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Abstract *To provide an advanced product definition methodology based on quality function deployment (QFD) principles to identify minimize the risks of project failures due to failure to align with the voice of the business. The methodology was developed by reviewing current design product definition and QFD tools and then applied to a number of industry-based design projects in academia as well as an in-depth case study at one industry organization. The tool has been well accepted for its ease and approach in both industry and academic environments and already used to help guide project management. The methodology has only been applied to limited projects in industry and advancements and improvements are still being made. A new simple but powerful tool based on QFD principles that can be readily applied to a number of current design projects; in addition, it demonstrates how the QFD method can be expanded to non-traditional domains and systems. This paper not only identifies current product development issues but also explores a practical and proven solution to error-proof the design process.*

Background

Product development failures

Designing a good product is not easy. With short time-to-market, fierce competition in an already crowded marketplace, and ever-more demanding consumers, organizations must continually make trade-offs in identifying project priorities and allocating resources. Cooper (2000) estimated that 46 percent of the resources that companies devote to the design, development, and launch of new products go into projects that don't succeed in the marketplace or perhaps never even make it to market. Though product development is only part of a product life-cycle, the importance of the design process is that the decisions made during have greatest effect on the cost of a product even though it requires the least investment.

A number of studies have tried to identify key elements of both successful and failed products and projects. Many of them pinpoint failures in product definition and management as major causes. Pinto and Kharbanda (1996) identified major causes of project failures, including ignoring the project environment and stakeholders, not understanding project trade-offs, and blaming the most visible when problems occur. Up-front homework really does pay off, not only in terms of high profitabilities and success rates, but also saves time. Gupta and Wileman (1990) surveyed large technology-based firms and found poor product definition was the most frequently cited reasons for product development delays, shown in Figure 1.

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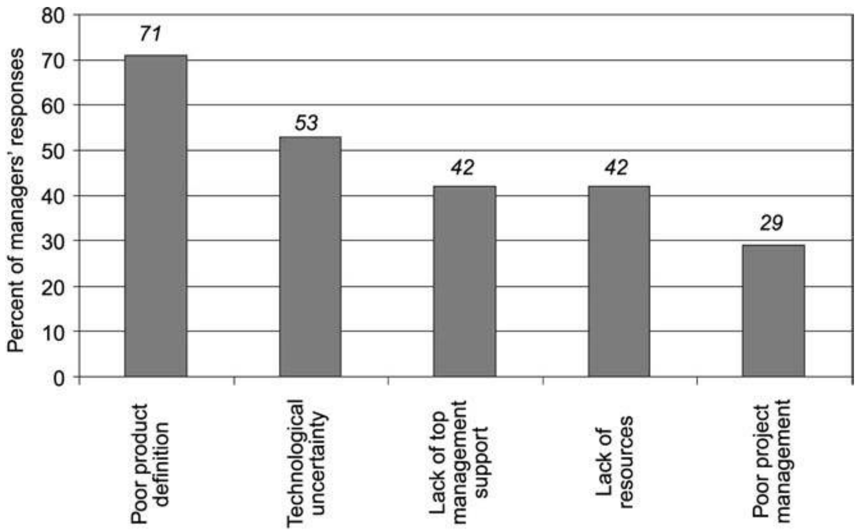

Figure 1.
Typical reasons for product development delays

Tipton (2000) attributed project failures, including the duplication of effort and extra costs, on a lack of constantly applied project management methodology. For this reason, many believe the key to project success and error-proofing design (Chao *et al.*, 2001) is by clarifying product definition through key design for manufacturability (DFM) tools.

DFM

DFM includes systematic methodologies to define, develop, and produce competitive products that bring increased profitability to companies. These methods identify the conflicting demands of features and functions, life-cycle cost, and development/production cycle time, throughout the product life-cycle. DFM extends beyond assembly principles and includes design tools for product definition and quality deployment.

