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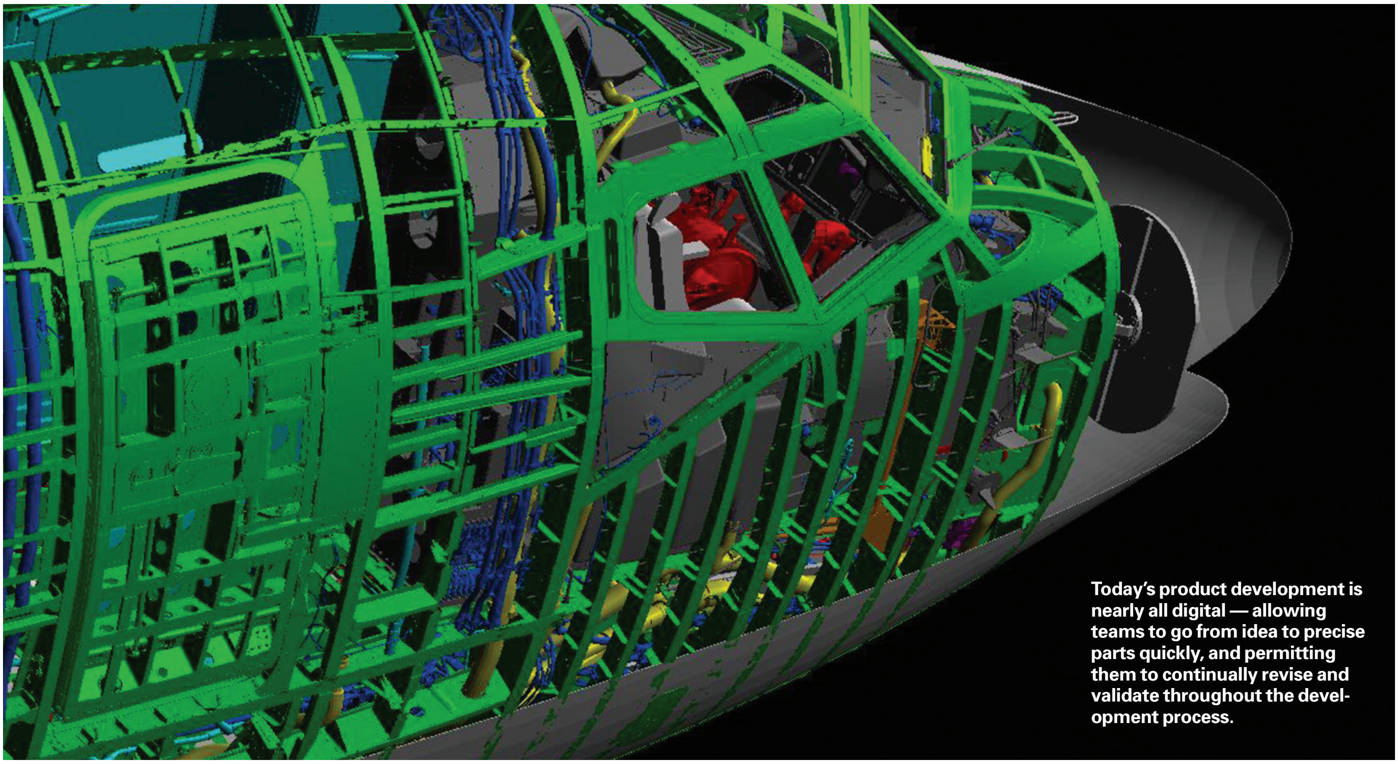


Today's product development is nearly all digital — allowing teams to go from idea to precise parts quickly, and permitting them to continually revise and validate throughout the development process.

The Problem With Digital Design

Yes, digital design is a wonderful tool. But unless it is supported with strong management processes, there can be unintended — and negative — consequences.

BY TUCKER MARION, SEBASTIAN FIXSON AND MARC H. MEYER

THE LEADING QUESTION

What potential downsides does digital design introduce into product development?

FINDINGS

- **Digital design tools can make the work appear complete before it actually is, creating problems down the line.**
- **Because the tools are simple to use, they can promote endless tinkering, delaying production.**
- **Strong managers — and well-defined management processes — are needed to guard against both potential problems.**

THE WIDESPREAD ADOPTION of digital design shows that it makes a powerful contribution to R&D effectiveness and efficiency. Design tools can be invaluable in visualizing ideas, quickly developing a detailed design and conducting fast iterations. On the surface, these are all good things. Yet our research suggests that digital design is not a panacea. Unless it is complemented with sound management practices, unforeseen problems will be introduced into the product development process.

