DFMA and Concurrent Engineering Application

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Abstract

This paper will explain how Brooks Automation Inc. has successfully applied the Boothroyd Dewhurst DFMA concept and software into our new product development process to help achieve product cost savings of 35-50%. It will discuss some of the key factors that led to successful implementation. This paper will also explain in detail two DFMA case studies and how it led to lower cost designs.

Brooks Automation Overview

Brooks Automation was founded in 1978 and has approximately 1,900 employees worldwide, with locations in North America, Asia and Europe. Brooks is a leading global supplier of automation to the semiconductor industry. In addition, Brooks provides solutions for other industries including flat panel display, data storage, medical devices, automotive, aerospace and defense.

Brooks three major markets are:

1) Tool Automation for OEMs
2) End-User Factory Automation Hardware
3) End-User Software called Real Time Enterprise software

Brooks had its start as a provider of wafer handling robots for vacuum-based semiconductor process tools. Brooks Factory automation hardware systems allows semiconductor manufacturers to transport, inspect, and store materials. Brooks Real Time Enterprise software addresses the need for Lean Manufacturing, Closed Loop Automation, Supply Chain Execution, and Enterprise Resource Management.

Brooks Automation DFMA History.

Brooks Design for Manufacture and Assembly (DFMA)[1] implementation did not happen overnight, in fact it took nearly two and a half years after we purchased the Boothroyd Dewhurst Inc (BDI) DFMA software[2] to finally implement it within our organization. I will walk you through our DFMA evolution process and how we eventually succeeded in implementing DFMA. Figure 1.0 below shows a timeline of Brooks DFMA history.
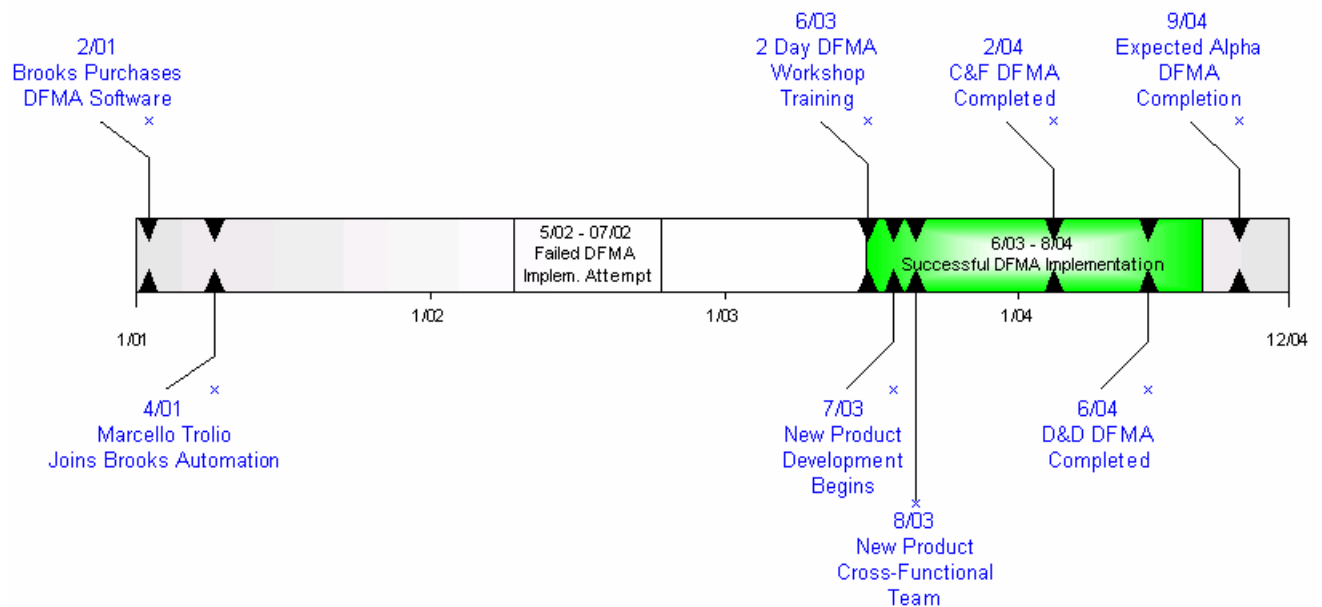
Figure 1.0 Brooks Automation Inc. DFMA History

DFMA Software Purchased & DFMA Expert Acquired

Brooks purchased the BDI DFMA software in January of 2001. Shortly afterwards, I was hired by Brooks Automation Inc. to help implement DFMA. However, my immediate assignment was to assume a role as project manager in helping to transition a product line from our Mountain View California facilities to our Chelmsford, MA facilities.

