Writing an article on a topic as broad and complex as designing for productivity can be challenging because it implies that you can say something that is meaningful and useful, and do it within the confines of a short article. But industry is starting to do some exciting new things that I believe will lead to more productive designs.

First, let me define the context of this article by expanding on the title. I consider product performance and quality to be "givens," so I won't discuss them. I consider simplicity the most significant attribute of a successful design. By simple, I mean fewer parts, parts that perform multiple functions, parts that are easier to assemble by people or machines, and parts that can be made with simple processes. By productivity, I mean approaches to designing products right the first time, with a shorter development cycle, and fewer product related transactions being accomplished. Others, of course, will have different views on the subject, but on something this broad in scope I think you should bound the breadth of discussion.

Simplicity

A nice word that everyone will defend but few will attempt to quantify is "simplicity." What is it? If you can answer the question, you can probably achieve it. Engineers are intrigued by complexity. Industry, however, needs to adopt the Honda slogan, "We make it simple." Different people have their own thoughts on how to achieve simplicity. I think the best way is for operating management to set quantified design goals at the beginning of a development project.

You have probably heard the expression, "If you don't know where you're going, any road will get you there." Consider it in terms of a product design. How do you know if a proposed design meets your objectives if you don't have relevant objectives? Most companies set goals that relate to functionality, reliability, and maintainability, and these are all necessary and good.

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But there are others that need to be quantified. How about parts count design efficiency? Assemblability? Sheet metal parts formability? Plastic parts producibility? Parts joining efficiency? Printed circuit board producibility? We are a numbers-oriented society. As such, we tend to react more to a specific quantified goal than some subjective, undefined parameter for which everyone has a different interpretation. How often have you heard someone say, "On a scale of 1-10 it's a ___." The problem is really in deciding what is important about an aspect of design and expressing various attributes in a way that can be quantified.

Most of the techniques mentioned above have been developed at GE and perhaps other companies, and are being successfully used to achieve the elusive goal of simplicity. It's not that hard to do when management decides to allocate the necessary resources to do it. I'll discuss the implementation approach that we use later.

Productivity

Productivity has to look beyond direct costs that determine only a small part of total product cost. For example, it's not unusual for direct labor to be 10 percent or less of a product's cost, yet many companies continue to concentrate on eliminating direct labor. I think it is more productive to go after the indirect costs. Again, you run into the problem of not being able to quantify indirect costs, so we often lump them all together as the "cost of doing business" and never realize that most of them are caused by the product design and its complexity.

At GE, we feel that a major driver of overhead cost is the number of transactions required to design and build a product. By transactions we mean each time material or data is gathered, procured, entered, recorded, sent somewhere, stored, inspected, moved, etc.

What drives transactions? There are many culprits. Some are the complexity of a design, the number of process steps to fabricate and assemble the product, vendor interactions, and failure to do a job right the first time.

Let me give you an example. One of our GE businesses offered incentives to draftsmen if they could eliminate active part numbers in the system. Within two months they
were able to eliminate over 1000 part numbers, which translated into a reduction of 39,000 annual shop releases and resulted in 125,000 fewer pieces being ordered, fabricated, stacked, and inventoried. That's productivity!

Another project focused on reducing engineering changes to correct errors. In two years, they reduced 12,500 changes per year to 7400. Still too many, but the trend is positive. Many people have trouble with the "error free" concept because they don't think that error free work is possible. They miss the point, which is to aim at improved productivity by working smarter, not harder. It's a direction, not an absolute. Managers need to provide the tools and techniques which will drive leadtime and errors down. It is a case where top-down actions are required, not bottom-up.

**Cycle Time: Save A Lot By Spending A Little**

I mentioned development cycle time as a key measure of productivity. I'm an advocate of the idea that long product development leadtime equates to higher program costs. It follows that any changes made to increase design productivity should result in a reduced leadtime. If not, the change is most likely going to be ineffective. In planning design, you should allow for design iteration since simplicity only comes from iteration. Does design iteration add to overall cycle time? I don't think it does, because of the positive effects it will have downstream. Sometimes you have to spend a little to save a lot.

A major Japanese company stresses what they call "The Six Horrors" in emphasizing the need for productivity to its employees. The six horrors are: 1) making too many parts, 2) making too few parts, 3) making non-conforming parts, 4) human movement, 5) parts storage, and 6) parts movement. The existence of any of these conditions leads to lower productivity and should be eliminated or minimized. There is a common solution to combating these horrors: design simplicity and process simplicity. You'll never make too many of a part that you eliminate in the design process, and you won't have to move it in and out of storage.

