Secure wire end lug - installation
- NUT, 6-32 HEX W/TOOT
- SPACER, 1/4 OD X 7/1
- WASHER, M3 FLAT NYLO
- NUT, 4-40 HEX NYLON
- Torque fasteners
- FILM, PROTECTIVE
- CABLE ASSY
- COVER, LOWER
- COVER, TOP
- FASTENER
- SCREW, M4 X 12 LG PH
- INSULATION, TOP
- COVER ASSY
- SCREW, M4 X 12 LG PH
- COVER, FRONT
- SCREW, M4 X 12 LG PH
- LABEL WARNING
- NAMEPLATE
- LABEL, SAFETY
- LABEL, SAFETY 2
- PROGRAM
- SOFTWARE
- Software Installation
- Prep unit for calibration
- Overhead
- TCO

Product Data	
Yearly Volume	300
Lead Time, wks	12
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One Time Cost per unit, \$	16.67
Risk Factor, %	8.3
Risk Unit, \$	280.53
TCO per unit, \$	1498.139

Risk Factor - Weight (1-17) and Probability	
Inflation, weight, #	11
Inflation, probability, %	100
Labor, weight, #	1
Labor, probability, %	20
Energy/Fuel, weight, #	6
Energy/Fuel, probability, %	75
Business Continuity, weight, #	5
Business Continuity, probability, %	50
Health/Pandemic, weight, #	12
Health/Pandemic, probability, %	100
Infrastructure, weight, #	4
Infrastructure, probability, %	80
Quality (recipe loss), weight, #	16
Quality (recipe loss), probability, %	100
Customer Perception, weight, #	3
Customer Perception, probability, %	25
Currency, weight, #	13
Currency, probability, %	100
IP Transfer, weight, #	17
IP Transfer, probability, %	100
People, weight, #	7
People, probability, %	75
Culture, weight, #	8
Culture, probability, %	75
Language, weight, #	9
Language, probability, %	95
Skill, weight, #	10
Skill, probability, %	100
Financial & Legal, weight, #	14
Financial & Legal, probability, %	100
Service Level, weight, #	2
Service Level, probability, %	100
Trust/Corruption, weight, #	15
Trust/Corruption, probability, %	100

Operation details

Total Cost of Ownership operation calculation. Use to analyze TCO for building product at different geographical locations.

Can be used with or without burden operation in a DFA analysis.

Operation input steps:

1. Enter TCO operation to end of DFA analysis.
2. Enter volume, lead time and total product cost (DFA total).
3. Enter transportation cost.
4. Enter percentages for cost of poor quality, profit, and inventory carrying cost.
5. Enter recurring and one time costs.
6. Enter weights and probabilities for all risk factors. For weights, numbers 1 through 17 should be used only once, with corresponding probability of occurrence, 0-100%.

Once TCO operation is complete, DFA analysis can be copied, TCO recalculated for different build site inputs, and compare TCO costs on the product.

Notes

Thumbnail picture

Load file

Results per entry for: TCO | Process time = 0.00s | Process cost = \$1498.14 | Assembly tool or fixture cost = \$0.00 | Item cost = \$0.00 | Total cost = \$1498.14

Figure 6 – Full screen shot of custom operation for TCO calculation in DFA.

Real World Example #1 – New Product Design

The first example to review on DFA application is on a new product development, or next generation project. The first concept design was modeled in 3D and analyzed in DFA. The DFA analysis totals for concept 1 are shown in Figure 7. DFA was used to analyze the concept product assembly. DFM was used to estimate the costs of all manufactured parts. Together, DFMA was used to determine the total part count, estimated labor time, and total product cost. The same was done for the concept 2 design idea. These designs were submitted by two separate engineering groups within Roper and Dynisco's VAVE group provided the DFMA analysis support. Comparison of the two design iterations shows that concept 2 had a lower total part count and lower labor time than concept 1. Concept 2 also had a lower number of parts that met the minimum part criteria so its DFA Index was slightly lower at 4.12 versus the concept 1 DFA index of 4.49. DFA Index is a function of theoretically required parts and labor time. An interesting interpretation of the DFA Index comparison is that it can be said that concept 1 has more parts that contribute to function of the product.