DFMA Implementation Failure

Upon successfully transitioning the product line and completing the objectives in my role, I was asked to take on a Manufacturing Engineering role supporting several products that we transitioned from Mountain View. In addition, I was asked to help initiate the implementation of DFMA. I began by creating a DFMA committee which met bi-weekly. Since the committee members had little knowledge of DFMA, I spent the first few weeks helping to increase their knowledge level. We then created a mission statement on what we wanted to accomplish with DFMA. We also established a timeline and goals for implementation. We created a DFMA overview presentation and shared it with upper management to help justify DFMA implementation.

While we were on the right track to success, our attempt to implement DFMA eventually failed two months later. A few key factors led to the failure. First, I was pulled out of my role and into a Production Manager role which allowed me zero time to spend on DFMA. At that time in Brooks history, consolidation of facilities was a top priority and upper management decided that I could be of best help in the Production Manager role.

The lessons learned from this experience is that you MUST have a dedicated person assigned to DFMA implementation or it will not happen. In my role as manufacturing engineer I could only dedicate at most 15% of my time to DFMA implementation. The second reason why DFMA failed was that upper management did not support DFMA implementation at this point.

DFMA Implementation Success!

About one year later a few things happened that put us on route to successful DFMA implementation. Firstly, I was pulled out of my role as a Production Manager and into a newly formed new product development team which had a goal to reduce our current product cost by 50%. I was put on this team because upper management recognized the need to apply DFMA and knew that I could help lead this effort. They understood that I had the know-how and understood that I needed to be 100% dedicated to the project in order for DFMA to be successful.   Secondly, upper management made it extremely clear to myself and everyone on the new product team that DFMA had to be applied on this new product. DFMA was not optional, it had to happen and I would champion the effort with full support from each new product development team member.

To begin, we initiated a 2-day DFMA training workshop. We outsourced the training to Boothroyd Dewhurst, Inc. who came on-site and provided all the training and material needed. We trained 25 engineers who all received hands-on training on the principals of DFMA and also on the BDI DFMA Software. This training helped to establish a foundation for the application of DFMA at Brooks Automation Inc. In addition, the training led to cost savings as we analyzed actual Brooks products and came up with DFMA solutions for cost reductions. The solutions were implemented and led to cost savings of over 5 times the cost of the DFMA workshop!

Another key factor that we did that helped to facilitate DFMA implementation was the creation of the new product development "War" room. The "War" room was a room designed and set aside for the use of the new product development team. We pulled every team member out of their offices and into the "War" room. We set up about 10 desks in a rectangular layout and side-by-side with no cubicles or any separations between each desk. Each team member took a desk and made it their new home. Sitting side-by-side were design engineers, software engineers, supply-chain manager, DFMA manager, manufacturing engineer, engineering project manager, and other disciplines which made this a true cross-functional team. After a few weeks we all realized the benefits of this setup. Firstly, it made it very easy to communicate. Since we were all in one room, talking to someone simply required turning towards them and initiating a conversation. This led to direct, quick and effective communication. Also, our arrangement provided great benefits in terms of project management as it helped to make sure everyone was on the same page.

Creation of a DFMA story board was also an important factor in helping to successfully implement DFMA. Santo Dinaro, VP of Engineering, approached me and explained to me the need for a DFMA story board. Santo Dinaro explained that it would help to both

increase the awareness of DFMA within Brooks and also to help our customers to realize the benefits that they would realize through our DFMA application. Through a series of one-on-one meetings between Santo Dinaro and myself we completed the DFMA story board. The story board was placed on a wall in a visible high traffic area of our company. It essentially had 4 columns of power point slides with the first row of each column stating the customer benefits of applying DFMA, which were:

1) Meet Customer Price & Brooks Profit Point
2) Improved Product Quality Improved Reliability & Cost of ServiceEliminate Post Product Introduction Cost

Below each of these title slides were supporting slides of examples of how DFMA helped to achieve each of the customer benefits. For example, under the Improved Product Quality slide we had a slide that showed the correlation between DFA Index and product quality to justify our claims that DFMA would lead to improved Quality. The DFMA story board was not only a great awareness tool but also became a very good marketing tool in helping our customers understand the benefits that they would realize through our DFMA efforts. The DFMA story board was a factor in successful DFMA implementation.