Some background will help explain why. It is well known that since the 1980s, the new product development process has evolved from traditional engineering teams working together in one place to an approach that is more global and virtual.[1] One major factor that has enabled this transition has been the proliferation of digital design tools such as highly capable computer aided design packages (such as Parametric Technology Corp.'s PTC Creo Elements/Pro (formerly Pro/ENGINEER), Dassault Systèmes' CATIA and SolidWorks), rapid prototyping technologies (such as 3D printers), and collaboration tools (such as Microsoft SharePoint, Google Docs and project wikis).

COURTESY OF BOEING

A second factor leading to increased use? Lower prices. Today, capable CAD packages can cost as little as a few hundred dollars and can run efficiently on desktop or laptop computers costing a fraction of those required just five years ago.

One of the most widely studied payoffs of digital design was the Boeing 777, which was designed, modeled and tested virtually by an extended development team.[2] The benefits of this approach included identifying part interference and fit issues before expensive physical prototyping and having different members of the organization (customers, manufacturing representatives, vendors, service and maintenance individuals, etc.) view and participate simultaneously in the design process.

Since the time of the 777, the use of information technologies and services has accelerated thanks to the proliferation of tools and IT solutions to support digital design through the entire new product development spectrum. Systems for 3D printing (from companies such as Z Corp.) allow designers to quickly produce prototype parts directly from CAD files, permitting the physical validation of engineered designs in a matter of hours. Power analysis tools, often integrated into CAD systems, allow virtual testing before any physical prototypes and preliminary manufactured parts are produced. From airflow within a jet engine (fluid dynamics simulation) to strength and fatigue testing on a vehicle chassis (finite element analysis), these tools offer the potential to reduce cost and improve design iteration efficiency.[3] And process management tools, such as product life cycle management and requirements management, have proliferated to dimensionalize costs, part reuse and customer needs. Moreover, engineers can vet concepts with colleagues around the globe through virtual collaboration technologies that are now commonplace and, increasingly, free. In sum, today's product development is nearly all digital — allowing teams to go from idea to precise parts quickly and permitting them to continually revise and validate throughout the development process. (See "The Evolution of Digital Design Tool Use.")

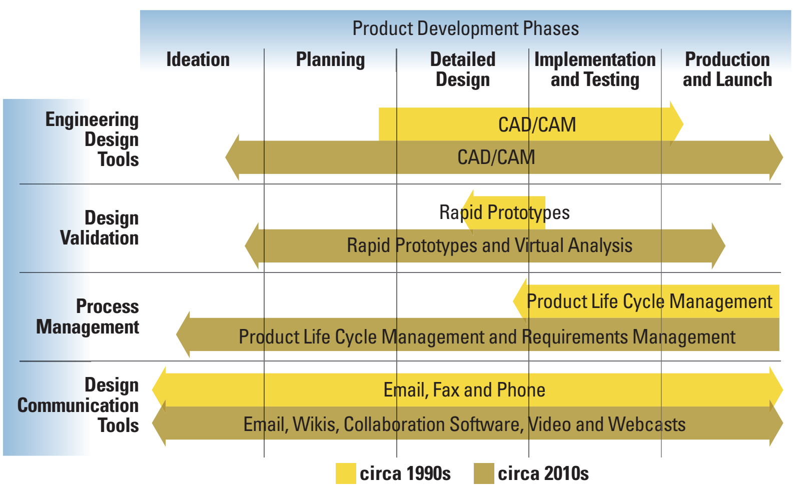
So, what's the problem? There are potentially two. First, because the technology makes the work look complete at every step in the process, it can create a false sense of security. There can be a tendency to move on to the next stage in the process before teams have taken the time to deeply learn user needs, construct alternative solutions and vet both of these. In other words, the "fuzzy front end" of the design process may be cut short — to the company's long-term disadvantage. This is, we believe, one of the major reasons product failure and success rates have changed little over the past several decades.[4]

Second, the very ease with which designs can be digitally drafted and prototyped might afford engineers the opportunity to "try it again and then, again and again." In other words, the final design process can remain fluid longer than is useful. The ability to quickly iterate designs can lead to a spiraling effect, chewing up time and labor expense and effectively mitigating the benefits of digital design itself. Research has shown that these "virtual design rounds" can account for 75% of total project development costs,[5] and they can delay project completion. For example, Airbus suffered severe delays in the development of its new A380 due to issues with CAD revisions.[6]

The net takeaway from this: While we are favorably inclined to the generally positive impact of digital design — who today would argue against the use of computers for any aspect of commerce? — we wanted to more deeply understand these two possible unwanted effects and how to best mitigate them. To accomplish this, we embarked on a longitudinal study of the product development activities of 145

THE EVOLUTION OF DIGITAL DESIGN TOOL USE

There has been a proliferation of tools and IT solutions to support digital design through the entire new product development spectrum.



firms that are heavy users of digital design technology. Given that a majority of engineering time is spent in front of a computer revising CAD models, we focused our lens on the engineering bullpen. We surveyed and interviewed engineers and managers to understand how digital design work is performed. (See "About the Research.") Here's what we learned.

