



L3HARRIS™
FAST. FORWARD.

Conducting a Step-by-Step DFA Analysis

Bill Devenish – Global DFMA Leader and Producibility Engineer
L3Harris Technologies

TABLE OF CONTENTS

Abstract.....	4
Key Take Aways	4
Author	4
Bio.....	4
Introduction	5
Establish the Product Structure	6
Importing a Parts List	7
Set Initial Data – Main Product Page.....	8
Name and Location	8
Life Volume	8
Assembly Data	8
Envelope Dimensions.....	9
Product Summary.....	10
Answer Questions for Each Part – The Meat of DFA Analysis.....	10
Individual Part or Subassembly	10
Repeat Count	11
Special Tool Cost	11
Item Weight	11
Envelope Dimensions.....	11
Item Function	11
Minimum Part Criteria.....	12
Symmetry	13
Handling Requirements.....	14
Handling Difficulties.....	14
Securing Process	14
Insertion Difficulties	15
Manufacturing Cost Data (if known)	15
Insert Operations.....	15
Review Results	17
DFA Index	17
Analyze Redesign Ideas.....	18
Conclusion	22
Appendix	22

LIST OF FIGURES

Figure 1 Eddie Rickenbacker	5
Figure 2 Sample Electronics Enclosure	6
Figure 3 Product Structure (a.k.a. Parts List).....	7
Figure 4 Main Product Page.....	9
Figure 5 Minimum Part Criteria Flowchart	13
Figure 6 DFA Question Answered	16
Figure 7 Baseline DFA Analysis	18
Figure 8 Redesign #1	20
Figure 9 Redesign #2.....	20
Figure 10 Redesign Comparison.....	21

Conducting a Step-by-Step DFA Analysis

ABSTRACT

The Boothroyd Dewhurst DFA (Design for Assembly) tool is a powerful instrument that fosters innovative and collaborative product design. Those who are new to the process may struggle with how to begin. The intent of this paper is to provide a step-by-step guide for commencing a DFA analysis and lay the foundation for achieving the benefits of the DFMA methodology.

KEY TAKE AWAYS

- New DFA users will understand the primary steps for conducting a DFA analysis.
- New DFA users will recognize how to analyze DFA results.
- New DFA users are expected to experience less anxiety associated with conducting first-time DFA analysis.

AUTHOR

Bill Devenish
Producibility Engineer
L3Harris

BIO

Bill Devenish is a long-time DFMA advocate and recipient of the 2016 DFMA Supporter of the Year award. He was first introduced to DFMA as a new mechanical engineer fresh out of college, and has been instrumental in implementing the DFMA methodology within large and small companies ever since. Bill received his bachelor's degree from Brigham Young University, a master's degree in Engineering Management from Oregon Graduate Institute, and a Systems Engineering certificate from Florida Tech. He has worked for Motorola, Nokia, FMC, and Kohler, and currently is leading the DFMA efforts at L3Harris, a recently merged company of L3 with one of his previous employers, Harris.

INTRODUCTION

The year was 1917, and eager to lend his patriotic support to the recent entry of the United States into World War I, a tall, lean, race-car driver with only a 7th grade education, arrived at a newly established US Air Service training center in France. His rugged individualism and mechanical aptitude created a burning desire to fly airplanes. He knew his destiny was to become an aviator. Since he didn't have any college education, and happened to be a brilliant mechanic, his duties were relegated to the maintenance pool. When not on duty he spent his free time teaching himself to fly, until he was quickly proficient enough to qualify as a pilot. However, due to his excellent mechanical skills, his commanding officers initially declined his application to join the newly forming squadron of pilots. After repeated attempts his request was finally approved, and Eddie Rickenbacker became the leading American Ace of the war, with 26 aerial victories during a 3 month flying period.



Figure 1 Eddie Rickenbacker

*First Lieutenant E. V. (Eddie) Rickenbacker, 94th Aero Squadron, standing up in his Spad plane
18 October 1918*

Photo: Courtesy U.S. National Archives and Records Administration

Fast forward a hundred years to the intrepid engineer attempting to conduct their first DFA (Design for Assembly) analysis. It can be daunting and intimidating. There is a profusion of new concepts, terminology, definitions and interactions that appear to simultaneously assault the fledgling analyst. Many beginners are faced with numerous questions and options when initially starting to perform DFA analysis. Even though he was faced with multiple challenges and copious new technologies, Eddie Rickenbacker became a well-respected pilot, through sheer determination and practice. He once said, "Aviation is proof that given, the will, we have the capacity to achieve the impossible." Similarly, completing a successful DFA analysis is not impossible. This paper offers some guidance to assist those who are new to the rigors of the Boothroyd Dewhurst DFA methodology. It takes the reader through a step-by-step analysis of a hypothetical product, providing insights and explanations along the way. Some cautions and warnings are mentioned, which will hopefully reduce frustration and wasted time. This information, coupled with a desire to succeed, and plenty of practice, will establish a foundation leading to positive DFA results and achievement of the impossible.

ESTABLISH THE PRODUCT STRUCTURE

Once the DFA software has been started, the first step toward conducting a DFA analysis is establishing the Product Structure. The Product Structure in DFA is similar to a parts list or Bill of Material. It is a record of all the parts, subassemblies and operations associated with assembling the product. The Product Structure is developed and maintained within the Structure Chart, which is located on the left side of the DFA software tool. This is where the entries for parts and operations reside.

This paper will use an initial design concept for the assembly of a simple electronics enclosure as an example. Figure 2 shows the components that make up the assembly, consisting of a Circuit Card Assembly (CCA) secured to a Housing with Screws, and then a Cover that is also secured to the Housing with Screws. There are four unique parts, with a sum total of 11 parts in the assembly.

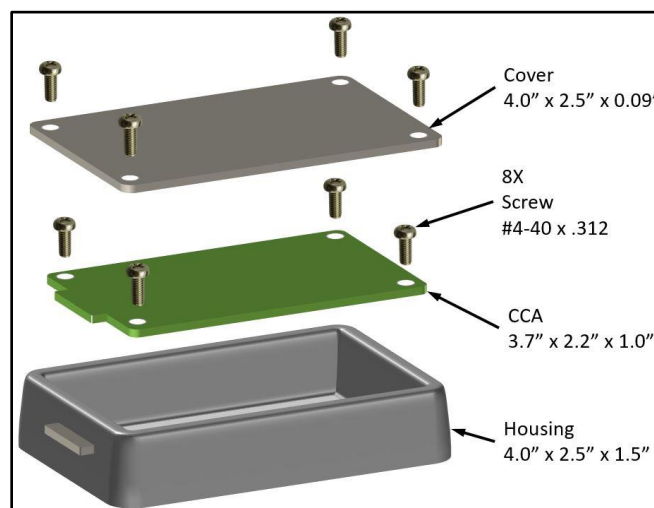


Figure 2 Sample Electronics Enclosure

Importing a parts list

To begin the analysis, the Product Structure, or parts list, needs to be entered into the Structure Chart. If the parts list already exists in Excel, or similar spreadsheet, it can be imported into the DFA tool, thereby saving data entry time. Within the Excel spreadsheet, save the parts list as a TXT or CSV file, then exit the spreadsheet, closing the program completely. Also, if importing cost or dimensional data, remove all associated characters, such as dollar signs and inch marks.