Most companies acknowledge that 80 percent of a product's life-cycle cost is "locked" in at the layout design stage. No matter how much the engineers try after design by innovative manufacturing process control, etc., the incremental improvement is quite small. Successful companies "life-cycle optimize" designs by employing well organized design reviews and utilizing the culturally inherent communication between designers and engineers responsible for production and maintenance. While the informal "human" interaction works in some companies, most companies need a systematic methodology helping engineers identify the required values, balance them, and generate a good design. Experience and good teamwork cannot catch up with the increasing complexity of products brought out by advances in electromechanical systems, computer technology, and materials and processing technology. It is not possible for one design engineer to be familiar with all facets of technology.

Most experts in product development agree that product definition is an essential key to providing high value to all the stakeholders in any new products or processes. In today's world of globally distributed corporate partnerships and concurrent development of fast-paced advanced technologies, engineers and managers need tools to effectively capture the stakeholder structure, various customers involved, and their values.

Edith Wilson (1993) cites that the deficiencies in understanding the value propositions for the stakeholders, in particular the customer needs, is the most prevalent failure mode of product development. Wilson's Sloan study verified Hewlett-Packard's ten-product definition factors and added an 11th factor, strategic alignment, creating the domino model. The first four steps are essential keys to product success. From this, she created the product definition checklist, represented in Figure 2, which can be used by a team to identify the team's alignment on the key factors.

Customer value chain analysis (CVCA) helps identify pertinent customers and stakeholders, their value propositions, and the relationships between these parties for any given product and process development project. CVCA facilitates product definition and feeds into structured methodologies such as quality function deployment (QFD) and failure modes and effects analysis (FMEA). The task should be a team effort involving multi-functional teams and top-level management. CVCA has grown from a sketch to visualize the customer structure to a diagram that analyses the stake-holder value structure in detail. By mapping the flows of money, information, complaints, and components between key stakeholders, the design team can better understand the value proposition to each link in the chain. Figure 3 shows a CVCA example for an aircraft engine manufacturer.

Depicted in Figure 4, the project priority matrix forces a team to agree on the goals of a project upfront. The priorities often depend on product positioning and the