The first two concepts were reviewed between the VAVE and engineering groups. Based on that review, a third design iteration was conducted and concept 3 analyzed in DFMA. Again, referring to Figure 7, concept 3's DFA data shows a slight reduction in total part count, reduction in labor time, and improved DFA Index of 7.50 when compared to the first two design concepts. The labor time was reduced by 47%, from concept 1 to concept 3 through DFA analysis. The total estimated cost of the product was reduced by 32% from concept 1 to 3. Based on these results, the design engineering groups at Dynisco's sister-company within Roper decided to move forward with prototyping the product and since that time has continued to develop the product towards launch. This is a real world example of early DFA application, cost avoidance, removing cost from the product before launching to production.

Entries including repeats	CONCEPT 1	CONCEPT 2	CONCEPT 3
Parts meet minimum part criteria	17	12	15
Parts are candidates for elimination	47	44	37
Analyzed subassemblies	3	1	5
Separate assembly operations	11	11	10
Total entries	78	68	67

Assembly labor time, s	CONCEPT 1	CONCEPT 2	CONCEPT 3
Parts meet minimum part criteria	123.79	84.51	74.63
Parts are candidates for elimination	1054.78	871.65	534.46
Insertion of analyzed subassemblies	20.67	11.44	43.54
Separate assembly operations	181.69	88.00	74.93
Total assembly labor time	1380.93	1055.60	727.56

Design efficiency	CONCEPT 1	CONCEPT 2	CONCEPT 3
DFA Index	4.49	4.12	7.50

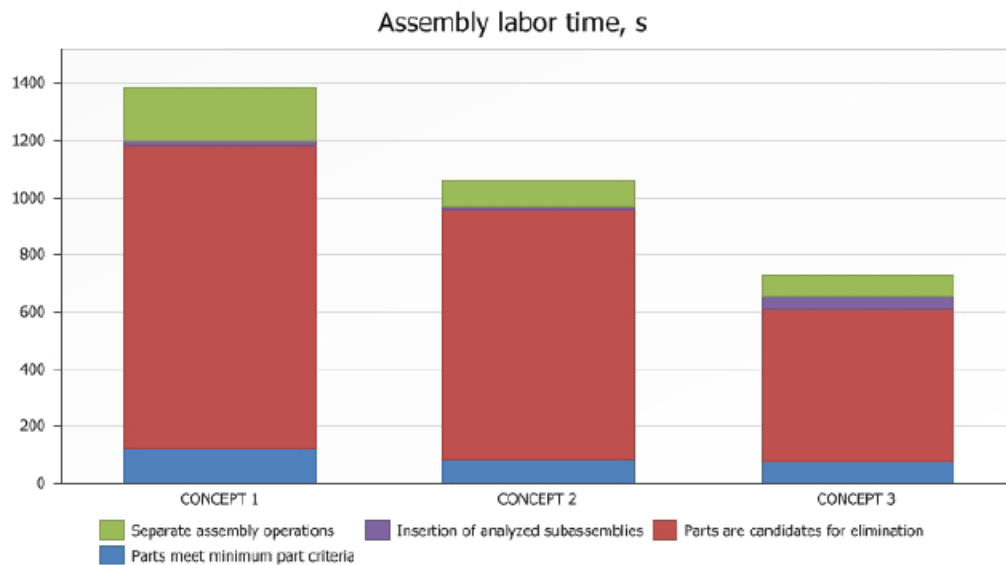


Figure 7 – DFA analysis totals comparison of three concept designs during new product development.