Management has two primary responsibilities in this design for productivity improvement process: 1) setting meaningful goals, and 2) providing the tools and techniques needed by the people to meet these goals. In setting goals, a manager should take care to not just set them and forget them, but to always aim for improvement, improvement that causes all of us to stretch a little. That's where quantifying goals come in again. How can you set a stretch goal without being able to quantify parameters?

Think of your own business. Are you happy with development leadtime? Do you know when you have a good design? ... Are your designs simplified? How do you know? Is your processing fabrication operation simplified? Do engineering and manufacturing work together toward common goals? Are you satisfied with the quality of your products?

**Meeting Requirements**

Phillip Crosby defines quality in his book *Quality is Free* as conformance to requirements. It's an interesting concept and can be used to compare the relative quality of similar function, but not differently priced products; that is, a lead pencil versus a mechanical pencil, or a $50,000 imported car versus an $8000 domestic economy model. Similar functions but different requirements are involved. How well the design and manufacturing team meets the design requirements is a measure of the quality of each product.

The concept of quality being measured by conformance to requirements is relevant to this discussion of designing for productivity. How well are the design require-

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**Some best practices are general:**

- Appearance surfaces are identified
- Edges exposed to the user are identified
- Others relate to drafting practices:
  - Dimension tolerance includes material thickness variation
The inside formed radius of extruded holes does not exceed __ (computed value based on material thickness)

Minimum spacing between adjacent tab sides = 0.200-in.

Some practices refer to part handling, that is, pilot holes, handling holes, etc., and some practices are written to minimize tool cost and breakage.

By assigning a numerical penalty to each of the practices based on the effect it has on producibility, a part score can easily be determined. Repetitive use of the assessment program has a subtle training and education benefit as well.

**Design For Assembly**

I'd like to discuss one of these techniques, *Design for Assembly* (DFA), and how we have trained engineers in its use over the last four years.

DFA is a subject that has gotten a lot of attention in the last few years, starting with the work done by Professor Geoffrey Boothroyd when he was at the University of Massachusetts and then work done by Hitachi, Toshiba, Xerox, IBM, GE, and others. The techniques all differ but are based on the same principles. The preferred design features include: straight line insertion, self-registering parts, minimal fixturing, simplified joining, and layered assembly. Each technique uses different scoring systems but they have one common objective: to provide a quantitative evaluation of a product's assemblability before it is released to production.

One of the reasons that DFA has been successful is that to use it properly, you must have multifunctional participation. Otherwise you may not give sufficient consideration to all aspects of a design.

There are aspects of a design to which product design engineering may not always give their greatest attention. They may even say, "It's manufacturing's job." If there is one thing we have learned the hard way, producibility is not just manufacturing's job, but the responsibility of management—best accomplished by a joint engineering/manufacturing team working together while a product is being developed. Providing management with what we call "Producibility Indicators" is one of the most important parts of the process.

So what is DFA? It's a means of evaluating a product against standard criteria and quantifying the results in an assemblability score, an estimate of the time to assemble a product in a given factory, and a comparison against one or more alternative designs. If we have all the facts about competing designs, we feel that we can usually make the right decision. It's when the facts are not available that we can get into trouble.

Using the DFA techniques we have developed, we evaluate each part in a product design for:

- Part insertion motions
- Fixturing needs
- Joining operations
- Part forming during assembly

We use these criteria to develop a product score which is indicative of how easy or hard the design will go together on the factory floor.

Once you evaluate a design and determine its weaknesses, you've solved half the problem. Knowing a design's potential problems and having some clear objectives regarding product assembly enables our design teams to modify a design to make it not only easier to assemble, but of higher quality and value to our customers. Let's discuss these benefits a little further.

**DFA Benefits**

The benefits that result from DFA include some that are obvious and some that are subtle. The obvious benefits are simpler designs containing fewer parts: designs that can be assembled with less operator skill, and with less chance of error. The less obvious benefits are higher product quality and reliability, a direct result of simpler designs.

Maybe the most important benefit is the improved working relationship between engineering and manufacturing, and the ability of management to better manage this element of product development. Studies have shown that 60–80 percent of costs are fixed at the design stage. That is a good reason for "Doing it right the first time."