Training on DFMA, strong upper management DFMA support, cross-functional team development, having a dedicated DFMA person, developing a DFMA story board, and the creation of the "War" room helped us to successfully implement DFMA within Brooks Automation. As evidence, we have just completed our Design & Development Phase of our new product and are very close to meeting our 50% cost reduction goals. We may not be at 50% but we are well above 35% cost reduction. We will know exactly how close we are to obtaining our goal as we begin to obtain firm part quotes from our suppliers. Based on the data that we have at this time, we have achieved significant cost savings that will help us meet our customers ever increasing need for higher performance and lower cost products.

Next, I will walk you through two examples that show how we have applied the DFMA concept and software in our new product design process. These are just two of the many cases in which we utilized DFMA to achieve lowest cost designs.

Example 1-Traverser Base Assembly DFMA Analysis

One major assembly on our new product is what is known as the Traverser assembly. Jeff Thompson, the design engineer for the Traverser and myself performed a DFMA analysis on a Traverser assembly using the BDI DFA Software and came to the following key conclusions:

1. The original Traverser base machine design part may not be the lowest cost solution
2. Sand casting may be a lower cost solution than machining

3. The following parts do not meet the DFMA "Minimum Part Count" criteria and are therefore candidates for elimination and are considered "Theoretically unnecessary":
    a. 2 Traverser Motor Mounts
    b. 2 Traverser Track Clamps
    c. 32 fasteners used to mount the above parts
4. Above parts could be eliminated by combining into a cast part

We recognized that casting the Traverser base would lead to substantial part count and assembly time reduction. The cast design would also eliminate all of the "Theoretically Unnecessary" parts as identified in the DFA analysis. However, we needed data to determine if casting the base would lead to a lower *total cost* solution. What is the expected cost of the machined base, Motor Mounts, Track Clamps and the new 1-piece sand cast base? We utilized the BDI DFM Concurrent Costing software to answer these questions.

Below chart 1.0 compares part cost between the two alternative designs obtained from DFM Concurrent Costing. Cost have been scaled by an X-factor for confidentiality.

Component Part	Original Design (Machining)	Redesign (1-Piece Sand Cast)	% Savings
Machined Base	$12.5X	-	-
Motor Mount (Qty 2)	$2.5X	Combined Into Cast	-
Track Clamp (Qty 2)	$X	Combined Into Cast	-
Sand Cast Base	-	$6.96X	-
Total Part Cost	**$16X**	**$6.96X**	**54 %**

Chart 1.0 *Part Cost Comparison*

The cost of the sand cast base ($6.96X) is much less then the machined base ($16X). In addition, the sand cast design incorporates the features necessary to eliminate the need for the Motor Mounts ($2.5X) and Track Clamps ($X). This essentially combines 5 separate parts into 1 part. Below chart 2.0 compares the total cost savings between the two designs.

	Original Design (Machining)	Redesign (1-Piece Sand Cast)	% Savings
Total Parts	37	1	97 %
Total Assembly Cost	$.36X	$.01X	97 %
Total Part Cost	$15.95X	$7.00X	56 %
Total Cost	**$16.36X**	**$7.01X**	**57 %**
DFA Index	*1.0*	*68.9*	

Chart 2.0 *Total Cost Comparison*

As shown, the 1-piece sand cast design leads to lower total cost, lower assembly cost, and reduced part count. Eliminating the Motor Mounts and Track Clamps also led to a reduction of 32 fasteners which were used to fasten these parts. As expected, the DFA Index increased significantly from 1.0 to 68.9 because of the significant part count and assembly time reduction.

We utilized the DFMA software's Executive Summary Report to help compare the two alternative designs. It is important to note that this report is easily generated from the DFA software and provides a very good way to compare alternative designs. Based on the report we decided to move forward with sand casting the Traverser base because of the expected $9.35X (57%) cost savings per part.

From this example we can easily recognize the bottom-line positive impact that DFMA can have on new product design. We realized these benefits by following a simple process. First, we performed a DFA analysis that allowed us to identify opportunities for part count reduction. Secondly, we developed alternative designs based on the DFA analysis that where targeted towards part count and cost reduction. Thirdly, we performed DFM cost estimates to compare alternative designs part cost. Fourthly, we obtained data from the DFMA analysis which allowed us to compare the two designs across 5 key metrics: 1) total parts, 2) total assembly cost, 3) total part cost, 4) total cost, and 5) DFA Index. Lastly, and most importantly, we reviewed the data and made a sound *data driven decision* to sand cast the Traverser base so to realize the cost savings.