Real World Example #2 – DFA Labor Time vs. Time Study

The second example will review how to look for opportunities to reduce labor time with DFA. This is on an existing product currently in production. A time study was conducted in the assembly cell and the result was a 1.48 hour routing of assembly time. This same product was also analyzed in DFA. The analysis produced an estimated assembly time of 1.35 hours. A comparison shows that the DFA estimate was 9% lower than the actual routing. DFA labor time’s accuracy is only as good as the accuracy of the inputs the user provides. Some assembly operations could be missed at times, but the user should focus on parts that are the outliers, in terms of having large labor times associated with the assembly of the

part. Additionally, after the DFA redesigns are examined and compared to the baseline, it's important to focus on the change in assembly time from baseline to redesign. This is to show the improvement to labor time and cost.

For the product with the 1.35 hours of labor time in DFA, one outlier stood out. That part was a category 2 part assigned as a fastener using the minimum part criteria. The part was a nylon standoff. This part had a quantity of 13 in the bill of material. It is also a threaded part that screws into the product base part in order to install printed circuit boards. The circuit boards snap into place into place, but the issue is with the nylon standoffs being threaded. DFA estimated over 500 seconds of labor time for the 13 standoffs (Figure 8). These 8+ minutes of labor time are easily spotted in the DFA model tree by clicking on the fastener radio button on the suggestions for redesign panel. Having participated in the time study to assemble this product, this author can state that the 13 nylon standoffs are indeed a “pain-point” in the design. The standoffs have to be screwed in by hand because the use of a tool tends to lead to the top of the standoff breaking off once screwed into the base part. This is the type of example that can be found with DFA, and something we want to improve upon. This example shows that the design decision to select a threaded standoff for printed circuit board mounting instead of a snap-in standoff with less labor time can be costly as it increased labor time. This is an example of a way to find a labor time opportunity and correct in a product assembly.

T1000		Repeat count	Total count	Process time per product, s
Questions	Worksheet	Redesign		
SCREW, 6-32 X 1/2 LG	2	2	36.05	
WASHER, 6 LOCK	2	2	13.65	
MODULE, PWR	1	1	10.80	
FUSE, 4 AMP	2	2	13.17	
CABLE ASSY	1	1	24.34	
Lay xfrmr wires to power module	4	4	9.04	
SCREW, 6-32 X 1/2 LG	4	4	58.47	
WASHER, 6 LOCK INT T	4	4	20.87	
WASHER, 6 FLAT PLATE	4	4	20.87	
MOUNTING RAIL, DIN U	1	1	14.54	
SCREW, M4 X 12 LG PH	2	2	36.05	
CLAMP,END E/UK 12014	2	2	33.78	
OVERVOLTAGE PROTECTO	1	1	10.04	
Connect xfrmr wires to overvoltage p	5	5	82.50	
STANDOFF, 1/4 INCH N	13	13	510.36	

Figure 8 – Completed DFA analysis showing a part with a large individual assembly time (bottom part).

Real World Example #3

The third example will review a request from another Dynisco sister-company within Roper for a full DFMA and TCO analysis by the VAVE group on an existing product currently in production. The goal of the analysis was to determine what cost savings opportunities existed in the product and how beneficial to cost would moving the build site to a low-cost geography be.

First the full product assembly was analyzed in DFA for cost reduction opportunities, identifying category 1 parts and labor time reduction opportunities where possible. DFM was used to analyze the should-cost of over 50 manufactured parts in the product assembly. Once the DFA was completed, the labor and overhead cost estimates were calculated in DFA. The actual routing of the over 700 part electromechanical assembly is 18 hours, which includes 12 hours for assembly and 6 hours required for the calibration process of a materials analysis instrument. The DFA analysis was lower on estimated assembly time versus the actual routing, as with a product this large it can be difficult to capture every exact detail in the assembly process. The custom operation for overhead in DFA can still be used to show the delta in labor and overhead costs between the existing build site and the low-cost geography build sites. The Figure 9 cost summary shown of the product at its existing build site in the U.S. will use the actual assembly routing time for this review. Also for this review, the product material cost will not be shown for privacy reasons on the product. Consider it a known fact that if the product supply base was moved to a low-cost geography, more than likely there would be a materials cost reduction. For this analysis, the labor, overhead, and percentage difference of total product cost and TCO costs will be shown.