A Rush to "Final" Design

Modern digital tools allow fast iterations of design features and dimensions, once the engineer constructs a virtual model. This ability creates a strong pull for product development teams to jump to building digital design models right at the start of the project. Because digital design applications are inherently precise, the "fuzziness" of wide-open concept exploration can be avoided for what seems to be a highly evolved design that is then prematurely moved downstream. That, we found, can lead the R&D team to shortchange valuable activities such as extensive user research, intensive parallel concept development, and deeper systems and architecture design as part of the front end of development.

Thomas Allen found decades ago that teams pursuing a number of parallel concept developments at the front end of design most often proved to be the winners over similar projects where teams finalized a design early in the process.[7] This supports the common sense understanding that rushed decisions are often not the best. In the case of engineering design, a rushed decision can ultimately lead to more work downstream in the process as other engineers are forced to improve things. We call this effect *back-loading*, where digital design tools are used to revise and rework design problems that should have been resolved early in the process.

The obvious point is that a fast rendering is not a complete product design. Digital design allows engineers to produce realistic-looking concepts and prototypes quickly and much earlier in the process than ever before. While these designs look finalized, they are not. A beautifully sculpted and realistic exterior shell may not contain the inner structure and supports essential to a finished product. As one engineer at an aerospace firm explained, "Management looks at the early designs and thinks it's done. However, there is a lot more engineering to be done on these early models."

ABOUT THE RESEARCH

This longitudinal study was undertaken from 2008 to 2011. The research was divided into two segments: an empirical study and an in-depth multiple case investigation. The empirical segment used an Internet-based survey tool. To ensure proper longitudinal research design, a framework of the impact of digital design on the innovation process was developed and vetted by academic and industrial collaborators. The instrument was beta tested in 2009 and distributed via blind electronic mail in 2010. The instrument used a mixture of established and new variables and scales. Multiple control variables were used. Scale Cronbach alphas, multicollinearity levels, nonresponse bias, etc. all conform to academic standards.

The survey results were self-reported on intensity of tool and practice adoption via psychometric scales, qualitative and quantitative inputs. Outcomes measures included measures for R&D efficiency (resources used, time to market, etc.) and effectiveness (unit costs, performance to specification). Some 145 multinational companies that actively employ digital design participated in the empirical segment. When we refer to the most successful or best-performing companies, we mean those that fall in the top 25% of our survey.

The second research segment centered on in-depth interviews of survey participants. These companies were comprised of a cross section of industries, from aerospace to robotics. Multiple cases were used; interviews were conducted in person and recorded or transcribed. Quantitative and qualitative results were synthesized and formed the basis for this manuscript.

What is clear from all of this is that interactive product development should be *front-loaded* in the development cycle.[8] Certainly, front-loading has been standard operating procedure in R&D. Concept developers (engineers) would complete and test new designs, then send them to manufacturing engineers for completion and potentially for modifications through tightly controlled drawings and a well-defined change management system. Not only has digital design allowed concept engineers a false sense of completeness, but it has also enabled later-stage engineers to more easily tinker with designs to try to make things better. And that brings us to problem number two.

Enough Is Enough

Digital design has made projects fluid across the entire development process, which ideally is a positive. However, on-the-ground reality sheds a different light on the situation. In an ideal environment, this flexibility might lead to a higher rate of problem solving and therefore, better products. In reality, however, many of the managers in our study complained about, in effect, too many cooks spoiling the broth. As one executive told us, "CAD has been democratized. It's now a lot easier to use and share. The downside is: Everyone thinks they're an engineer."

In a poorly monitored process, the number of engineering changes to a specific design can increase dramatically. In fact, minor changes in one aspect of design can have strong ripple effects on other areas, potentially leading to an overall poorer final solution. Without a well-structured engineering process, the number of unnecessary iterations can mushroom simply because the technology makes changes so easy to perform. Chaos can ensue.

