Design for Manufacturing - what is it and how does it fit with Design for Function, Design for Assembly and Design for Cost?

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Why does anyone care about Design for Manufacturing (DFM), Design for Function (DFF), Design for Cost (DFC) and Design for Assembly (DFM)? The answer is simple – we want to make money. To make money we establish exquisite product development processes, hire expensive engineers and develop products using "design for this" and "design for that". Then we throw our designs over the wall so that manufacturing/operations teams can "make it to the print". Next we kid ourselves that product development creates cash and delivers value to the bottom line. In reality our product development processes do not create any cash or deliver any value. We don't sell our designs; we don't sell our drawings; we don't sell our tests; we don't sell our analyses. Our operational value streams – the collection of processes that start with raw material and end with delivery of product to the customer – create the products that our customers buy. It is the purchase of the products that delivers cash to the bottom line. In short, the true customers of our product development processes are the operational value streams (aka, manufacturing) that convert raw materials into products.[1]

Mike, why did you start the introduction with the design stuff and end it with the heretical statement that operational value streams are the only things that deliver cash to the bottom line? I did that to drive home the importance of manufacturing and assembly considerations during the product development process. It is in manufacturing and assembly where a majority of costs are realized. Also I did it to make clear that "design" is broader than just creating product functionality; "design" includes creating efficient operational value streams. Design covers three spaces - functional, physical, and process.[2] The functional space defines what the product does; the process space defines how to make the product; the physical space, which sits between the other two, defines what the product looks like. The information in the physical space is best thought of as the information found on an engineering drawing – size, shape, and material properties. Figure 1 is shows the three spaces.

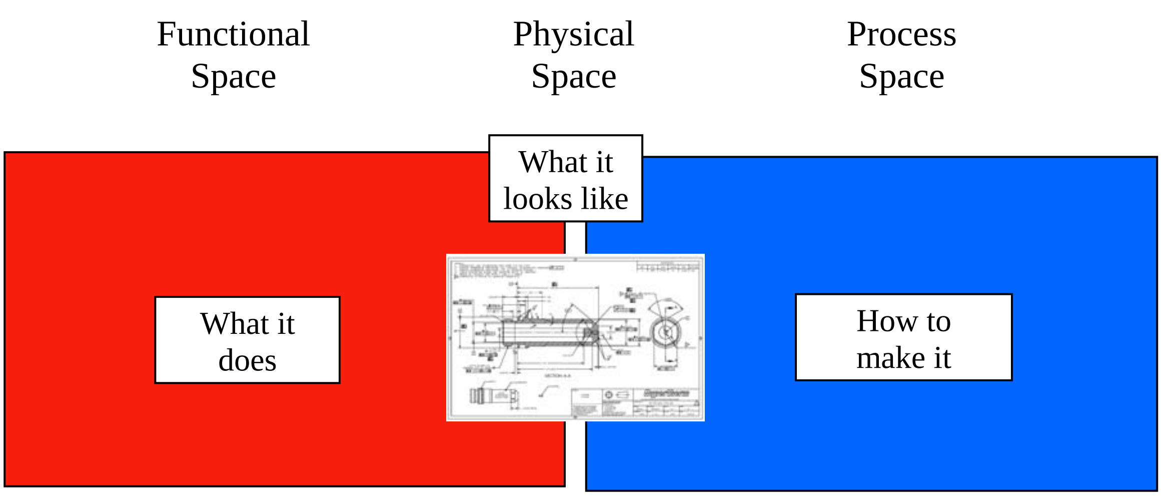

Figure 1. Three spaces of design.

Design for Manufacturing versus Design for Assembly

Mike, you said in the title that this paper was supposed to be about DFM, so are you almost ready to talk about that? Yes I am. DFM and DFA are all about designing for the process space (see Figure 1) or the "how to make it" space. The engineering drawing defines what the operational value steams must create and operational value streams turn raw materials into product. Now let's differentiate between DFM and DFA. Manufacturing is all about creating parts. The parts must have surfaces located in the right places (part tolerances); the parts' surfaces must have the right form (e.g., straightness); the surfaces must have the right character (e.g., average roughness, Ra); and the parts must have the right material properties. Some important manufacturing processes include machining, casting and injection molding. Assembly is all about putting things together. Two important "putting together" mechanisms are fasteners and snap fits. With that, here are working definitions for DFM and DFA:

> Working Definition 1. Design for Manufacturing is methodology to change a design to reduce the cost of making parts while retaining product function.
>
> Working Definition 2. Design for Assembly is a methodology to change a design to reduce the cost of putting things together while retaining product function.