In addition to the $9.35X or 57% cost savings realized, I believe there are even further savings that are not immediately recognizable. For example, we eliminated 4 major parts, 2 Motor Mounts and 2 Track Clamps. What further benefits do we realize by eliminating 4 major parts? I refer to these benefits as "hidden benefits" because they are so often unnoticed and not even considered in product design. Let me propose that 4 less parts would lead to 4 less parts to order (lower purchasing costs), 4 less parts to stock (lower inventory costs), 4 less parts to worry about arriving late from a supplier causing late product shipment (higher on-time shipment %), 4 less opportunities for defective parts (higher quality), and the list goes on and on. These are additional saving that go unnoticed but have lasting positive impact.

Example 2-Top Plate DFMA Analysis

A design engineer approached me and wanted to understand the most cost effective way to produce a Top Plate that was used in our new product.

After reviewing the part we determined that we should investigate three alternative processes:

1. Machining

2. Sand Casting
3. Die Casting

Our objective was to understand the piece part cost and tooling cost for each alternative process so that we can make a data-driven decision to facilitate lowest cost design solution. We decided to first cost estimate the machining option using the BDI DFM Concurrent Costing Software. Below I will outline a step-by-step approach of how we completed a DFM cost analysis of the Top Plate.

Step 1.0 Obtain Pro-E Model & Load into DFM Software

We obtained the model for the Top Plate and then imported it into the newly created DFM file. By doing this, we essentially allowed the DFM software to obtain the overall part envelop dimensions which is needed to determine the raw work piece cost. An alternative approach would be to manually input the parts envelope dimensions into the DFM Software. The latter approach is often used in early concept design where the model has not been created.

Step 2.0 Select Process and Material

Upon providing the DFM Software with part envelope shape, we proceeded to select the process and materials needed. We choose Machining as the process and Aluminum 6061 for the material. While the DFM software does have a wide variety of materials, it is scalable and allows for modification and addition. For example, I have modified some of the materials to match material used often by Brooks Automation Inc.

Step 3.0 Update Material Cost, Batch Size and Life Volume

We obtained material cost and batch size information from our internal supply chain management team and life volume information from our marketing group. In our situation the material cost was set to $2/lb, batch size to 100, and life volume to 2000. It is important to ensure that accurate data is entered into the DFM Software to help obtain the most accurate results.

Step 4.0 Select Machine Tool

We determined that we needed a vertical machining center to complete the machining steps necessary for this part. The vertical machine tool that best fits our needs was the Hass VMC-VF-OB. The DFM Software has many machine tools to choose from and its important to pick one that meets the needs on a given part. In addition, you could select machine tools that aligns with the machine tools that your suppliers use.

Step 5.0 Enter Machining Operations

Entering the machining operations is the second most time consuming step of the DFM cost estimating process. After reviewing the Top Plate we determined that we needed a

number of different machining steps including face milling, pocket end milling, peripheral end milling, drilling, center drilling and a number of other operations. We utilized the Library Operations list found in the software to choose the operations needed to complete the machining of this part.

Step 6.0 Enter Machining Operations Data

For each operation, data must be entered which is needed for the software to estimate the cost of each operation. For example, for a pocket end milling operation, information such as depth of pocket, length and width of pocket along with other information is needed.   We reviewed each of the operations and used the model to help us enter data needed for each operation. This step is the longest step in the DFM Cost estimating process but is well worth the effort as it provides the DFM software with accurate data which subsequently leads to accurate cost estimates.

Step 7.0 Generate Cost Report

Utilizing the Report Drop-Down menu within the DFM software we generated a standardized report to help understand the cost of machining. This report helped us to understand the breakdown of the piece part cost. In this case, the piece part cost, scaled by an X factor, is $119.3X of which $56.9X is material cost, $56.8X is processing cost, and $5.5X is set up cost. This information, acted upon correctly, helps to pin point cost drivers and opportunities for cost reduction. For example, if material costs are proportionally high, then alternative processes may be the solution to driving material cost down, likewise for processing cost. If set up costs are substantially high, then an effort should be made to reduce the number of setups needed during machining by changing the part design accordingly.