WARNING: Sometimes, if Excel remains open, a file read error occurs, therefore, it is good practice to close Excel completely prior to importing a parts list into DFA.



WARNING: Before importing data, verify that the DFA tool has been set to the appropriate measurement units. This can be done by selecting the “Set Units” drop-down of the “Analysis” menu option. There are two options; “English” and “Metric”. Selecting the measurement units in advance avoids cross-unit contamination within the analysis.

Sometimes the conceptual design is so new, or early, that there is no electronic parts list available. In this case, the parts can be entered manually. There are three methods for inserting parts into the Structure Chart. The first is to select the “Part” drop-down of the “Insert” menu option. Another option is to right-click in the Structure Chart area and select “Insert Part”. Finally, a part can be inserted by selecting the “Insert Part” icon on the menu bar. Once a part has been inserted, highlight the “Untitled” label for the part and change its name. Repeat this step for all parts that will be included within the assembly. Additionally, highlight the “Untitled” label for the assembly itself, at the top of the list, and change its name. At this point, the Product Structure would look similar to Figure 3.

The screenshot shows the DFA tool interface. The left pane displays the Structure Chart for an "Electronic Enclosure" assembly. The parts list is as follows:

Part Name	Quantity
Housing	1
CCA	1
Screw, 4-40x.312	1
Cover	1
Screw, 4-40x.312	1

The right pane contains the following data fields:

Field	Value
Part number	
Manufacturer Name	
Manufacturer Location	
Life volume	10,000
Labor rate, \$/hr	40.00
Overall plant efficiency, %	85.00
Cost of assembly fixture, \$	0.00

Figure 3 Product Structure (a.k.a. Parts List)

Organize the parts within the Structure Chart in order of assembly. Even though the design might be conceptual, it is important to visualize how the parts are put together. Ordering the assembly of the parts will also be important during later efforts in the analysis. Don't forget to save the file occasionally, even though an auto-save feature is included in the tool.

SET INITIAL DATA – MAIN PRODUCT PAGE

Name and Location

Prior to analyzing the individual parts in a DFA analysis, there is some basic information about the assembly that needs to be input. This top level information is used to determine the data and questions to be applied to the various parts of the assembly. While the name and location of the manufacturer is optional, it is helpful to identify who is performing the assembly, and where, especially when different manufacturers and locations are compared to each other.

Life Volume

The "Life volume" number is used to amortize one-time costs, such as dedicated tools and fixtures used for the product assembly. This is the estimated total number of assemblies that will be put together over the life of the product. This number will often be more than the short-term Business Development or Marketing plan. These types of plans usually project 3-5 year timeframes, but realistically many products are manufactured for much longer, sometimes 10, 20 or 30 years. Occasionally, products are cut short of the plan and might be made for only 1 or 2 years. Investigate and discuss with key stakeholders to determine which situation applies, and then estimate the number. Document the reasoning for the "Life volume" number in the "Notes" field below.



ADVICE: A critical piece of advice is to form the habit of using the "Notes" field. This is an ideal place for recording assumptions, decisions, questions and ideas. It becomes a life saver later when attempting to remember everything that was thought about or discussed during the analysis. For example, a brief explanation about the Life Volume decision might look like, "The Life Volume of 100,000 is based on an average of 10,000 for 10 years per the Marketing estimates." The "Notes" field can be found on every screen.

Assembly Data

"Assembly data" is the next section of top level information to be input on the main product page. It is used to calculate the cost of the assembly process, excluding recurring material costs.

The "Labor rate" is the fully burdened cost for an assembly worker. The current default rate is \$40/hr, and is based on data collected and averaged from numerous North American sources. The "Labor rate" can be modified to reflect local wage conditions. If this rate is modified, it is good practice to record the reasoning in the Notes field. On rare occasions, and based on the latest collection of data, the default rate will change with some software updates. A Labor rate of \$100/hr was chosen for the Electronics Enclosure.

The default value for "Overall plant efficiency" is set to 85%, and is another averaged value from collected data. It is a ratio of the actual amount of time that an operator is assembling product compared to their total available time. The ratio indicates the typical amount of time

where an operator is involved in non-assembly related activities; such as breaks, meetings and training. Rarely does this number need to change.

The “Cost of assembly fixture” records the total cost of any tooling or fixtures uniquely associated with the assembly. The cost is then amortized over the life volume of the product. Keep in mind that this is to track the cost of dedicated equipment, and not general assembly equipment, such as screwdrivers and wrenches, that are used on multiple products and considered part of overhead. For the Electronics Enclosure, it is assumed that an assembly fixture will be needed to hold the Housing during assembly, with an estimated cost of \$2,000.



ADVICE: Use the On-Context “Help” button when seeking more information about a field. Place the cursor in the desired field and then selecting the blue/white question mark button along the top menu. Usually, an explanation will provide helpful clarification.

Envelope Dimensions

The next section on the main screen of the initial data is “Envelope dimensions”. Three dimensions are used to define the final size of the assembled product. These dimensions help determine the typical size of the workspace, and will have an impact on assembly times and the types of questions that will be asked by the software during the DFA analysis. The dimensions represent the three sides of a box that the assembly would theoretically fit within. Even though the fields allow for three decimal place dimensions, the software doesn’t need that level of accuracy. There is also no need to orient the X, Y, Z axis. Assemblies smaller than 15 inches are considered small, while those over 65 inches are large.



ADVICE: When entering the overall envelope dimensions it is a good practice to check the measurement units and make sure that they are set appropriately.

An option is available for loading a picture within the “Thumbnail picture” field. This is an excellent location for placing drawings, data sheets and preliminary sketches. Most picture formats are supported, however, PDF files are not, and will need to be converted prior to loading. Freezing the picture allows it to be viewed as each part is selected in the assembly.