It is important to note that the working definitions include reducing cost, retaining function and changing the design. Three important rules can be created based on the working definitions.

> Rule 1. Design for Function first - establish functionality first and hold onto it while you do DFA and DFM.
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> Rule 2. Product cost and product functionality must be considered together or you are not doing DFA or DFM.
>
> Rule 3. The design must change or you are not doing DFA or DFM.
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> Comment on rule 3 - The "D" in DFA and DFM stands for DESIGN, so design engineers are the ones that do DFA and DFM. Therefore, manufacturing engineers, even those advanced ones, do not do DFA or DFM and a DFA/DFM effort lead by manufacturing is usually a euphemism for a campaign to put your suppliers out of business by taking their margins.

There is a fourth rule, but does not come from the previous Working Definitions - it comes from greed and experience.

> Rule 4. Do DFA before DFM because that's where the money is.
>
> Comment on rule 4 – Though there is more benefit from eliminating a part with DFA than reducing part cost with DFM, everyone wants to do DFM before DFA. The reason is simple. There is a desire to reduce costs without changing the design. No one wants to change the design because changing the design is hard work and, since we don't know what features control function, it's scary. In reality since the design does not change (violation of rule 3), the so-called DFM activities are not DFM activities at all. They are either lean activities or activities to wring margin out of the supplier under the banner of DFM.

Design for Function – the Backplane
Now that DFA and DFM have been defined and differentiated it is time to focus on DFM and how it fits with Design for Function (DFF) and Design for Cost (DFC). From Rule 1 it follows that DFF is the first consideration, and this is what happens in practice. Design engineers first establish functionality – they investigate the broad design space and narrow the space down to concepts that may meet functional requirements but are yet unproven. The design concepts are then wrung out and those that don't meet functional requirements are discarded - resulting in a further narrowing of the design space. Last, secondary considerations - cost, DFA, DFM - are used to further narrow the concepts to those that are cost effective yet still function. Design for Function (DFF) is considered at all times during the design process.

Features That Control Function – the Key to DFM
How do you verify that the design engineering team has done Design for Function (DFF)? First, ask the engineers for the list of features that control function. If they manage to have the list, ask to see the test results that show that the features matter. If they make that hurdle, ask them if the test results are statistically significant. If they manage to say t-test or F-test give them credit. Next, ask them for the graph of product function over a range feature values. Then, ask them to see the test results showing product function drop to **unacceptable levels** as value of the features were investigated. Finally, finish them off by requesting to "show me how you used the data to set the tolerances".

The features that control function must be explicitly called out on the engineering drawing. Putting the features on the drawing communicates what is important to manufacturing/operations. The important features usually require special process controls and process capabilities which require significant time and attention from the manufacturing experts. Engineers usually argue that all features are important and all should get the same level of process controls and capabilities. In truth, their own test results show that not all features are created equal and the features that control function deserve more attention.

Paradoxically, Design for Function (DFF), expressed in the form of features that control function, is the key to Design for Manufacturing (DFM). A strong knowledge of what controls function lets the team "lock down" features of the design responsible for function and "open up" more features for manufacturing changes that can reduce manufacturing costs. More design for manufacturing changes (and more profits) are possible when the universe of changeable features is expanded.

Features That Create Cost – Prioritization of DFM Opportunities
Just as the design engineers must create a list of important features, the manufacturing engineers must create their own list of important features - features that create cost. The manufacturing engineers usually have a good handle on the features that create cost. These are the features that create long cycle times; features that require bigger, more complicated, more expensive machines; features that drive defects, rework and sorting; features that require significant amounts of labor.

Features that create the most cost are the features, that when changed, generate the most savings. These features can be used to prioritize the DFM efforts. However, the priority must tempered by the degree of difficulty to realize the savings. There is no need to set up a complicated ranking mechanism for the DFM efforts. The manufacturing engineers define the changes that save the most money and are easiest to implement. The design engineers define the degree of change that can be made while maintaining product functionality.

