Design for Six Sigma (DFSS) has been publicized as a product development approach that complements the Six Sigma problem solving methodology. Promoted as “Six Sigma goes upstream,” DFSS encourages systematic anticipation of customer needs and disciplined application of scientific and statistical methods to meet those needs. Many organizations, enthusiastic to build on Six Sigma momentum, generated their own DFSS processes before a standard template emerged.

While Six Sigma is widely recognized by the DMAIC acronym that represents its five standard phases (define, measure, analyze, improve, control), DFSS has no standard acronym. Therefore, organizations have adopted a variety of approaches that resulted in acronyms such as IIDOV, CDOV, IDOV, DMADV, DCOV and IDEAS. Despite these naming differences, all versions of DFSS share fundamental strategies and tools that promote a common goal: to create a data driven product development culture that efficiently produces winning products.

Initial Assumptions

Ford decided to launch “consumer driven Six Sigma” in 1999, with an initial focus on two things:

1. Training Black Belts (BBs).
2. Completing DMAIC projects.

Management set targets for the percentage of each division trained and dollar savings resulting from projects. It created a central, prioritized list of all corporate quality issues to aid the coordination of improvement efforts with available resources.

The implementation strategy assumed people throughout the organization...
would be more likely to buy into Six Sigma if results were quickly realized from the company’s short-term (four to six month) “find and fix” DMAIC projects. That buy-in was considered necessary to start a culture change. And while significant energy was focused on achieving the short-term targets, the importance of developing DFSS for the long term was also recognized.

A small development team with representatives from various divisions embarked on a plan to develop DFSS for Ford. The team held benchmarking discussions with early DFSS adopting companies and listened to consultants familiar with those efforts. Much of what was learned paralleled quality and reliability initiatives already under way at Ford.

The team settled on a four-phase process: define, characterize, optimize and verify (DCOV). The DCOV framework aligned with Ford’s existing product development (PD) system and built on the disciplines of systems, robust and simultaneous engineering, all of which had been in use at the company for more than 10 years. Introductory training in related tools was already available through the Ford technical education program (FTEP), an online curriculum all engineers are expected to pass (see Table 1).

Implementation began with Ford’s Powertrain Division, which wanted to apply DFSS to the development of new engines and transmissions. Work was divided into a large number of subprojects with an active BB assigned to each. Growth in the number of projects was driven by a senior vice president, who demanded regular status reports.

Key to progress was the strategic placement of a DFSS Master Black Belt (MBB) as manager of the department responsible for the computer modeling of new engine designs. This manager teamed up with an engine program manager to act as working level champions for DFSS. Soon other divisions were launching DFSS by identifying beta projects and training teams to carry them out. Issues with the training and execution of these early projects highlighted implicit assumptions that needed reevaluation. For example:

- The rationale for DFSS would be clear to midlevel management, and DFSS would be embraced as a natural extension of Six Sigma.
- Projects would easily integrate into the company’s standard PD process because the DFSS steps had been carefully aligned to that process.
- Similar to DMAIC, steps to project completion could be detailed in a prescriptive set of procedures using a standard toolset.
- The DFSS training should follow the BB model, in which all participants receive extensive training in Six Sigma tools.

The following sections address these assumptions one at a time, explaining why they were flawed and outlining implementation changes required to maintain momentum of the DFSS rollout.

**DFSS Rationale**

DFSS proponents argue the benefits reaped from DMAIC defect reduction multiply when Six Sigma rigor is applied to defect prevention. But even when an organization has achieved significant DMAIC success, management may be legitimately skeptical of DFSS.

At Ford it became clear early on that DFSS acceptance could not be achieved riding on the coattails of Six Sigma. Basic questions such as “Isn’t DFSS just good engineering with a fancy brand name?” and “The tools are not new—so what is new?” needed to be clearly answered up front. To answer these questions, the team concluded Six Sigma culture, which establishes statistically verifiable facts as an underpinning of all product decisions, could be a lever to increase the influence of Ford’s ongoing quality engineering initiatives.

DFSS packages methods and tools in a framework that promotes cultural change under a recognized brand name that helps overcome an initial resistance to change. It is most useful if it generates permanent behavior changes that outlast its own life as a brand.

Given the DFSS toolset is not substantially new, the rationale for DFSS should not focus on tools. Over time, DFSS at Ford has emerged as a scientific approach to PD that leverages Six Sigma culture. It has become a means to reinstate rigorous deductive
and inductive reasoning in PD processes. It requires:

- Identifying customer desires.
- Developing validated transfer functions (mathematical models) that describe product performance through objective measures.
- Correlating these objective measures to customer desires and effectively assessing the capability to meet those desires well before product launch.
- Applying transfer function knowledge to optimize designs to satisfy customer desires and avoid failure modes.

