QUALITY FUNCTION DEPLOYMENT

DFX and DFSS: How QFD Integrates Them

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Design for excellence (DFX) and design for Six Sigma (DFSS) have been two of the most popular concepts in quality management in recent years, but very little has been written comparing DFX and DFSS. This article aims to clarify the differences between them in concept and application and further identify how to integrate them effectively by using quality function deployment (QFD).

In 50 Words Or Less

- **Quality function deployment provides an architecture that can effectively position and combine design for excellence and design for Six Sigma.**
- **By combining these methods, manufacturers can differentiate a product in terms of quality prior to the actual production process.**

It is a good starting point to understand the roots of the words "excellence," "Six Sigma" and "quality." Aristotle might have been the first person to talk on the subject of quality in any systematic way.[1] In his book *Metaphysics*, he gave four definitions of quality and later summarized them with two basic meanings: "differences of real substance" and "mode of a subject in motion, of itself." Good (excellence) and bad (inferiority) are parts of the latter mode.

Simply speaking, there are two aspects of quality, according to Aristotle: different quality and good quality. Discussions of quality have revolved around these two aspects since Aristotle's time.[2]

Whether you're creating different quality or trying to achieve good quality, you must build quality into a product when it is planned and designed. Quality built in at this stage has the maximum return in terms of cost benefits and customer satisfaction. It far surpasses the improvements brought about by relying separately on promotional efforts in selling or detection and modification in manufacturing after a product is released. DFX and DFSS both help build quality into the design stage.

Design for Excellence

DFX has evolved and is still evolving from design for manufacturability. By manufacturability, we mean the ease with which a product or component can be produced. Historically, designers have overlooked manufacturability and have concentrated their efforts on function, features and appearance of their products. However, concentrating on manufacturability during product design has great cost benefits.[3]

Today, a limited series of design objectives—function, features and appearance—even when manufacturability is added, is not enough to provide the most competitive, economical and beneficial design to customers and society over the long run.[4]

DFX is intended to provide designers with an objective deployment framework and a means to achieve all desirable dimensions of quality. DFX can be viewed as a design approach that deals with Aristotle's different quality while focusing on the right thing to design.

When we look at research in this field, two renowned examples are the eight quality dimensions David Garvin proposed[5] and the internal structure of quality Noriaki Kano proposed.[6] Based on these ideas, we propose nine dimensions of quality, or DFX objectives:

1. **Higher functional performance:** Higher effect levels of a product's main operating characteristics.
2. **Physical performance:** Dimension, volume and weight of a product.
3. **User friendliness:** How easily a product is used.
4. **Reliability and durability:** Reliability refers to how free of failure a product is during a period of time. Durability refers to a product's lifespan.
5. **Maintainability and serviceability:** How easy it is to restore a product's usability after a failure.
6. **Safety:** How free of injury and hazard the product's user is.
7. **Compatibility and upgradeability:** Compatibility refers to the ease of combining a product with another product. Upgradeability refers to the ease of incorporating improved or additional features into a product.
8. **Environmental friendliness:** The product's manufacturing process, use and disposal are free of environmental pollution and hazards.
9. **Psychological characteristics:** Product aesthetics as perceived by the user's five senses and the sensibility that relates to the user's thinking, feeling and discerning about a product.

It should be pointed out that DFX objectives are all the desirable factors a product should theoretically have. In practice, DFX objectives are met by a company's selective quality characteristics.

Design for Six Sigma

Six Sigma is a disciplined and highly quantitative approach to improving product or process quality. The goal is to reduce defects to no more than 3.4 per million opportunities. Six Sigma was introduced at Motorola and has been adopted and generalized by numerous companies, such as Allied Signal and General Electric.

Companies that have adopted Six Sigma have realized that once they have hit a "five sigma wall" and progress has come to a standstill, the only way to surpass this wall is to apply DFSS. DFSS is a rigorous approach to designing products from the beginning to ensure customer requirements are met.[7]