Design for Cost – Bringing Both Sides Together
Traditionally, Design for Cost (DFC) has been limited to the manufacturing costs or the conversion costs, which are the costs to convert raw materials into products. For example the DFA and DFM

communities talk about costs as labor, material and overhead. I see DFC more broadly. Following is a working definition that captures the broader view of DFC.

> Working Definition 3. Design for Cost (DFC) is the balancing of the cost of creating function (Design for Function) and the cost of converting raw materials into product (DFM/DFA).

From Working Definition 3, there are two sides of DFC that must be balanced. The first side is DFF, where the design engineers add cost to the design to create functionality, define the features that control function, and put those features on the engineering drawing. The second side is DFA/DFM, where the manufacturing engineers define the features that create cost, communicate those features to the design engineers and both groups work together to remove conversion/manufacturing cost from the design. (see figure 2) I'll finish with a Working Definition for the best design.

> Working Definition 4. The best design is the one that requires the minimum cost to create functionality and the minimum cost to convert raw materials into product.

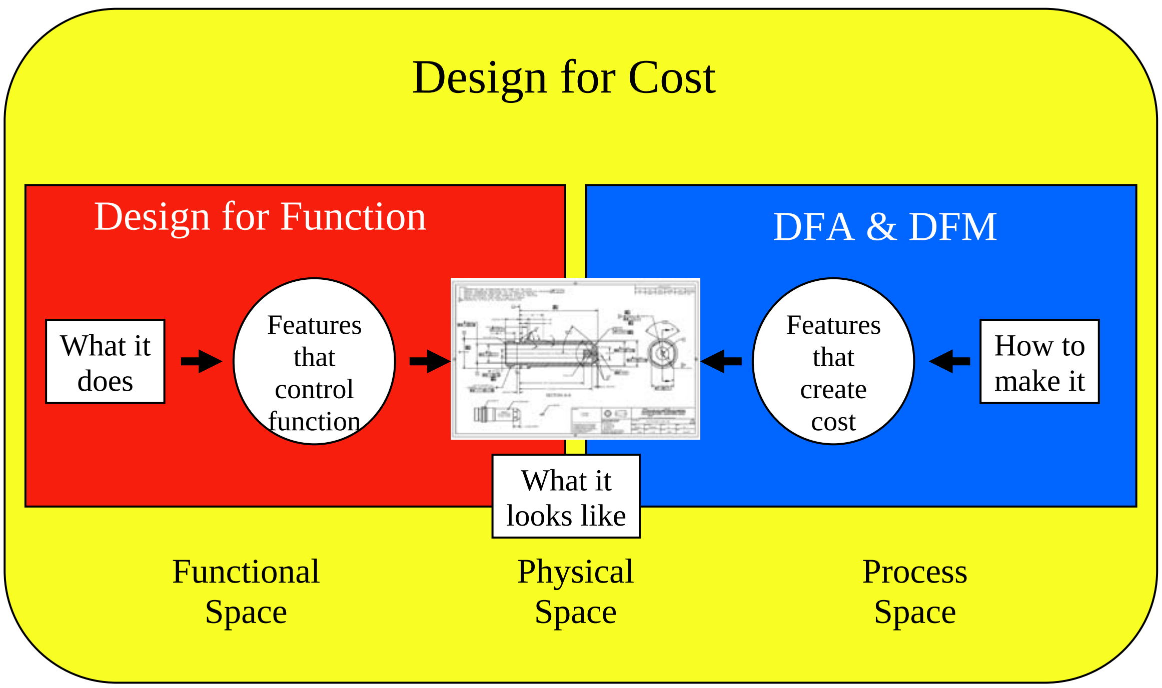

Figure 2. Design for Cost. The two sides of DFC must be balanced – DFF which adds cost to create functionality and DFA/DFM which removes cost to convert raw material into product.

Decrease the Overlap between Features That Control Function and Features That Create Cost

Paradoxically, understanding features that control function, defined during Design for Function (DFF), is the key to successful Design for Manufacturing (DFM). A poor understanding of features that control function is the culprit that creates fear around changing the design and limits the success of a DFM program. Since we don't know what is important in the design, we decree that **EVERYTHING** is important and, ultimately, we change **NOTHING** about the design. We change nothing because our lack of knowledge creates total **overlap** between the features that create cost and features that control function. The set of features that control function become the **superset** which contains the **subset** of features that create cost.