To date we have identified several million dollars in potential cost savings throughout General Electric. The average reduction in parts is about one third, and the average reduction in assembly labor is 44 percent. In addition we save the expense of fabricating parts that are eliminated. The real benefit is in productivity and quality.

I'd like to mention a few applications. Our jet engine business in Evendale, OH, was able to reduce parts count by 35 percent in an engine gear box. Think of the benefit this can mean to a flight component's reliability and quality.

Our Naval Ordnance Division in Pittsfield, MA, reduced parts count by 70 percent in a power supply. It involved using printed wiring board technology not to that business, so that DFA actually led them to seek a better solution.

Our Major Appliance Business Group (MABG) in Louisville has been one of the most aggressive users of DFA in GE. They have used it on more than 100 different designs since 1981. It's built into their development cycles, and the results are reported. MABG also uses DFA in competitive evaluations to keep up with competitors' advances in this field. A recent major appliance design was reduced in total parts from 622 to 478, a reduction of more than 22 percent, and that's on a mature product that had been through many cost improvements over the years.

Think of what a 30 percent or 40 percent reduction in parts count could mean to your business. The direct cost of making the product, and the indirect cost of procuring, handling, storing, inspection, etc., of these extra parts would be affected.
Parts Count Reduction

We have an expression, “Design drives product cost, and parts count drives design, so the road to product cost reduction is achieved through parts count reduction.” It implies that any new design or redesign should be reviewed for opportunities to reduce parts count. The techniques for achieving it are relatively simple and easily taught.

First, we identify difficult-to-assemble parts and attempt to eliminate them or combine their function with another part. Then we use a brainstorming technique that asks three questions of each part with respect to its mating part:

1. Is there relative movement?
2. Does the part require a different material?
3. Does the part have to be removed for service?

If the answer to all three questions is no, then we consider the part a candidate for elimination. We may not know how to eliminate it, but we flag it for consideration. You’d be surprised at how effective this simple technique can be.

Another approach we recommend is to design every product for automatic assembly, regardless of volume. Whether you actually use automation is irrelevant. The result is a simpler design that’s easier for people to put together. In fact, we originally called the techniques Design for Automation. When we discovered that if you do the job right you may not need automated equipment, we changed the name. Some people refer to it as Design for Manufacturability. I don’t care what it’s called as long as it’s used.

DFA has been shown to have equal application to high and low volume businesses. We use it on jet engines, washing machines, and low volume aerospace equipment. All want designs that assemble reliably with little opportunity for operator error in order to minimize cost while maximizing product quality as seen by the customer.

One objection we hear quite frequently is “It will take too long to evaluate and improve each product. I can’t afford the time.” The only answer to that is to consider short-term costs against long-term benefits. Problems generated in the design stage have a way of lasting for the entire product life. If you want to make real improvements, do it in the design stage when you can change a drawing, instead of modifying tooling later.

DFA potential benefits are sometimes what I call a “Good News, Bad News” situation. The good news is that we can identify improvements that make a design more competitive. The bad news is that when we identify improvements on an existing design, we can’t always make the changes because of tooling costs, scheduling interruptions, etc. What can be more frustrating to a business manager?

Clearly the way to avoid this problem is to use DFA as a development tool when you plan to make a change in design or facilities. It’s when changes of the type DFA offers are more likely to be acceptable and easily implemented.

Working Smarter

Let’s talk about obsolescence and the effect it can have on your business. Ten or 20 years ago, you probably didn’t care much about the elegance of a design. You could sell what you produced without much difficulty. But times have changed, markets have changed, and your customers have changed. You have to work smarter. Not harder, but smarter. DFA, a relatively new design technique, has been mentioned frequently in the trade journals the last few years. It’s a tool that can help your development team work smarter and produce a better product design. It can help avoid obsolescence of your development team by introducing new thinking and perhaps changing the team’s perspective on design.

We have concluded that we can’t afford not to use DFA—the long-term penalties are too serious in today’s competitive world. Otherwise we will be carrying the extra parts for as long as we make the product. That adds up to a lot of dollars.

Let me close by quoting from Lord Kelvin. What he said 100 years ago is still true today:

“Unless you can quantify your knowledge of a subject, your knowledge is meagre and unsatisfactory.”

I know that a short article can’t do justice to this subject but I hope that I have shed a little light on the road to “Designing for Productivity.”

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