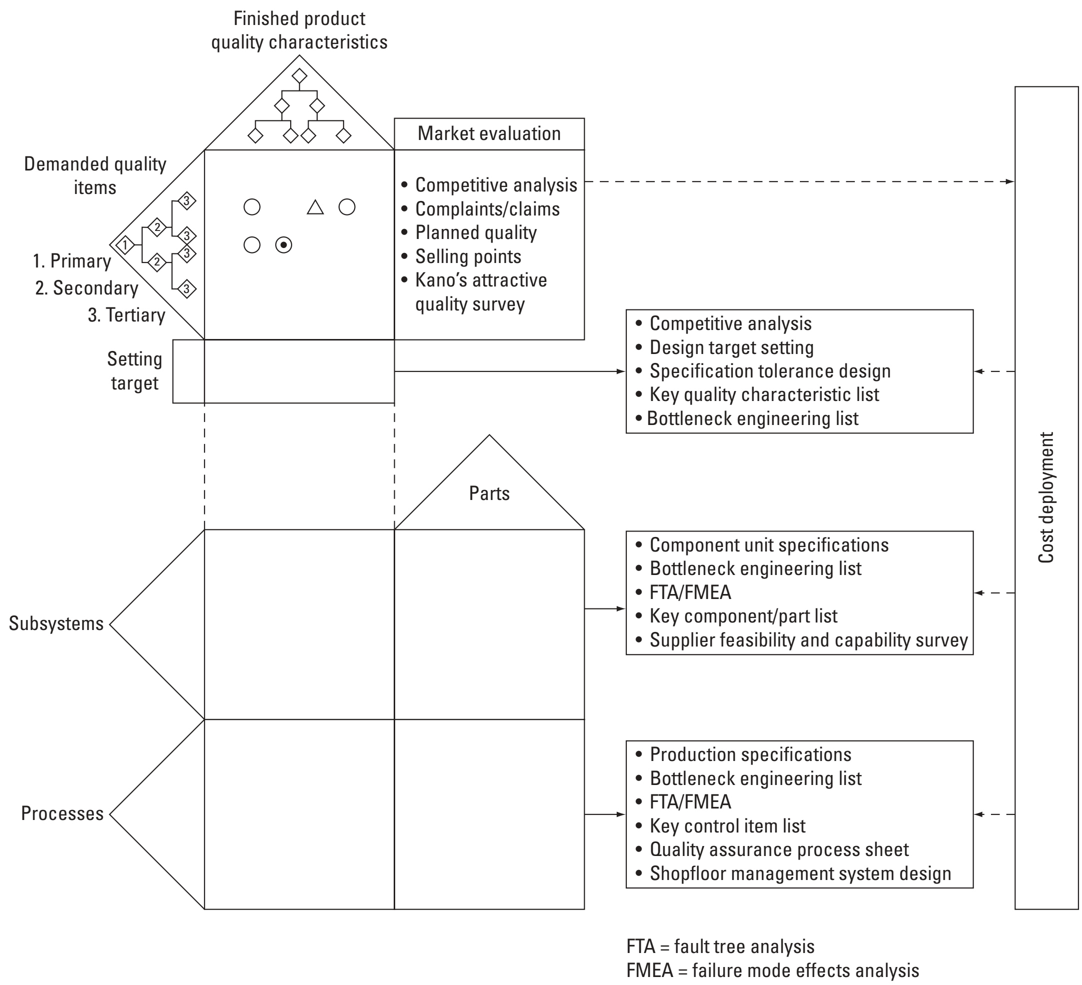
DFSS can be viewed as a design approach that deals with Aristotle's good quality and a focus on how to design the right thing right. DFSS follows the define, measure, analyze, design and verify (DMADV) phases during design projects. The core concept of DMADV implementation is to gradually flow down new products' critical-to-quality characteristics to functional design, detailed design and process control variables, and then flow up capability to meet these requirements.[8]

Quality Function Deployment

QFD is a method of new product development under the umbrella of total quality management. It is a process for systematically converting customers' demands into design quality, and it deploys quality over design targets and major quality assurance (QA) points, or milestones, used throughout the product development process.

QFD was conceived in Japan in the late 1960s while Japanese industries were departing from their postwar mode of product development, which had essentially involved imitation and copy-

FIGURE 1 Comprehensive Quality Function Deployment System



ing, and were moving toward original product development. At that time, there was recognition of the importance of designing quality into new products, but there was a lack of guidance on how to achieve it.

Companies were already inspecting for quality, but it was happening at the manufacturing site after new products had been produced.[9]

Yoji Akao first presented the QFD concept and method to solve these problems, and QFD has continued to spread since Shigeru Mizuno and Akao published their first book on the topic in 1978.[10]

To ensure smooth product development, Akao constructed a comprehensive QFD system that considers quality, technology, cost and reliability simultaneously.[11] The objective of each deployment is as follows:

- Quality deployment is to systematically deploy customers' demanded quality over the design targets and major QA milestones used throughout the product development process.
- Technology deployment is to extract any bottleneck engineering (BNE) that hinders quality and solve it at the earliest possible time.
- Cost deployment is to achieve the target cost while keeping a balance with quality.
- Reliability deployment is to prevent failures and their effects through early prediction.