The overlap between the two feature sets (cost and function) is problematic because it gets in the way of our efforts to make money. We are blocked from saving money (by changing features that create cost) because we are afraid we may unknowingly change a feature that controls function. The risk of mistakenly changing product function outweighs the potential cost reduction. We must reduce the risk of changing product function by improving our understanding of the features that control function and narrow the set down to the features that **actually** control function. With this narrowing, the overlap between the two feature sets is reduced and we have a larger pool of changeable features to help realize our cost reductions. Figure 3 illustrates how the overlap between the two feature sets decreases as our knowledge increases of features that control function.

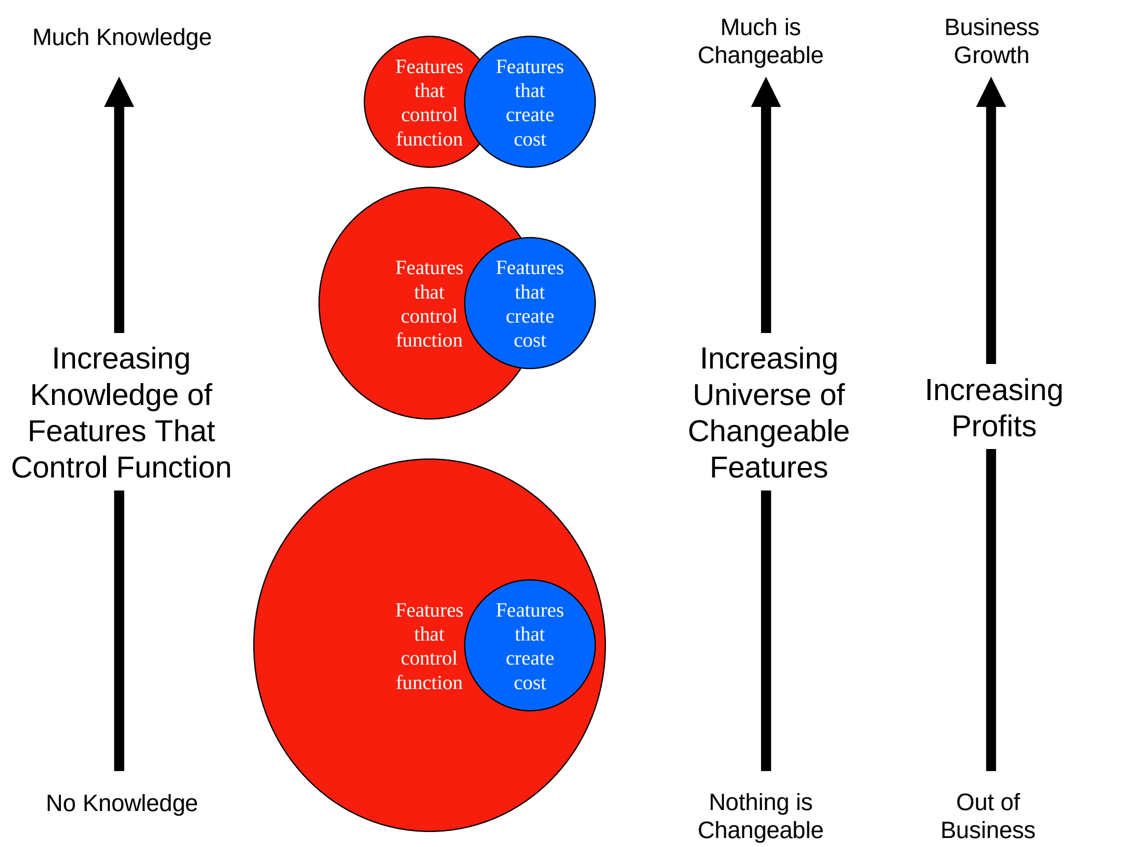

Figure 3. Overlap between the two feature sets (cost and function) is reduced as the knowledge increases of features that control function.

Pulling it All Together

In order to create products with low cost content product designers must be held responsible for costs created in the operational value streams. (see Figures 1,2) To realize products with the lowest cost content the Design for Function (DFF) phase must identify features that create function and put them on the engineering drawings. With that, manufacturing/operations teams can change features to reduce costs with less risk of changing product function.

References

1. Ward, Allen, C., Lean Product and Process Development, The Lean Enterprise Institute, Cambridge, MA, 2007.
2. Suh, Nam, P., The Principles of Design, Oxford University Press, 1990.