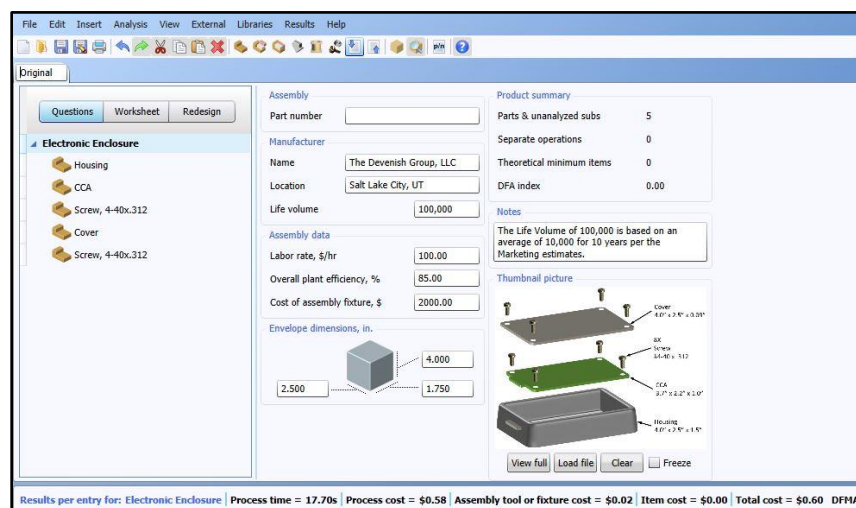


Figure 4 Main Product Page

Product Summary

The “Product summary” section on the main product page shows a quick overview of the DFA analysis results. It lists the number of parts, subassemblies and operations that comprise the assembly. It additionally provides a count of the parts that have been identified as meeting the minimum part criteria, a subject which will be covered later in this paper. Another topic to be covered later is the DFA Index, which result is also shown in the summary.

Results are also continuously displayed at the bottom of the screen. They represent outcomes for the highlighted item within the Structure Chart. When the top-level assembly, subassembly, operation or part is selected, the following five results are shown; “Process time”, “Process cost”, “Assembly tool or fixture cost”, “Item cost”, and “Total cost”. The “Process time” is the combined time for handling and inserting the part or subassembly into the product assembly, including any difficulties that have been identified. The “Process cost” is the result of the “Process time” multiplied by the “Labor rate” and factoring in the “Overall plant efficiency”. The “Assembly tool or fixture cost” is the amortization of the cost for the assembly fixtures based on the “Life volume”. “Item cost” is the cost of the part or parts. “Total cost” is the sum of the “Process cost”, “Assembly tool or fixture cost”, and “Item cost”. Figure 4 shows the completed main product page for the Electronics Enclosure example.

ANSWER QUESTIONS FOR EACH PART – THE MEAT OF DFA ANALYSIS

Once the Product Structure has been created, and the information entered into the main product page, it is time to begin answering questions about each part in the assembly. These questions help determine the amount of time it will take to assemble the part. This constitutes the substance of DFA analysis.



ADVICE: Approach the DFA analysis as a team. While entering data to start the analysis can be accomplished individually, it is vital that answering the questions for each part be performed as a team. It requires input, and insight, from a combination of engineering, manufacturing, quality, and sometimes procurement representatives.

When answering the questions, it is good practice to start at the top, left-hand side, then work down and across to the right, entering data and selecting responses along the way.

Individual Part or Subassembly

The DFA software tool wants to know if the item to be analyzed is a part or a subassembly. A Part is considered one physical item, compared to a subassembly that is comprised of multiple parts. A subassembly is typically assembled at a workspace different from where the current assembly is located. This accounts for the time to load the subassembly into some form of transport device to be taken to the next assembly level. If the entire assembly takes place at the same workspace it is considered flat, and there should be no subassemblies to be analyzed. The exception includes something known as a “Sub not analyzed”, which is a collection of multiple parts that are treated as a single part. In other words, this particular subassembly is purchased, received and assembled as a single item, though it may contain many parts, similar to a CCA (Circuit Card Assembly) or a motor. For the Electronic Enclosure example the Housing, Cover and Screws are considered Parts, while the CCA is a “Sub not analyzed”.

Repeat Count

“Repeat count” is another term for the quantity of identical parts to be inserted at the specific assembly step. Sometimes this can be overlooked during the analysis, so it is important to check the “Repeat count” for each part.

Special Tool Cost

This is the cost for any specialized tool required to assemble the part into the product. It will be amortized across the estimated Life volume of the product. This is not intended to capture typical overhead costs and the cost of general purpose tools. It is also not intended for tracking the potential tooling costs for parts that require new tooling. Tooling costs for the manufacture of parts are captured elsewhere within the DFM Concurrent Costing software tool.

Item Weight

Each part falls into three weight categories. Parts are either less than 5 pounds, between 5 and 30 pounds, or over 30 pounds. The weight category is used to help determine which time standards apply to the part. For the Electronic Enclosure example it is assumed that all of the parts are less than 5 pounds.

Envelope Dimensions

The Envelope dimensions for parts operate similarly to the dimensions for the assembled product. Additionally, this is where the general shape of the part is defined. There are two categories of shapes. The default shape is a block (non-rotational), with X, Y and Z dimensions. The dimensions are defined by the smallest box that the individual part would fit within. The other shape is a cylinder (rotational) defined by diameter and length. The dimensions are defined by the smallest tube that the part would fit within. There is no need to enter dimensions with 3 decimal place accuracy. Usually, being within half an inch is sufficient. This becomes useful when the design is still conceptual and the general size of the part can be estimated, but the exact dimensions are unknown.

Importing a CAD model can help speed the process of identifying and entering the envelope dimension data. To import a CAD model, select the “Load” option from the “CAD Model” drop-down list of the “External” menu item. The following file formats are recognized; STP, STL and IGS. Importing a CAD model will also show a picture of the part, which provides useful clarification to the part identification. The part shape will still need to be defined manually.

Item Function

The next step is to determine if the part is a fastener or connector within the “Item function” section. Fasteners have the sole function of securing two or more parts together. Fasteners are automatically candidates for elimination. Fasteners are more than just screws, they also include bolts, nuts, washers, pins, clips, nails, studs and rivets.

Connectors have the function of connecting two or more items together that theoretically could be combined. Therefore, connectors are also candidates for elimination. Connectors include wires, cables, terminals and hoses.

If the part is not a fastener or connector then the default value of “Item has other function” is maintained. Notice that if the “Fasten” or “Connect” option is selected the “Minimum part criteria” section disappears. This, again, is because they never meet the criteria, so it is not given as an option. The Screws for the Electronic Enclosure are considered fasteners.