The data gathered from the companies in our study confirmed this problem. A large number of engineering changes late in the process were associated with the poorest-performing R&D organizations. Moreover, the poorest-performing organizations were heavy digital design users, underscoring the second potential problem. Since it is so easy to make changes, people continue to do so late in the process. (Of course, it is possible that the changes were necessary because the company moved too quickly on the front end.)

On the other hand, the most successful companies were practitioners of systematic planning in the upfront phases of product development and allocated considerable amounts of time and resources to these early stages. For example, the highest performing companies in our sample were 18% more likely to adopt systematic product road mapping and planning procedures than the rest. These companies also made cost engineering for new product designs a clear requirement during concept development.

The best-performing companies in our study were also 17% more likely to employ cost engineering during the front end of development. Managers would be well served to focus on defined planning and specifications, development of robust product architecture, well-defined interfaces and shared subsystems. Companies that operate in this fashion, such as Honda Motor Co., have a strong record of maximizing R&D investment over multiple, highly profitable product lines.[9]

Better upfront planning can reduce later iterations because fewer are necessary. And simple, better process adherence reduces later iterations by enforcing discipline. The lesson is clear: Use digital design tools and systems but not without a disciplined, well-controlled R&D process. Otherwise, product designs will continue to shift until near the moment of manufacture, causing undue waste and churn. (See "A Manager's Guide to Eliminating Digital Design Problems.")

A Structured, Well-Managed Process Is Important

Confirming the existing new product development literature that endorses structured processes, we also found significant correlation between efficient use of R&D resources and well-defined conceptual and systems design phases.[10] The most successful companies in our study were heavy users of digital design that combined these tools with management-driven process discipline. Specifically, they maintained a structured R&D approach that protected and preserved a front-loaded process that had sufficient time for deep user research (ethnography, focus groups, etc.), competitor analysis, and rough prototyping and systems architecture. As a manager of one of these well-managed companies told us: "We don't see a ton of back-loading here because we are so focused on process. We're very rigorous upfront, especially during planning." Not surprisingly, the need for strong project management and communication was pervasive throughout our study. Often, a good project manager was seen as the key figure to stop back-loading from occurring. As one engineering vice president at a technology company explained: "We don't see endless iterations in design. This is up to the project manager. We go through the necessary iterations and do not overdo it."

A key contributor to project management and team effectiveness on the management of digital design was collaboration software such as wikis and Google Docs. We found that the best-performing firms were 26% more likely to adopt and use collaborative IT tools during design. In sum, powerful digital design systems need to be matched with appropriate process discipline, supported by a relevant IT infrastructure and collaboration tools.

We also observed that companies with incompatible CAD systems within development groups, or between themselves and suppliers, suffered significant disruptions and diseconomies in the development process. Companies that focused on implementing and maintaining a top-level IT infrastructure to bridge different R&D applications performed significantly better in terms of engineering efficiency.

It is imperative that internal departments, vendors and suppliers maintain consistent levels of software revision and training and that detail issues, such as tolerances, for example, are clearly communicated.

A MANAGER'S GUIDE TO ELIMINATING DIGITAL DESIGN PROBLEMS

One size does not fit all when it comes to the best way to employ digital design tools effectively. Still, managers told us they found these four approaches extremely helpful.

1. No points for finishing first. The migration to digital tools for design and rapid prototyping is now standard industry practice, and that isn't going change. Perhaps your biggest challenge as a manager is keeping teams from settling prematurely on detailed designs. As we have shown, this can lead to back-loading of problem solving, which is the least effective approach for the development of compelling products.

Encourage teams to create as many different designs as possible upfront and create clear processes for vetting so that the best one wins. Part of those processes will require showing these designs to target users. And part, obviously, will require access to data that provide good projections of manufactured costs. Since 70% of development costs are decided in the very early stages of development,[i] having detailed cost estimates derived from detailed concepts is highly beneficial.

2. Supplement the tools with process discipline. While individual tools such as CAD are essential in design and engineering, the power of digital design is truly realized when it is combined with digital communications and information management tools. These tools include communication, collaboration and project management tools and applications. Reviewing a CAD model on Skype with global vendors can reduce communication errors and not only reduce travel time and expense, but actually leverage the fact that teams are far apart. For example, one company in our research had Skype calls nightly with its team members in China, who were exactly 12 hours ahead. This enabled a near-24-hour development cycle, truncating total time to market. Our empirical research showed a significant connection between the use of IT support tools and R&D efficiency.