Figure 1 shows the concept in an integrated way. The first step for QFD implementation is to

decide on a target market and formulate a product portfolio strategy. Then, a survey is conducted with the market's customers, and a demanded-quality deployment chart is made.

According to market evaluation information such as competitive analysis and claims analysis, the company might conduct quality planning and determine the new product's individuality or selling points. Kano's attractive quality survey helps to conduct product planning for creating attractive quality.[12]

Customers express demanded qualities by directly describing and perceiving what product quality is. However, demanded qualities must be converted to quality characteristics—that is, the technical language a company's R&D personnel use to understand how to technically achieve the demanded qualities. Only in this way is it possible to materialize them through development technology.

Like product design, process design must effectively prevent a recurrence of the existing process's design problems and the potential design problems of the new process.

Therefore, it is necessary to carry out a quality characteristics deployment of the finished product to transform product quality from the world of the customer into the world of technology. The company can choose design specification values according to competitive analysis and extract the BNE, which hinders the realization of the design quality.

When a product is designed and developed, rather than directly designing the entire product, R&D personnel view the subsystem or component unit (also known as a building block) of the intermediate layer of the product architecture as the design unit. As a result, a subsystem's deployment is necessary to allocate the specification tolerance of the finished product's quality characteristics to relevant component units.

In the design stage, the product must effectively prevent a recurrence of the existing product's design problems as well as the new product's potential design problems. To that end, a fault tree analysis (FTA) and failure mode effects analysis (FMEA) can be employed. With respect to parts and materials needed for constructing subsystems, deployment is required, and an evaluation of the supplier's feasibility and capability should be conducted.

Products are made through processes and completed by assembling semifinished products. Therefore, a semifinished product and its specifications defined by the subsystem's deployment are made using process deployment and design and by deciding specifications of process conditions (also known as production specifications).

Like product design, process design must effectively prevent a recurrence of the existing process's design problems and the potential design problems of the new process. This can be done by drawing on equipment FTA and process FMEA.

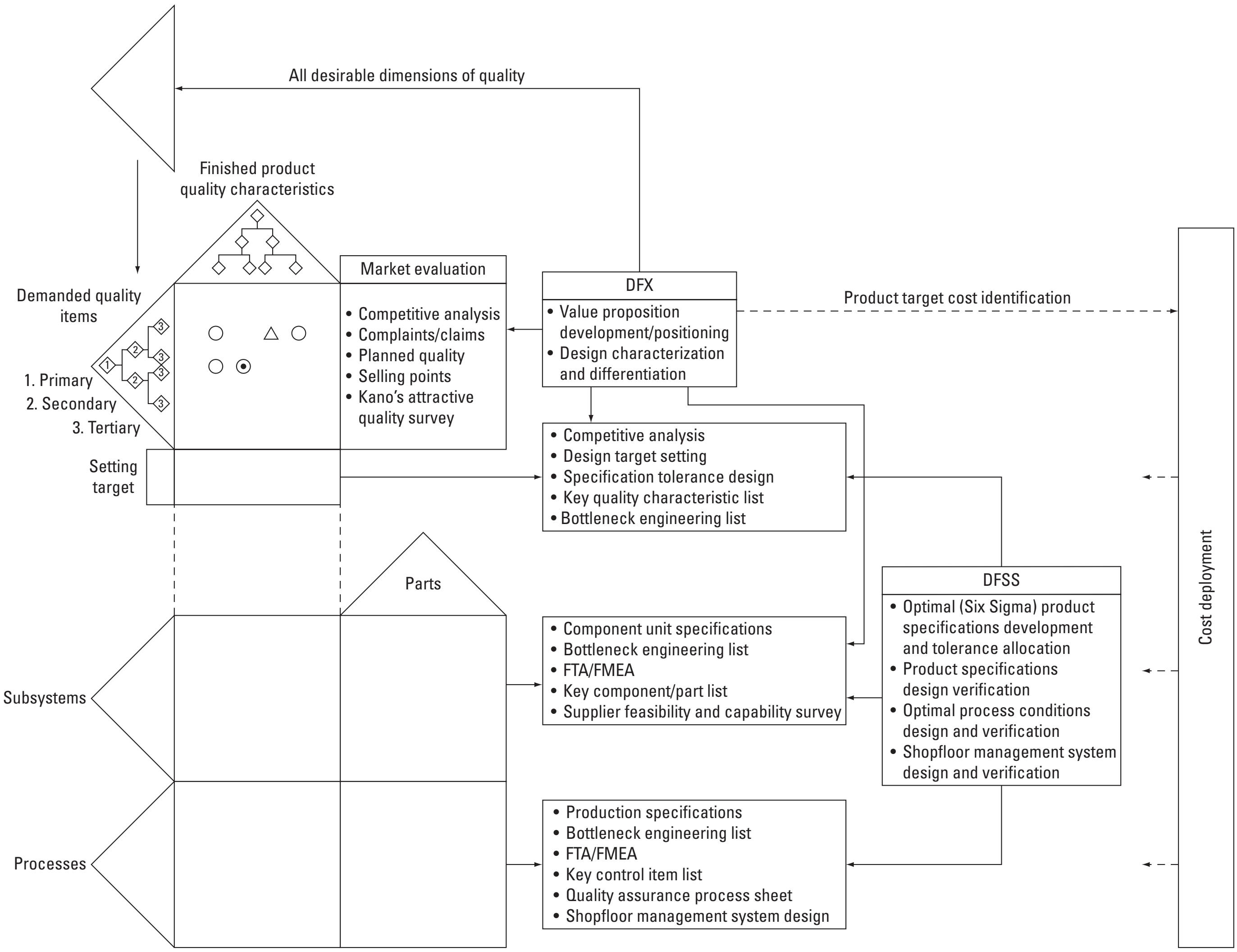
Based on process deployment and FMEA information, a QA process sheet (also known as control plan) can be created to provide an overview of information needed for process control. The design of the shop floor management system needed to execute the QA process sheet, which is part of the process design, ensures that before a product enters mass production, adequate preparations are already in place to achieve manufacturing QA.