Cost Summary	US Existing	China	Asia
Labor Rate	\$33.00		
Overhead Rate	503%		
Labor Hours	18		
Materials, \$	\$X		
Labor, \$	\$594		
Overhead, \$	\$2,988		
Total Product Cost	\$X	?	?
TCO Cost	\$X	?	?

Figure 9 – Table showing existing U.S. build site data.

The chart in Figure 10 shows the results of the completed analysis and a one year snapshot of building the product overseas. It is easy to see that the direct labor rate is much lower at the two overseas build sites. Even though the overhead rates are much higher, there's little impact to overhead costs since the direct labor rate is so much lower than the U.S. build site. Total cost of the product COGS are projected to be 23% and 24% lower at our build site in China and other Asia site for year one, respectively. What is not factored in are the TCO costs of moving the product and sustaining the product at the other build sites. That's where the TCO analysis comes into play. For the TCO analysis, the biggest changes for the inputs are as follows; cost of poor quality, lead time, transportations costs, and overall risk factors increased at the China and other build site in Asia. IP transfer became the risk factor weighted 17 with a high probability. Reoccurring and transition costs totaled over \$25,000 that led to an overall increase in TCO costs per unit.

Cost Summary	US Existing	China	Asia
Labor Rate	\$33.00	\$4.56	\$2.04
Overhead Rate	503%	600%	1020%
Labor Hours	18	18	18
Materials, \$	\$X	\$X	\$X
Labor, \$	\$594	\$82	\$37
Overhead, \$	\$2,988	\$410	\$375
Total Product Cost	\$X	-23%	-24%
TCO Cost	\$X	-2%	-9%

Figure 10 – Completed table showing comparison of three build site options after TCO analysis.

Based on the DFMA and TCO analysis, the decision was made to keep the product at the current U.S. build site. The TCO analysis determined that the year one cost savings would only be 2% or 9% lower than the baseline or existing build site. Collectively, two major items factored greatly in the decision. IP transfer was a risk the company was not willing to take from building in another country and the DFMA analysis showed the potential for greater than a 10% cost reduction over the next year. Therefore, sustaining activities have begun to cost reduce this product.

Summary

Adding a few custom operations in DFA that compliment the inherent capabilities of the software provide a tool for the design engineer to fully understand 100% of the total product cost and additional TCO costs during product development. Using DFA to track the costs of materials, labor, and overhead early in product design should guide the engineer towards hitting that elusive manufacturing cost target in addition to meeting the product function and time-to-market goals during product development.

The techniques reviewed such as DFA application targeting parts and labor, understanding company finance basics and overhead, and TCO application are examples of suggested areas for the design engineer to expand their knowledge base of the product value stream. While it does take time, design engineers should always be investing in expanding their manufacturing knowledge. Some sources to use include; if you have in-house manufacturing, talk to your company's manufacturing engineers and visit the shop floor to go see how parts are machined; visit and listen to the individuals who assemble the products, get their feedback on the ease or lack thereof of how the product goes together; visit suppliers to understand their manufacturing capabilities (good learning and good lunches go a long way on these visits). Do this to understand that design decisions have a great impact towards the entire value stream of the products built at your companies. If you became a design engineer it was probably due to a passion for problem solving and creativity. Maybe you have the design part down pat, but expanding your knowledge base into the areas of manufacturing, assembly, and beyond will be a great compliment to your skill set. So start with learning how to use DFA, it's a great place to start the journey and can be your guide . . . once again, speaking through experience.

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