Minimum Part Criteria

The Minimum Part Criteria is a part categorization technique that facilitates part combination and/or elimination. It increases understanding of product functionality and then assists in the effort to combine parts that meet required functions. It also provides justification for parts to exist as separate components in the design.

The Minimum Part Criteria consists of four categories; Base Part, Movement, Material and Assembly. Parts that meet these criteria are considered theoretically necessary. A part that doesn't meet one of these criteria is considered a candidate for elimination.

A part that meets the criteria for Base Part is usually the first part in an assembly, and is the one that most all other parts are attached to. There can only be one base part in an assembly, therefore, it is typically found in the top level of a parts list. Lower level subassemblies generally will not have parts that meet the criteria for Base Part. The Housing of the Electronics Enclosure meets the Base Part criteria.

A part that meets the criteria for Movement is one that must move relative to the parts already assembled. During operation of the product, significant movement must take place between the part and the other assembled parts. Part movement that could theoretically be obtained by integral elastic elements, such as a living hinge or spring, does not meet the criteria for Movement. Some common examples of parts that meet the criteria for Movement include a piston in a cylinder, a wheel rotating on an axle shaft, or a handle on a faucet.

A part that meets the criteria for Material must be made from a different material than the parts already assembled. It is important to only consider fundamental material properties, such as light permeability, sealing, applied force, life cycles or electrical conductivity. Some common examples of parts that meet the criteria for Material include a window, O-ring or electrical insulator. Sometimes there might be multiple parts made of the same material in an assembly that could theoretically be consolidated into a single part, and in this instance the first part meets the criteria for Material but subsequent parts do not meet the criteria. There may also be times when a collection of multiple materials grouped together are treated as one part, such as the CCA in the Electronic Enclosure.

Finally, a part that allows for the assembly of previous parts is theoretically necessary, and so it meets the assembly criteria. This is usually a cover, or the part that holds all the other parts together, similar to the Cover in the Electronic Enclosure.

If a part is not a fastener or connector, and it doesn't meet any of the four Minimum Part Criteria (i.e. Base Part, Movement, Material, or Assembly), then there is no fundamental reason for it to exist. It is a candidate for elimination or combination.

When conducting a DFA analysis, all parts in the assembly must be assigned a Minimum Part Criteria category. The purpose of the Minimum Part Criteria is to examine each part for the possibility of elimination or combination with other parts in the product. When assigning parts

their respective category it is important to proceed in the order of the actual assembly process. This provides the opportunity to compare the current part against the parts that have already been assembled and not those expected to come later in the assembly. Figure 5 shows the process for applying the Minimum Part Criteria to parts.

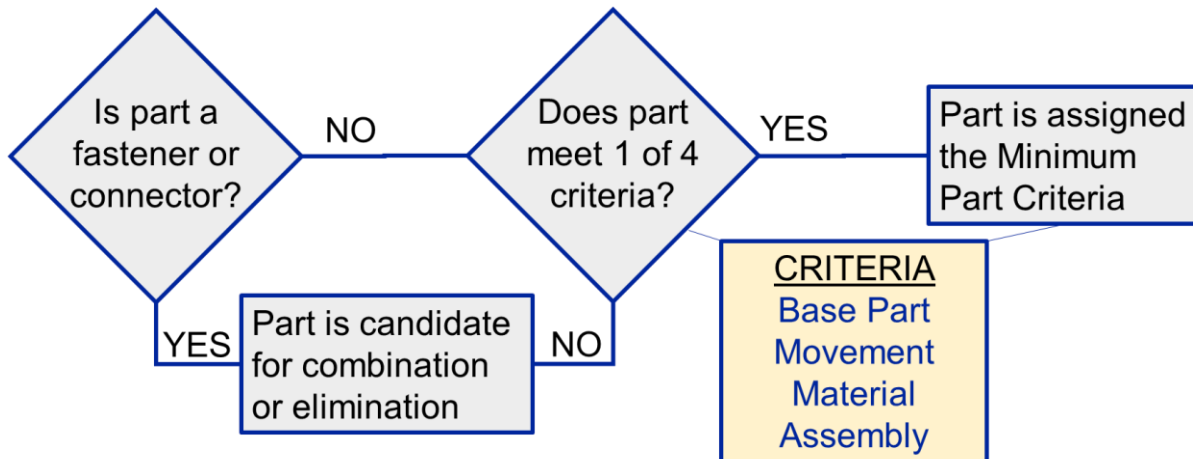


Figure 5 Minimum Part Criteria Flowchart

When applying the Minimum Part Criteria it is also imperative to keep in mind what is theoretically possible, ignoring practical, economic and technical limitations for the moment. While evaluating parts for Minimum Part Criteria, think of them in the context of a theoretical redesign of the product. In other words, determine if the parts need to be separate, or can be combined, considering the theoretical alternatives. There is no need to have expert knowledge of the alternatives, just an awareness of the possibility. It can be helpful to repeatedly ask the question, “Theoretically, can I accomplish the design objective without this part?” or “Theoretically, can I combine this part with another?” This leads to creative solutions for optimizing the design. Record any improvement ideas in the “Notes” field. For instance, the Screws in the Electronic Enclosure are classified as fasteners and don’t meet the Minimum Part Criteria, so therefore, could be eliminated by securing the CCA, as well as the Cover, to the Housing with some type of snap feature.

Symmetry

Parts are evaluated to determine their symmetry during the assembly process. Most parts can only be inserted into the assembly in one orientation, indicating that they have no symmetry. Some parts can be rotated 180° or less about one axis and still fit within the assembly, so they are considered to have one axis of symmetry. Parts considered to have two axes of symmetry can be rotated 180° or less in two or more axes and fit into the assembly. The Housing and CCA from the Electronic Enclosure have no axis of symmetry, while the Screws have one axis, and the Cover has two axes of Symmetry. Sometimes the part symmetry might not be presented as an option. This usually means that the part is so big or heavy that its size and/or weight has no influence on the assembly time.

Handling Requirements

The “Handling requirements” section essentially wants to determine if the part can be grabbed with one hand, or if two hands are needed. Most parts can be grasped with one hand and without the need for a grasping tool. In some instances, a tool, requiring the use of only one hand, is used to grab the part. At other times it is necessary to use two hands for grabbing the part, especially if the part is flexible, or if it nest or tangles and requires two hands to separate them. All of the parts for the Electronics Enclosure can be grabbed with one hand and without the aid of a tool.