Six Sigma culture aids implementation of these steps by providing:

- A cross company common language for problem resolution and prevention.
- A mind-set that demands the use of valid data in decision making.
- An expectation across the organization that results should be measurable.
- A disciplined project management system to help achieve timely results.

None of the elements of this approach are revolutionary, but together they provide a template for success. Based on experience applying DFSS, Frank McDonald, a VP of Cummins Inc., observed: “[DFSS] may sound like the latest new way if not for the fact that it really is more like the development of the old way to a higher standard that feels a lot like the right way.”

Recently, some DFSS proponents have contended that organizations should begin Six Sigma deployment with DFSS instead of DMAIC. Ford’s experience indicates otherwise. Short-term DMAIC projects led to rapid elimination of a significant number of issues and resulted in measurable financial benefits. This success boosted confidence in Six Sigma, and continued institutionalization helped build a culture receptive to DFSS. Furthermore, once BBs had successfully completed a few DMAIC projects, they were better equipped to support the longer and more complex DFSS projects.

**Project Integration Within Existing Processes**

Even when the rationale for DFSS is clear, practical reservations about its alignment with existing processes may remain. Ford had been evolving its PD system for years when DFSS was introduced. Natural fears arose that DFSS was intended to replace this system, potentially causing disruption and confusion. To counter those fears, senior management made it clear DFSS would not replace, but would augment, the existing PD process in specifically designated areas.

DFSS projects would demand a deeper dive into the establishment of customer connected performance targets (Y’s) and transfer functions that link those targets to critical design characteristics (X’s). This approach is consistent with the experience of other DFSS implementers: “We shouldn’t tell our engineers we’re discontinuing the

The Powertrain Division was the first to implement DFSS.
process they’ve been working with for 10 years and replacing it with DFSS. We should integrate DFSS deliverables into the current development process and ask project managers to commit to providing them,” said Doug Mader, president of SigmaPro.4

Integrating DFSS deliverables into the current PD process sounds simple, but it involves real challenges. For example, PD entails at least three different categories of scope: the creation of a new product or technology, the evolution of a next generation product from a current design or the enhancement of an existing product. The rhythm and timing of DFSS projects associated with these efforts will vary depending on the category (see Table 2).

Boundaries are not always well defined, but the categories provide initial guidance for establishing project expectations and timing. Breakthrough projects have the most design latitude and typically require the most time to complete. Evolutionary projects have less design latitude, and their timing is tied to standard PD milestones. Adjustment projects have the least design latitude, and they are generally expected to be completed as soon as possible.

In addition to delivering an optimized design, each DFSS project at Ford is required to institutionalize learning and transfer functions by developing design guidelines and training that can be reused in the future. This effort to reduce waste in the PD factory is what distinguishes an adjustment DFSS project from a DMAIC project.

*To reduce waste in the product development factory, each DFSS project develops reusable guidelines and training.*
Some practitioners use different process phases for different categories of projects. For example, the authors of *Design for Six Sigma in Technology and Product Development* use invent, innovate, develop, optimize and verify (IIDOV) to describe DFSS for technology development and concept, design, optimization and verify (CDOV) to describe product commercialization (design). To reduce confusion, Ford uses the DCOV abbreviation for all categories of DFSS projects.

A second challenge in integrating DFSS deliverables into the current development process is determining the manager to which they should be assigned. DFSS projects typically deal with the most challenging designs, such as new concepts or technologies linked to a compelling business case or complex systems that have exhibited problems in the past. In the first case, no natural project owner may have yet evolved in the organization. In the second case, the natural owner may not be clear or may be disputable because product attributes and system interface issues often cut across system boundaries.