For project management and team collaborations, more companies are using internal project wikis (such as PBWiki Inc. and 37signals' Basecamp.com). These allow distributed team members to share a common virtual development space where they can comment on, edit and revise designs in a socially networked environment. We saw a significant correlation between improved efficiency and increased communication and knowledge sharing among team members.

Many companies still face challenges though, particularly with product life cycle software. These systems can be cumbersome for teams to use and can result in layers of old part revisions, duplicate files and mismanaged data. As one lead engineer told us, "We use PLM, but it's really a messy vault system. We have 27,000 variations in the vault. So, say you want to look for a design, you have to go back and look at all the revisions. There are multiple copies saved. There is no structure. It's really extremely big and complicated." Often, instead of reusing a design, this company will just design a new part because it's more efficient. Our study data showed no significant difference in the development outcomes of those firms that intensely adopted PLM and those that did not.

It is clear that R&D managers need to ensure discipline not only in the development process, but also in the maintenance and use of stored data. One large company we visited ensures that all files are properly maintained and stored in a secure intranet vault, with a clear indexing system to facilitate rapid lookup for engineers working on new projects. We found a significant connection between the use of a design repository and R&D efficiency.

3. Ensure compatibility across the work force and with partners. One of the challenges faced by companies that are heavy digital design users is software revisions and data commonality throughout the value chain. There are often issues with design revision levels, such as part files not containing information on tolerances and desired materials and finishes, and a reduced reliance on control drawings. In one example, an American company transferred CAD rendering for a new printed circuit board to a Chinese contract manufacturer. The contract manufacturer opened the files with an older software revision of the CAD package. Unbeknownst to the team, a small short appeared across two circuit traces as a result of the software generation difference. The error was discovered in pre-production testing and resulted in a time-consuming, manual fix that delayed order fulfillment. Engineering managers need to ensure that the digital design files contain the proper data and, more importantly, not eschew important control drawings for the sake of "just sending the file."

4. Manage expectations of executives and clients. Digital design can also improve senior management's understanding of new concepts by virtue of hands-on visualization. But it also presents a challenge discussed earlier: Some executives may perceive the project as complete, or close to complete, when being shown digital images. Expectations may be raised for rapid completion — leading to inappropriately tested concepts being rushed to market. This is all the more risky for truly novel concepts where the company is exploring new markets, new users and new component technologies.[ii] Consequently, senior management needs to be educated about the difference between a photorealistic rendering and a completed design.

The most successful companies in our study reported a greater use of IT in facilitating training, compatibility and communication. The most successful companies in our study reported a 22% greater intensity in the use of IT to play a role in interdependencies among teams and organizations — facilitating training, compatibility and communication. In companies where such coordination doesn't occur smoothly, problems can occur. As one engineer at a high-technology company explained: "It used to be that vendors — people making sheet metal parts or injection molded parts — would receive dimensioned, 2D drawings and check their parts versus samples, etc. Thought went into tolerances, fit, etc. Now, these vendors work right off the 3D solid models. The parts come back to us, and they don't fit well." That can cause unnecessary tooling and design revisions during production ramp-up. However, digital design allows for dimensions and drawing information to be included in the files. It is poor process discipline and equally poor management of the IT tools and their features, that is the root cause of the problem in this particular example. Ultimately, such problems have to be solved further down the line, causing unwanted back-loading.

Training and bullpen proficiency were shown to be important in our study. In the companies we studied, up to 75% of project time was directly related to digital design hours; without proper training in the digital design tool, that use of time is suboptimal. An engineering manager at a large aerospace company noted that designers were "the real experts," and they needed to be trained accordingly. Training and proficiency are critical to R&D success. In our interviews, we found that younger engineers were often heavily reliant on digital design and were not fully vetted in engineering methodology. These less-seasoned engineers went right to solving the problem digitally, without fully defining and exploring the problem first — a significant contributor to back-loading.

The bottom line from our research? Innovation managers need to use caution in wholesale adoption of digital design technology. There is no doubt that having a computerized drafting board, backed by access to libraries of prior design widgets, product components and manufacturing costs, can save engineering design teams time and expense. Besides, new recruits live and breathe digital technology as college students, and there is no way that one can prevent their use of computers in the early design process.

That being said, while digital design certainly helps enhance R&D productivity, it also carries the risk of allowing designers and engineers to rush to conclusion prematurely, bypassing critical upfront steps that are so valuable to the project. The result is often a need to rework designs later in the process, reducing efficiency while increasing the risk of implementing "tweaks" that were not intended by upstream developers. In our research, the best-performing companies ensured that this does not happen through managerial oversight and protection of the front end of product development.

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