This is a good time to mention the difference between part handling and insertion of parts. The time standards that support much of the DFA analysis are comprised of two sets of data. One is associated with part handling, which is the time to acquire the part from the parts bin, box, bag or shelf. The other is the time it takes to orient and insert the part into the assembly. This is one of the reasons why there are separate sections for Handling and Insertion difficulties.

Handling Difficulties

There are a variety of handling difficulties which are presented, depending upon the size and weight of the part. Handling difficulties add time penalties to the process time for the part, increasing the total assembly time for the product. Review each one to determine if it applies to the specific part being analyzed. For the Electronics Enclosure, the difficulty of “Requires careful handling” was chosen for the Housing and Cover because the parts are aesthetic, and care must be taken to avoid scratches, or other deleterious marks, on the surface of the part. The same difficulty was also chosen for the CCA because there are some components on the PCB that are fragile prior to assembly within the Housing. “Slips from fingers” was chosen for the Screws because of their small size.

Securing Process

The securing process identifies how the parts are held within the assembly. One of the more common securing processes is “Added not secured”, which means that the part is inserted into the assembly and will be secured later, either with another part that is inserted or a separate operation. A part that is “Added not secured” goes into place without the need to exert a force. A good visual to remember for “Added not secured” is to picture the assembly being turned upside-down and the newly inserted part falling out.

Parts that are “Added and held down” require a continuous force be applied to the newly inserted part to keep it in place until another part or operation secures it. A “Snap/push fitting” implies that the part has an integrated securing feature. This could be a snap or a slight interference fit that requires a force to be exerted to the part to secure it in place. If the assembly is turned upside-down, the newly inserted part will remain in place. Screws, nuts, studs and bolts utilize “Threaded fastening” as their securing method, however, keep in mind that some parts have threaded features integrated into them for the purpose of securing them into the assembly. When “Threaded fastening” is selected, there will be an additional option to define the type of tool used. The “Pop rivetting” securing method is to be selected when rivets and associated tools are used, and “Self-stick securing” should be selected when parts are secured using typical double-sided adhesive material. The securing processes for the Housing, CCA and Cover are all “Added not secured”, while the Screws are “Threaded fastening”.

Insertion Difficulties

The type of insertion difficulties presented are also dependent upon the size and weight of the part. Just like handling difficulties, insertion difficulties add time penalties to the process time. Review each insertion difficulty to determine if it applies to the specific part being analyzed. For the Electronics Enclosure, the difficulty of “Not self-locating” is applied to the Cover because the design currently doesn’t have any features that line up the Cover to the Housing, instead relying on the assembler to align the parts.

Manufacturing Cost Data (if known)

The cost of the parts can be tracked in the “Manufacturing data” section. This data is then used to show the cost of all the parts in the assembly. The total cost for the assembled product is then shown, which includes the assembly labor cost and the amortized cost of the assembly related tools. The part cost information can be entered manually for each part, or the DFM Concurrent Costing tool can be linked and used to estimate the “Should Cost” of the parts. Any applicable “Tooling investment” can also be tracked for each part, as well as the entire assembly. Since the focus of this paper is on DFA analysis, the part cost information is not being evaluated for the Electronics Enclosure.



ADVICE: Keep in mind that “Piece part cost” is uniquely different from “Item cost”. Think of the “Piece part cost” as the cost, or price paid, for the part or subassembly, while the “Item cost” is the cost for the part or subassembly, plus the amortization of any applicable fabrication tooling included.



ADVICE: DFM should be used for estimating the cost of manufactured parts, and is typically not necessary for commodity items, such as; screws, labels, O-rings and connectors.

Insert Operations

Once all of the parts have been analyzed by answering the DFA questions it is time to insert any applicable operations, if this hasn’t already been done. Operations are inserted using the three different methods similar to the insertion of parts. The Electronics Enclosure gets a serial number marked on it after the assembly is complete. To simulate this activity, the “Mark label” operation was added after the last part and then renamed, by highlighting the operation in the Structure Chart, to “Mark Serial Number”.