The foregoing quality deployment, which includes technology and reliability, can realize customers' demanded qualities and failure free qualities, yet it might increase the cost as a result. By using market evaluation information to decide the target cost of the finished product, and by corresponding to quality deployment flows to set up cost targets for materials and labor, a balance between QA and cost reduction can be achieved.

Integrating DFX and DFSS

QFD's structural integrity when dealing with

FIGURE 2 QFD Toward DFX and DFSS Positioning and Integration



DFX = design for excellence
FTA = fault tree analysis
FMEA = failure mode effects analysis

critical issues (quality, technology, cost and reliability) of new product development helps position and integrate DFX and DFSS, as illustrated in Figure 2.

DFX is a design method that deals with Aristotle's different quality. It can integrate with QFD in converting demanded qualities into quality characteristics. In other words, it ensures that:

- In planning all desirable dimensions of demanded quality, a value proposition is developed based on the selection of quality niches (one X or several Xs).
- In the design stage of demanded quality characterization, the design targets that can support the value proposition are set.
- Product design for the DFX and its verification can then be conducted downstream.

DFSS can integrate with QFD in tolerance design and process design of a product. That is, after setting the design targets (also known as nominal values) of quality characteristics, reference is made to specification values, actual performance and process capability of similar products developed in the past. This is done to develop a product specification tolerance with Six Sigma design quality and allocate the tolerance to related subsystems, component units, parts and materials.

Moreover, DFSS also includes the design and verification of optimal process conditions and shop floor management systems to ensure the manufacturing of semifinished products can achieve Six Sigma design quality.

Using the quality deployment of a headlamp as an example,[13] Figure 3 shows QFD integrated with the DFX and DFSS in Figure 2 (p. 49).

In this example, a chart is used to deploy all demanded qualities of the headlamp. All the columns in the quality planning section are used to prioritize the demanded qualities that can support the company's market positioning and that are considered selling points. When demanded qualities are converted into substitute quality characteristics, R&D personnel must base the differentiation on technical measures that can achieve the selling points.

For instance, to make sure the demanded quality "lamp shines brightly" becomes a quality characteristic, R&D personnel must determine a target value for the technical measure, transmissivity, with a great difference from that of competitors' headlamps and make it have significant brightness.