Upon completing the machining cost estimate, we followed the same 7 step process outlined above to obtain the Sand casting and Die casting estimates. To help us compare the alternative designs, we generated a Totals report from the DFM Software that gave a us a convenient side-by-side comparison chart similar to the chart shown in Chart 3.0 below.

Process	Life Volume	Material	Setup	Process	Piece Part	Tooling	Total	Initial Tooling
Machining	2000	$56.9X	$5.5X	$56.8X	$119.3X	$0	$119.3X	$0
Sand Casting	2000	$17.2X	$22.7X	$49.2X	$89.1X	$2.0X	$91.1X	$4080X
Die Casting	2000	$21.8X	$20.7X	$25.2X	$67.8X	$55.8X	$123.6X	$111,623.3X

Chart 3.0 Cost Comparison

It is evident that machining is not the best solution as it has the highest piece part cost of $119.3X, higher then both Sand casting ($89.1X) and Die casting ($67.8X).   It is also clear that while Die casting is the lowest piece part cost solution it is not the lowest total cost solution as the tooling cost ($111,623X) is significantly higher then the Sand

casting tooling cost ($4080X). From this data we decided to Sand Cast the Top Plate leading to a $30.2X piece part cost savings or a 25% cost savings.

In summary, we were able to utilize the DFM Concurrent Costing Software to make a data driven decision to choose Sand Casting to produce our Top Plate.   We were able to do this following the above seven step process. Our objective was to understand the piece part cost and tooling cost for each alternative process so that we can make a data-driven decision to select the lowest cost design solution. Utilizing the concepts of DFMA, along with using the DFM Concurrent Costing software, we have met our objectives.

Next DFMA Steps

We have followed the BDI 3-Phase DFMA Implementation[3] approach as shown in Figure 2.0 below:
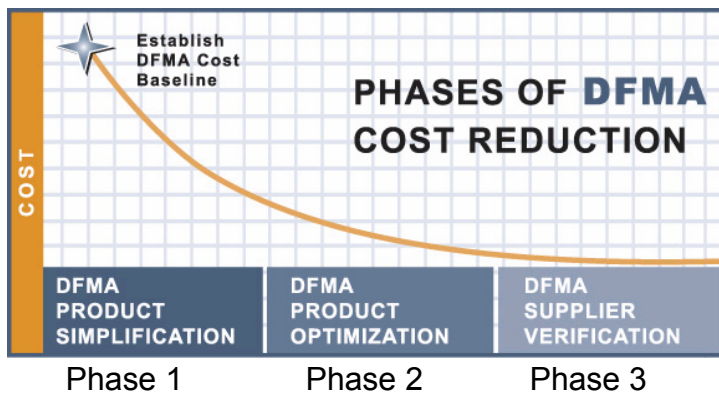

Figure 2.0 3-Phase DFMA Implementation

This graph above shows that there are essentially 3 phases of applying DFMA:
1. DFMA product simplification-which entails part count reduction focus and other product simplification techniques.
2. DFMA product optimization-which entails selecting the optimal processes and materials to achieve lowest cost.
3. DFMA supplier verification-which entails working with the supply chain to further reduced part cost and to validate supplier quotes.

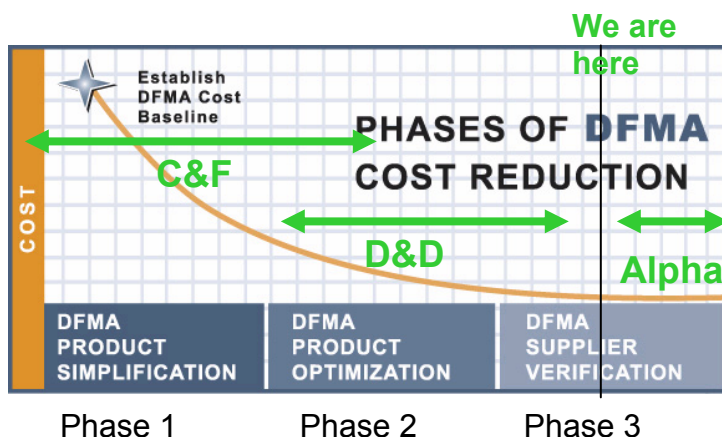Figure 3.0 below shows where we are in this 3-Phase DFMA implementation approach.