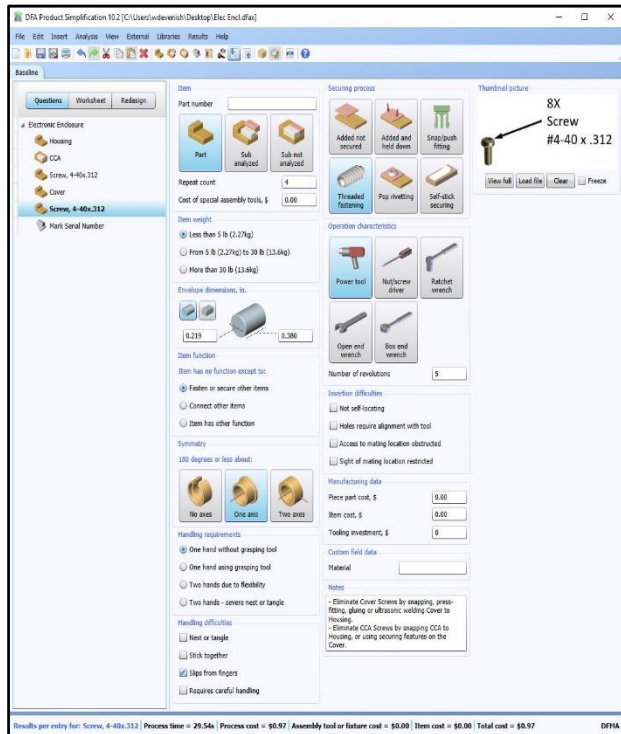
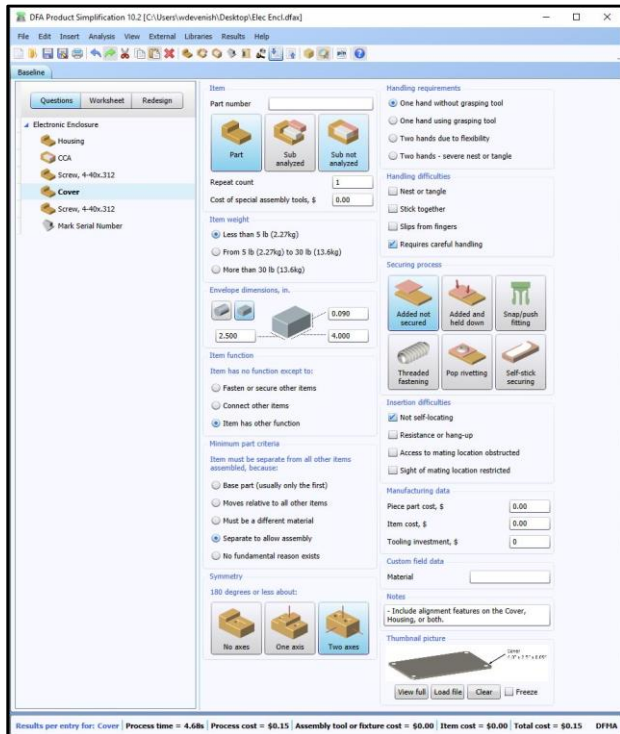
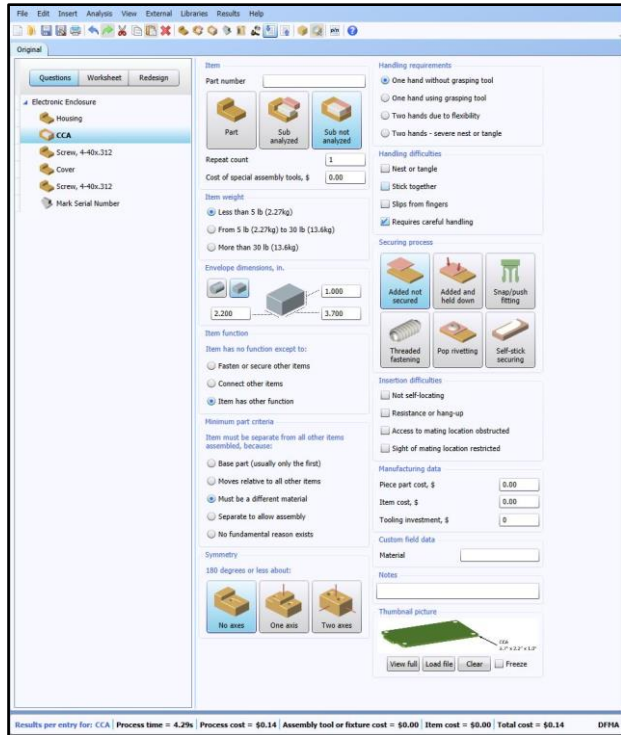
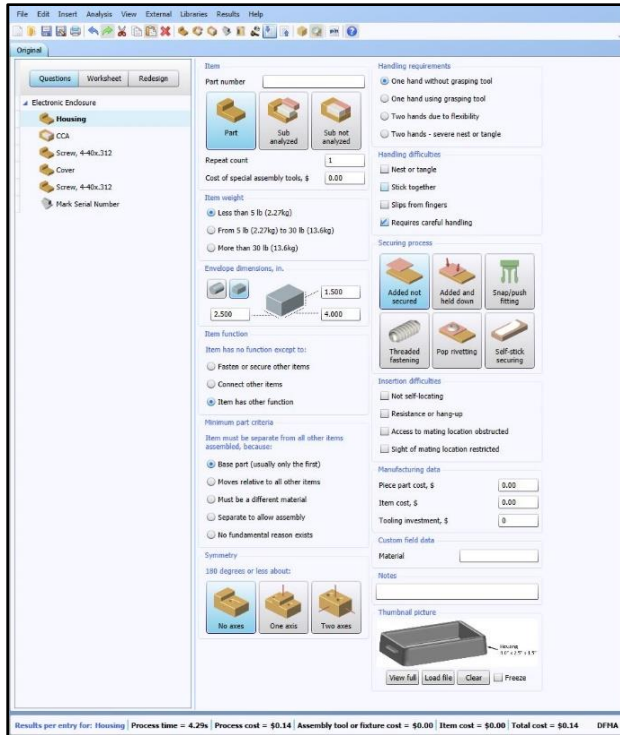


Figure 6 DFA Question Answered

REVIEW RESULTS

After the DFA questions for each part have been answered, and the operations entered, the results of the assembly can be reviewed. The following data for the assembly can be gleaned from the Product summary and Results per entry when selecting the top-level Electronic Enclosure in the Structure Chart (see Figure 6).

- Number of Parts = 11
- Number of Operations = 1
- Theoretical Minimum Parts = 3
- DFA Index = 11.76
- Assembly Time = 87.64 seconds
- Assembly Labor Cost = \$2.86
- Assembly Tool Cost = \$0.02
- Total Assembly Cost = \$2.88 (excluding cost of parts)

The baseline DFA analysis has now been established, and can be used as a comparison reference for redesign ideas.

DFA Index

An essential ingredient of DFA, known as the DFA Index, provides a way to measure assembly efficiency. It is a ratio of the theoretically ideal assembly time over the actual assembly time. The range is from 0 to 100, with a higher number representing a more efficient design. The DFA Index is based on decades of performing time studies and collecting data by Boothroyd Dewhurst, and it can be used to compare alternate design concepts that have been created to meet the same functional requirements. The DFA Index can also be used to make data driven decisions, instead of relying on instinct, gut-feel, or intuition.

The formula for calculating the DFA Index is shown below.

$$E_{ma} = \frac{N_{min} * t_a}{t_{ma}} * 100$$

E_{ma} represents the value for the DFA Index. The Numerator in the equation is defined by the theoretically ideal assembly time, where N_{min} is the Theoretical Minimum Number of Parts multiplied by t_a , the Ideal Assembly Time for a given part, which is equivalent to 2.93 seconds. The Denominator is defined by the Estimated Assembly Time, t_{ma} , which includes penalties for handling and insertion difficulties, along with time penalties for operations and parts that don't meet the Minimum Part Criteria.

The DFA Index can be used as a quantitative metric to track the progress of product development. It also encourages Product Simplification by facilitating creativity.

Analyze Redesign Ideas

With the baseline DFA analysis completed, the next step is to collect as many improvement redesign ideas as possible. Reviewing the notes for each part provides a good beginning. This can quickly be done by selecting the “Worksheet” button, where all of the DFA information for the assembly is presented in a large spreadsheet format. Selecting the “Redesign” button highlights various categories of suggestions for generating redesign ideas. Significant improvements can be made when focusing on category 1 suggestions. However, the other suggestion categories can also help uncover exceptional ideas for improvement.