Even if the organization dictates a clear owner, the fact existing designs are underperforming indicates a need for a new approach. In each of these cases, it is critical to apply basic project definition and management techniques. These include:

- Ensuring the team is led by someone who has responsibility for the design and can engage the appropriate technical expertise.
- Providing mentoring in statistical and PD tools—

<table>
<thead>
<tr>
<th>Project category</th>
<th>Design latitude</th>
<th>Timing</th>
</tr>
</thead>
<tbody>
<tr>
<td>I. New product or product breakthrough:</td>
<td>Open—exploration of alternative concepts allowed.</td>
<td>Driven by market opportunities and technology feasibility; linked to technology development plans.</td>
</tr>
<tr>
<td>• Introduce new product, concept or technology.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Add a new feature to next generation product.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>II. Evolutionary change in next generation product:</td>
<td>Moderately constrained—concepts often already selected, assumptions for component reuse limit design space.</td>
<td>Driven by market trends and competitive pressures; linked to existing product program milestones.</td>
</tr>
<tr>
<td>• Upgrade performance.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Maintain performance while lowering cost.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Prevent problems.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>III. Adjustment to existing product design:</td>
<td>Heavily constrained—limited to “running changes” to existing designs.</td>
<td>Driven by waste reduction goals; linked to yearly budget targets, similar to DMAIC projects.</td>
</tr>
<tr>
<td>• Optimize performance within existing production constraints.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Reduce current costs.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Fix problems.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

DFSS = define, measure, analyze, improve, control.
for example, assigning BBs and MBBs or their equivalents.

- Securing an executive Champion to actively support and review the project.
- Committing the team and Champion to a project charter that outlines goals aligned with organizational objectives, scope matched to team resources, roles and responsibilities, and key project milestones with delivery dates.

The importance of active senior management leadership cannot be overestimated at the project or organizational level. In a division whose senior leader actively drove DFSS from the start, project numbers grew exponentially over the first three years of implementation. In a similar sized division, in which DFSS deployment leaders solicited projects from mid-level management, project numbers remained in the low teens for the same time period.

**Process Flexibility**

The variety of scope addressed by DFSS projects means DFSS needs to be more comprehensive and flexible than DMAIC. In DMAIC, BBs identify and reduce the frequency of defects generated by existing processes. The majority of work is analysis. In DFSS, teams must not only anticipate and prevent defects, they must anticipate and meet explicit and latent customer needs.

DFSS must address all three types of quality represented in Noriaki Kano’s model: basic, performance and excitement. DFSS requires a balance of analysis and synthesis—the synthesis of new designs and design standards from a combination of deductive and inductive reasoning based on experience, observation and theory. While analysis often proceeds linearly or is at least guided by procedure, synthesis proceeds iteratively and sometimes unpredictably as connections are made between disparate ideas. Such iteration is an inherent part of the PD progression from the conceptual to the concrete. Elements of each DCOV phase are repeated as designs proceed from concept to computer model to prototype to production.

Compounding the challenge of DFSS is the added uncertainty about future customer desires and future sources and levels of production and usage variability that will affect product performance. Assessing these types of uncertainty is often not possible by collecting frequency data from existing processes and making statistical inferences. Such phenomena are either not random or their random nature is not discernible.

So in addition to being equipped with statistical tools, DFSS teams must have knowledge about nonstatistical methods outside the typical BB curriculum, including methods for obtaining consumer insight, cascading customer desires down to component specifications, designing for robustness, mistake proofing and verifying designs with small sample sizes for testing. This methodology expertise, typically provided by
Design for Six Sigma at Ford

BBs and MBBs, must be combined with deep technical expertise in the product functionality in question. An ideal situation occurs when a BB from a functional area finishes certification and returns to the area to support related DFSS work.

The Ford team initially devoted time to devising a single DFSS flowchart. Attempts to capture any substantial detail were finally abandoned because they ended up being redundant to existing PD flowcharts and failed to adequately address different project categories and represent iteration in the process. It was also difficult to clearly represent the proper relationship between tools and outcomes in a single chart.

The team, therefore, decided to produce two documents:

1. A tool matrix to outline which tools might be applied at each project phase (see Table 3).
2. A project checklist to delineate intended outcomes at each phase. It is used with the understanding some items may not apply to a particular project as determined by the MBB and executive Champion.

Training

One of the key DFSS implementation challenges is training. Ford first applied a typical BB training model to entire teams. Team members attended two weeks of classroom training during the early months of a project. They studied a curriculum that included in-depth coverage of process and tools.

Participants in these pilot teams had two major concerns:

1. Some general tool and process information was redundant to FTEP.
2. Not all the specialized tools presented would apply to a particular project. For those that would—due to the extended length of DFSS projects—the team members worried they would forget much of the training by the time they needed to apply it. They concluded it was inefficient to train all team members in all tools.

As a result of the feedback, DFSS training was restructured. To enhance continued adherence to the process, teams now meet periodically in workshops corresponding to each project phase (D, C, O and V). Instead of teaching tools, the workshop teaches the process and describes the results expected from the team. The bulk of the time is devoted to helping the team make progress on its specific project by interpreting data and formulating strategies for the technical work ahead. By the end of each workshop, the team has a written work plan for the project’s next steps.