FIGURE 3 QFD Integrated With DFX and DFSS

Quality chart (two-dimensional matrix of demanded-quality deployment chart and quality characteristics deployment chart)

Quality characteristics / Demanded quality	Flux distribution value: Flux distribution value	Lens size	Low beam/high beam	Aiming angle	Flux of light: Brightness of light source	Transmissivity	Reflection factor	Color temperature	Electric power	Voltage	Efficiency: Air tightness	Filament strength	Quality planning: Importance	Competitive analysis	Planned quality	Level-up rate	Selling points	Absolute weight	Demanded quality weight
Bright enough to see well																			
Can see distant objects																			
Lamp shines brightly	○	○	△	△	○	◎	◎	○	◎	○									
Broad beam	◎	○	△		△	△	△		△										
Shines with directional stability			△	◎															
Light does not scatter	◎																		
Can see close objects well																			
Low beam is bright enough	○	○	◎	△	△	◎	◎	○	◎	○									
Broad beam	◎	○	△		△	△	△		△										
Shines with directional stability	◎																		
Can see well even under adverse conditions																			
Can see well in poor weather conditions	○		△																
Coordinates with steering wheel																			
Can see well even when vehicle bounces																			
Direction of beam correct under no-load condition																			
Specification nominal value	JIS requirement	160 φ	1°	±4° (up/down, left/rigt)	7.5 cd/mm²	0.9 min	0.9 min	3000°K	37.5/ 50W	12.8 V	0.2 a. p.	SAE% impact 95° min							
Specification tolerance																			

Subsystems deployment chart

Subsystem	Flux distribution value	Lens size	Low beam/high beam	Aiming angle	Brightness of light source	Transmissivity	Reflection factor	Color temperature	Electric power	Voltage	Air tightness	Filament strength
Headlamp												
Unit holding mechanism												
Left retaining ring												
Right retaining ring												
Left mounting ring												
Right mounting ring												
Bolt												
Unit												
Lens	◎	◎				◎			△			
Reflector		○					◎		△			
Bulb			◎		◎	○		◎	◎	◎		◎

Quality planning for the company's market positioning and sales proposition

↓

Design target setting for technical differentiation that can communicate the company's positioning

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Tolerance design for Six Sigma quality by analyzing historical process control data and capability studies

↓

Tolerance allocation to lower level characteristics

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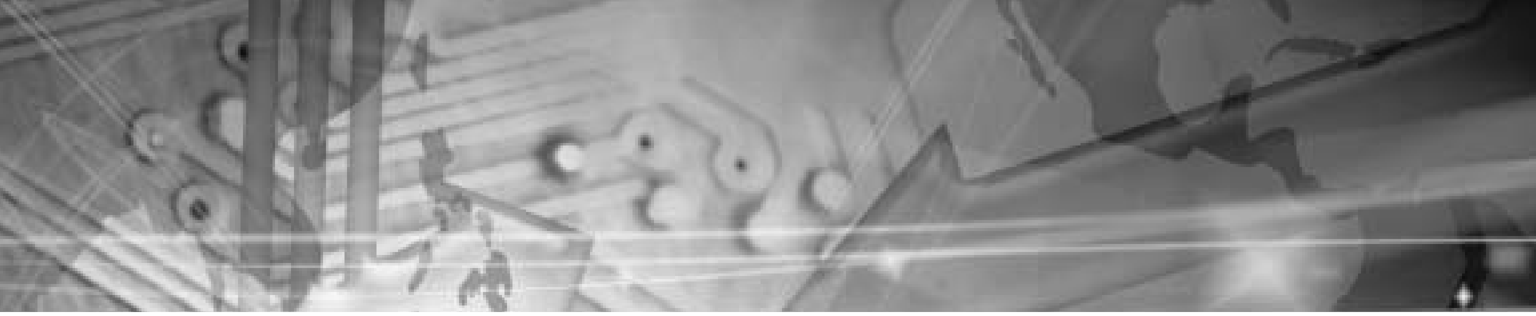
Product and process detail design and verification

△ = Low corresponding strength
○ = Moderate corresponding strength
◎ = High corresponding strength
JIS = Japanese industry standard
SAE = Society of Automotive Engineers



Assume we set the transmissivity value to be 0.9 minimum. As for the decision of the specification tolerance for making 0.9 minimum, the nominal value, we can use the data on variance and process capability obtained from the analysis of historical process control data to calculate the tolerance width required for Six Sigma quality. This tolerance is then allocated to lower level characteristics by simultaneously using the subsystems deployment chart.

The development of the headlamp follows the remaining product and process development. Meanwhile, other quality deployment charts are used, and the Six Sigma target values are flowed down to accomplish the detail designs and their verifications.

DFX and DFSS are two design methods that have been used in recent years for effective new product development. But, more and more, new product development requires combining the two. QFD offers a structure for linking and integrating them. It uses the resultant synergy to create an advantage for product development.

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