After reviewing and discussing the redesign suggestions from the DFA tool, the team should review the notes they made during the baseline DFA analysis. Collect all of the redesign ideas into one location (i.e. white board, PowerPoint slide, note pad, etc.). The next step is to conduct a short brainstorming session, utilizing the basic rules. The objective is to generate as many redesign ideas as possible, stretching the typical boundary constraints. Once a large number of ideas have been generated, they should quickly be evaluated for feasibility. The remaining redesign ideas are then evaluated individually, or within logical groupings, and compared to the baseline DFA analysis. The typical approach for comparing the redesign ideas to the baseline is by copying, and pasting, the Baseline tab in DFA. Another suggestion is to rename the tab for the baseline analysis from “Original” to “Baseline”, as shown in Figure 7 for the Electronics Enclosure assembly. This is accomplished by hovering the mouse over the “Original” tab, right-clicking, and selecting “Rename” from the drop-down menu.



ADVICE: Make sure that the baseline DFA analysis is well established first, before copying the tab, to minimize the compounded effort when a change needs to be made to the baseline.

The screenshot displays the DFA Product Simplification 10.2 software interface. The window title is "DFA Product Simplification 10.2 [\\SLDAT30\Home\wdevenish\My Documents\DFMA Stuff\DFMA Workshop & Training\CCA Enclosure\Electronics Enclo...". The interface is divided into several sections:

- Navigation:** "Baseline" and "Redesign 1" tabs are visible at the top. Below them are buttons for "Questions", "Worksheet", and "Redesign".
- Assembly Tree:** A tree view on the left shows the assembly structure: "Electronic Enclosure" (expanded) containing "Housing", "CCA", "Screw, 4-40x.312", "Cover", "Screw, 4-40x.312", and "Mark Serial Number".
- Assembly Data:** Fields for "Part number", "Manufacturer" (The Devenish Group, LLC), "Location" (Salt Lake City, UT), "Life volume" (100,000), "Labor rate, \$/hr" (100.00), "Overall plant efficiency, %" (85.00), and "Cost of assembly fixture, \$" (2000.00).
- Envelope Dimensions:** A 3D model of a rectangular box with dimensions 2.500, 4.000, and 1.750.
- Product Summary:** A table showing: "Parts & unanalyzed subs" (11), "Separate operations" (1), "Theoretical minimum items" (3), and "DFA index" (11.76).
- Notes:** A text box stating: "The Life Volume of 100,000 is based on an average of 10,000 for 10 years per the Marketing estimates."
- Thumbnail Picture:** A 3D exploded view of the assembly with labels: "Cover 4.00' x 2.50' x 0.00'", "8x Screws 4-40 x .312", "CCA 2.00' x 2.25' x 1.00'", and "Housing 4.00' x 2.50' x 1.50'".
- Results Bar:** A status bar at the bottom shows: "Results per entry for: Electronic Enclosure | Process time = 87.64s | Process cost = \$2.86 | Assembly tool or fixture cost = \$0.02 | Item cost = \$0.00 | Total cost = \$2.88 | DFMA".

Figure 7 Baseline DFA Analysis

The Baseline DFA analysis can then be copied by right-clicking the “Baseline” tab, selecting “Copy”, and then right-clicking again while hovering the mouse over the tab and selecting “Paste”. Rename the new tab “Redesign 1”, or some other label that best describes the new design.

Make changes within the newly created tab to capture the redesign ideas. The changes usually include eliminating parts, combining parts, removing part handling/insertion difficulties, as well as changing or removing operations. Record the changes in the “Notes” field.



WARNING: Be careful when combining, and deleting or adding parts. For example, when two parts can be combined, and one of them meets the Minimum Part Criteria, the part to delete is the one that doesn't meet the criteria. If a redesign idea includes the deletion of a part that meets the criteria then the team will want to go back and re-evaluate the application of the Minimum Part Criteria, or consider the redesign idea more carefully. Make sure that the number of parts that meet the criteria is the same for each tab that represents the various redesign ideas. This ensures that the DFA Index, which utilizes the number of minimum parts in its calculation, can be used as a valid comparison tool.

Two redesign ideas were identified for the Electronics Enclosure. The first, Redesign #1, involves elimination of the Screws that secure the Cover to the Housing by replacing their function with a snap-fit feature that is integrated into the Cover. The Screws were deleted from within the Product Structure, and the securing process for the Cover was changed to “Snap/push fitting”. Details of the design have not yet been developed, but there is high confidence that the idea can be implemented. Notice in Figure 8 that a note has also been included describing the change made for Redesign #1. Additionally, the symmetry for the Cover was changed to “No axes” because of the proposed snap feature, and a note was made that alignment features will be added to the design, removing this insertion difficulty.

Looking at the results, the DFA Index for Redesign #1 is 17.63, which is a 50% increase in assembly efficiency. This indicates that the redesign idea is a significant improvement. There is also a related decrease in assembly time (~29 Seconds) and process cost (\$0.95).

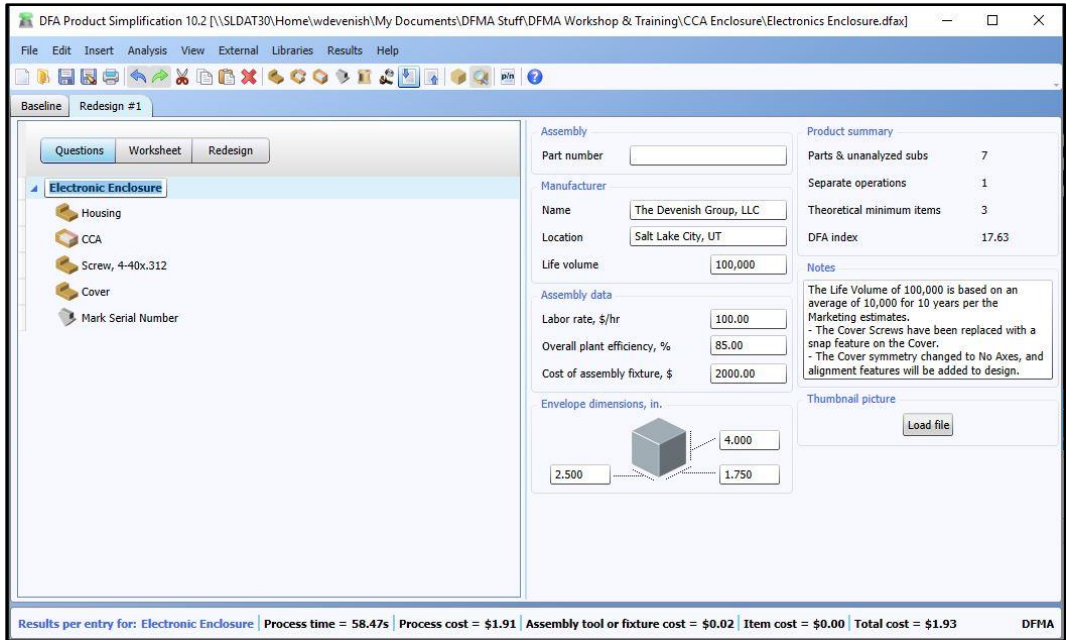


Figure 8 Redesign #1

The other idea, Redesign #2, includes the changes in Redesign #1 and additionally replaces the Screws securing the CCA with snap features in the Housing. An alternative approach is to include some CCA securing features in the Cover. Either way, the Screws can be deleted. The Redesign #1 tab in the DFA software is copied and renamed Redesign #2. Within the new tab the remaining Screws are deleted, CCA securing process updated, and comments added to the Notes field. See Figure 9.