A team process leader, typically a trained BB, guides the application of Six Sigma tools. An MBB facilitates the workshops, collaborates with team leaders throughout the project and provides additional training in advanced DFSS tools as required.

To supplement knowledge of basic DFSS tools already provided through FTEP, Ford’s office of the Technical Fellow in Quality Engineering sponsors reliability and transfer function seminars for the engineering community at large and targeted to DFSS teams. Baseline DMAIC skills are also reinforced as engineering organizations near completion of a corporate mandate requiring all engineers to achieve DMAIC Green Belt status. The current flexible training model in Table 4 (p. 22) rationally leverages

Table 3. Ford DFSS Tools Matrix

<table>
<thead>
<tr>
<th>D</th>
<th>Consumer insight</th>
<th>Market research</th>
<th>Brand analysis</th>
<th>Noriaki Kano model</th>
<th>Quality function deployment</th>
<th>Benchmarking</th>
<th>Quality history: surveys</th>
<th>Quality history: repairs</th>
<th>Quality loss function</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>Concept generation and selection</td>
<td>Design of experiments</td>
<td>P-diagram</td>
<td>System and functional diagrams</td>
<td>Reliability and robust engineering design</td>
<td>Axiomatic design</td>
<td>Dimensional variation analysis</td>
<td>Failure mode and effects analysis</td>
<td>Measurement system analysis</td>
</tr>
<tr>
<td>O</td>
<td>Numeric/heuristic optimization</td>
<td>Parameter design</td>
<td>Tolerance design</td>
<td>Analytical reliability and robustness</td>
<td>Statistical tolerancing</td>
<td>Design for manufacture/assembly</td>
<td>Process capability assessment</td>
<td>System engineering</td>
<td>Target setting and verification</td>
</tr>
<tr>
<td>V</td>
<td>Model validation and uncertainty assessment</td>
<td>Design verification plan and report</td>
<td>Robustness/reliability demonstration</td>
<td>Control plan</td>
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<td></td>
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</tbody>
</table>
existing training programs while driving projects forward on a just-in-time basis.

Implementing DFSS can be challenging for any organization. Experience at Ford revealed the challenges are more likely to be cultural and organizational than technical. Through adjustments based on lessons learned, DFSS at Ford has emerged into what it is today: an enhancement to the current PD system that leverages the company’s extensive Six Sigma skill base and culture to fundamentally understand product performance and deliver customer satisfying, robust designs. It adapts to wide ranges of scope and allows flexibility in the choice of tools to achieve the required results. It augments existing training with just-in-time workshops to help teams efficiently deliver results.

ACKNOWLEDGMENTS

Many people have contributed to the success of DFSS at Ford. I have had the pleasure of collaborating with Dave Amos, Tim Davis, Agus Sudjianto, Tom McCarthy, Chris Gearhart, Bob Thomas, Ellen Barnes, Garry Smith, Fred Johns, Sam Hamade, Mahesh Vora, John King and Belinda Hodge.

Table 4. Training To Support DFSS

<table>
<thead>
<tr>
<th>Kind of training</th>
<th>Audience</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>All engineers</td>
</tr>
<tr>
<td>DMAIC prerequisites</td>
<td>Req</td>
</tr>
<tr>
<td></td>
<td>Req</td>
</tr>
<tr>
<td></td>
<td>Req</td>
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<td></td>
<td>Req</td>
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<tr>
<td></td>
<td>Opt</td>
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<tr>
<td></td>
<td>Req</td>
</tr>
<tr>
<td>DCOV</td>
<td>Req</td>
</tr>
<tr>
<td></td>
<td>Req</td>
</tr>
<tr>
<td></td>
<td>Req</td>
</tr>
<tr>
<td></td>
<td>Opt</td>
</tr>
<tr>
<td>Shadows a working DFSS MBB</td>
<td>Req</td>
</tr>
</tbody>
</table>

Key:
- Req = Required
- Rec = Recommended
- Opt = Optional
* Not applicable, BB training supersedes this requirement.
** DFSS process (one day), analytical reliability and robustness (two days), structured inventive thinking (three days)

REFERENCES AND NOTES

2. IIDOV = invent, innovate, develop, optimize, verify.
CDOV = concept development, develop, optimize, verify.
IDEA = identify, design, evaluate, assure, scale-up.

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