Figure 3.0 Brooks DFMA 3-Phase Implementation Progress

As shown, we have completed phase 1 and 2 during the Concept and Feasibility and Design and Development phase of our product design. We have completed 50% of phase 3 because we have performed DFM cost estimates on all of our "A item" high dollar parts but have not compared the DFM cost estimates with the supplier quotes which is the next step. Its important to note that we outsourced part of the DFMA cost estimating work load to reputable DFMA consultants. We found this approach to be extremely successful in helping us complete our DFM cost estimates in a timely fashion at the lowest cost and highest quality. In order to do this it is recommended that you have someone within your company who thoroughly understands the DFM cost estimating process. In our case, I was that internal DFM cost estimating expert and could utilize my knowledge to help guide the DFMA consultants to success. In addition, I would also complete DFM cost estimates so to minimize outsourcing costs.

Figure 4.0 below shows a flow chart of the process that we will follow to complete phase 3.
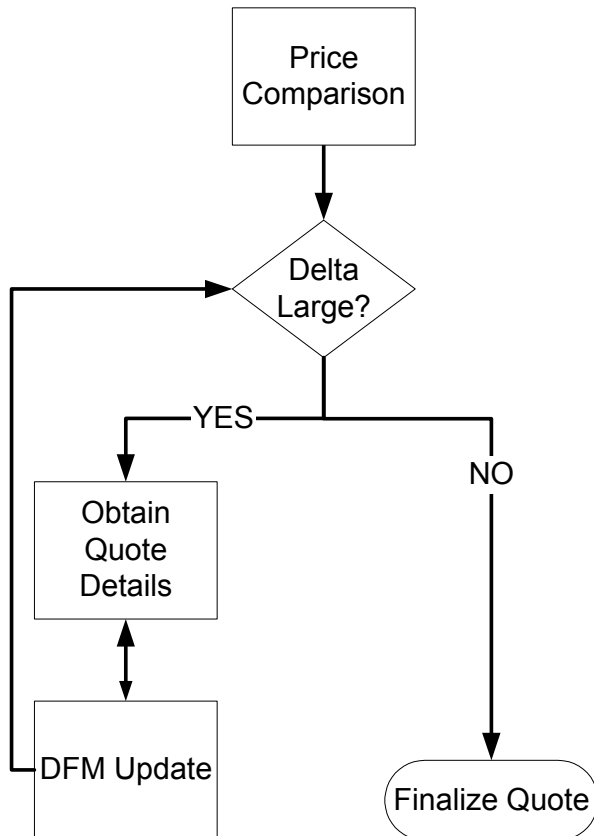
Figure 4.0 DFMA 3-Phase Flowchart

To summarize, we are going to compare the DFM estimates to the supplier quotes. If the delta is large, then we will obtain further quote details, such as material cost, operator rate, etc to help us understand the delta.   As we obtain this information we will begin working with each supplier to obtain a fair and accurate quote. The objective is not to hammer the supplier to get the lowest quote.   We want to make sure that the supplier obtains a fair profit margin for each part supplied; however, we need to provide our customers with lower cost products. Achieving both simultaneously would lead to a win-win relationship with our suppliers. In order to do this it will take a collaborative effort with our suppliers to help reduce their cost which would help to reduce Brooks cost while maintaining a fair profit margin for our suppliers.

Conclusion

We have shown the process of how Brooks Automation has successfully implemented DFMA. We have outlined some of the key factors that led to early DFMA failure. We have also outlined some of the key factors that led to successful implementation, namely, 1) DFMA training, 2) strong upper management support, 3) cross-functional team development, 4) dedicated DFMA manager, 5) DFMA Story Board, and 6) the creation of the "War" room. We have shown that through the application of DFMA on our new product we were able to reduce total cost by 35-50%. We also have shown a few examples of how we applied the DFMA concept and software to help to reduce product cost. Lastly, we explained how we are using the BDI 3-Phase DFMA implementation process and what we needed to do to successfully complete phase 3. It is hoped that this case study will help others to understand how to successfully implement DFMA so to realize the significant product cost savings. The author can be reached at Marcello.Trolio@brooks.com for questions and assistance.

Notes:

1) "Product Design for Manufacture and Assembly", Geoffrey Boothroyd, Peter Dewhurst, Winston Knight. Second edition. Marcel Dekker, 2002.
2) See http://www.dfma.com/software/index.html
3) See http://www.dfma.com/dfma.htm