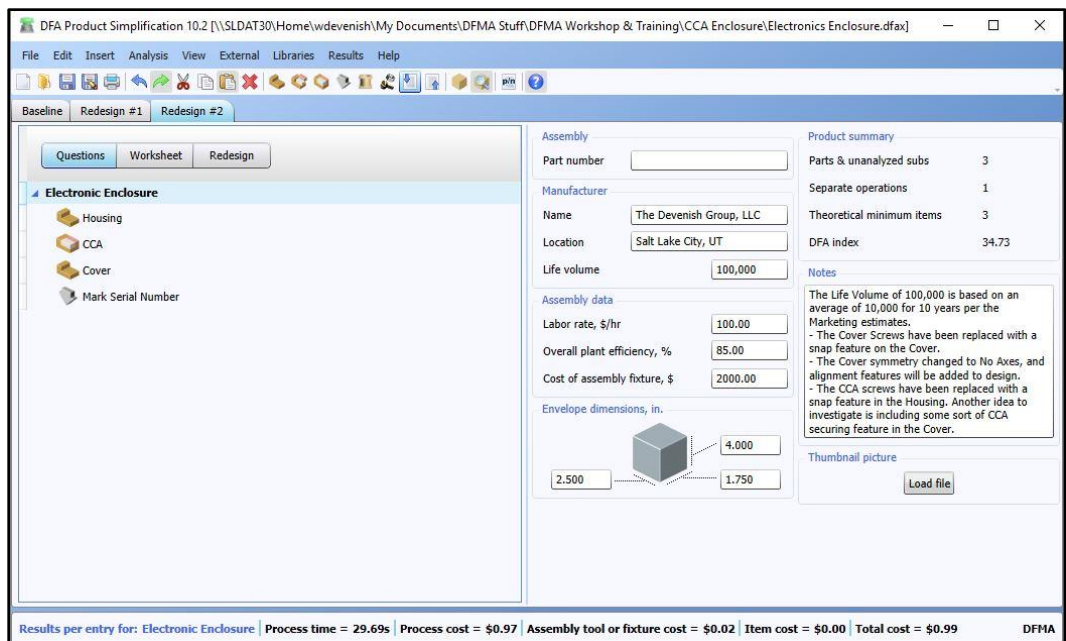


Figure 9 Redesign #2

A quick way to compare the redesign ideas, after modeling them in their respective tabs, is to run a DFA report. This is accomplished by selecting “Analysis Totals- DFA” from the “Results” menu drop-down list. When the dialogue box appears, select the Baseline analysis in the associated drop-down menu, and then select the two redesign analyses to be compared. Hold down the “Shift” key to make multiple selections. A sample of the results is shown in Figure 10.

Entries including repeats	Baseline	Redesign #1	Difference	Redesign #2	Difference
	Baseline				
Parts meet minimum part criteria	3	3	0 0%	3	0 0%
Parts are candidates for elimination	8	4	-4 -50%	0	-8 -100%
Analyzed subassemblies	0	0	0 0%	0	0 0%
Separate assembly operations	1	1	0 0%	1	0 0%
Total entries	12	8	-4 -33%	4	-8 -67%
Assembly labor time, s					
Parts meet minimum part criteria	13	14	0.37 3%	14	1.13 9%
Parts are candidates for elimination	59	30	-30 -50%	0	-59 -100%
Insertion of analyzed subassemblies	0	0	0 0%	0	0 0%
Separate assembly operations	15	15	0 0%	15	0 0%
Total assembly labor time	88	58.47	-29.17 -33%	29.69	-57.95 -66%
Design efficiency					
DFA Index	11.76	17.63	6 50%	34.73	23 195%

Figure 10 Redesign Comparison

The first item to scrutinize in the DFA report is the number of parts that meet the Minimum Part Criteria. The number should be the same for the Baseline and both Redesign concepts. For the Electronic Enclosure, the number of parts meeting the criteria is three. Next, the number of parts, subassemblies and operations are totaled and compared. The times associated with the parts, subassemblies and operations is also shown. Finally, the DFA Index for each design concept is displayed. It can be seen that Redesign #1 is an improvement from the Baseline, and that Redesign #2 builds upon the momentum of #1 with an assembly efficiency that almost triples the Baseline. The ideas contained within Redesign #2 show some real promise, and should be seriously considered, especially since the design effort is still in the early concept stage.

However, there are some other considerations that need to be evaluated for the redesign concepts. One of the first questions might be, “Will the Cover with integrated snap features cost as much, or less, than the flat Cover with Screws?” This is where the DFM Concurrent Costing software tool can be used to obtain preliminary “Should Cost” estimates for the fabricated parts, and the use of DFM is a topic for another paper. An effort should also be made to determine the amount of work and resources needed to create the new design idea and still meet schedule constraints. Potential risks should be identified and used to determine

which, if any, of the redesign options are to be pursued. Before making a final decision, it is good practice to review some of the other reports available within the DFA software tool.

CONCLUSION

The intent of a DFA analysis is to evaluate the efficiency of an assembly, unleash team creativity to improve the assembly, and compare alternate design approaches. The first few attempts at conducting the DFA analysis can be overwhelming for novice users of the Boothroyd Dewhurst DFA software tool. Skill in using the tool can be increased through regular practice and use, coupled with review of the items outlined in this paper. Another way to gain competence with DFA analysis is to experiment with different responses for the parts, to see if the results reflect what is expected, and what actually happens. Ultimately, DFA analysis leads to simplified product designs and helps teams achieve the impossible.

APPENDIX

Version 10.2 of the Boothroyd Dewhurst DFA software tool was used for screen shots

Instructional DFA tutorials can be found on www.DFMA.com

Product Design for Manufacture and Assembly, Third Edition, *edited by Geoffrey Boothroyd, Peter Dewhurst, and Winston A. Knight* (Minimum Part Criteria and DFA Index calculation, pp 81-82)