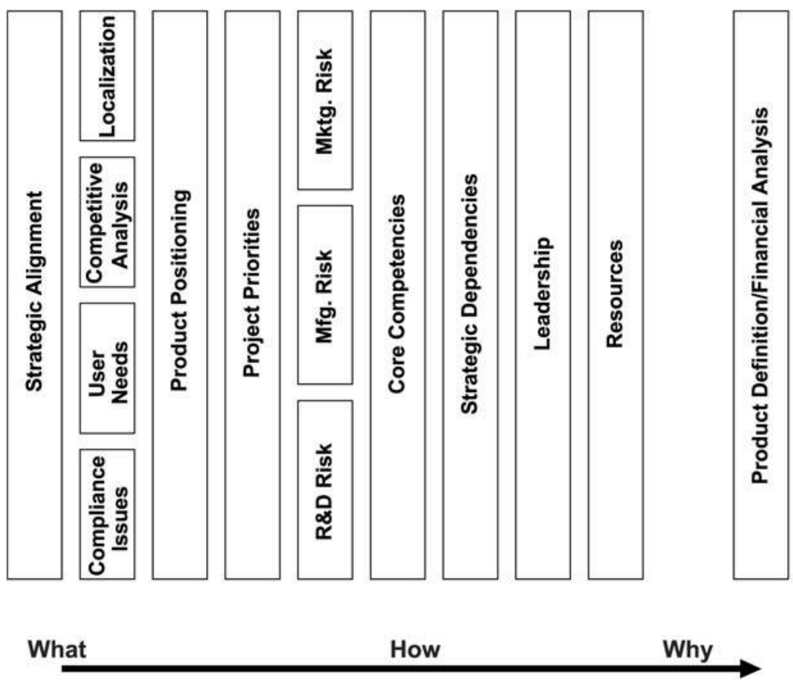

Figure 2.
Steps in the product definition checklist

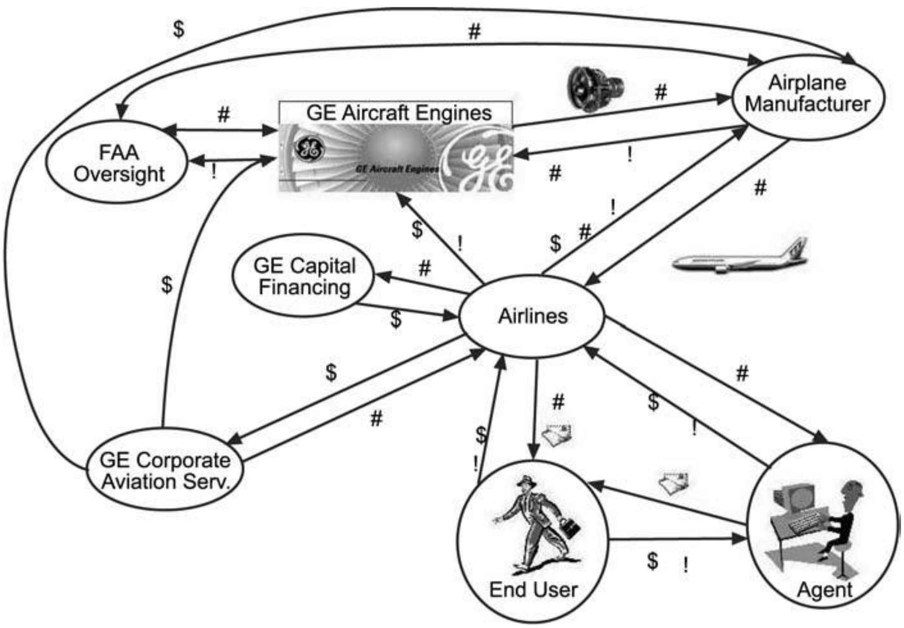

Figure 3.
Customer value chain analysis of an aircraft engine manufacturer

	Constrain	Optimize	Accept
Feature		X	
Cost	X		
Time			X

Figure 4.
Project priority matrix

S-curve. For example, depending on whether the model is a value-priced or top-of-the-line the role of features, cost, and time will vary. The matrix begins by identifying constrained factor (e.g. hard limit on time-to-market, hard budget/cost target, a new level of features/functions). Next, the priority to be optimized is determined (e.g. quicker time-to-market, minimize cost, maximize features). The remaining item must then be accepted.

These tools help correct common product development failures caused by excessive time spent in the definition phase due to poor direction, incomplete information, or lack of consensus as well as poor definition.

QFD is a structured approach for translating customer requirements into design specifications. It is a powerful tool that ensures proper communication between the client and design team (Cohen, 1995). QFD plays a central role in the design process. QFD can use information compiled from value graph and customer value chain analysis, and many other design tools and methodologies can be based on the QFD analysis results, like FMEA and cost-worth analysis (CWA). Traditional QFD analysis can be divided into two major steps. Usually QFD is associated with houses I (house of quality) and II (parts development), which relate the customer requirements, engineering metrics, and part characteristics (see Figure 5). Houses III (process planning) and IV (production planning) catalog key process operations and product requirements. The cost-worth table outlines a comprehensive analysis of worth based on functional importance and compares it to relative cost (Tanaka, 1989).

The heart of QFD is in the correlation matrices. Though there are various ways of representing the relationship, we advocate using the traditional simple use of the 0-1-3-9 correlation scale. Certainly, a continuous 0-10 scale can be used, but this scale is used for speed and simplicity. A score of "9" is given if the two factors are highly correlated. For example, a customer requirement of "lightweight" and the engineering metric "weight of the product" would likely have a "9." A "3" is given if the two factors are somewhat correlated, while a "1" is given for factors that are only slightly related. If the two factors have nothing in common, no score is given in the corresponding box of the matrix, (i.e. a zero). It is important to emphasize that the 0-1-3-9 scale is an ordinal relative scale and consider it as low-medium-high.

Project QFD method

Motivation

Project QFD helps clarify project goals and achieve organizational alignment. This tool can play an important role in managing the projects in an organization's portfolio and help organize future generation and platform issues. It is a tool that attempts to aid in the management of risk in product development projects. Sarbacker (1998) identified three axes in the framework of risk:

(1) *Envisioning risk*. Will a targeted product with the targeted product attributes create value for the customer and company?

(2) *Design risk*. Does the product as designed, embody the targeted product attributes create value?

(3) *Execution risk*. Can the development team deliver the product as-designed?

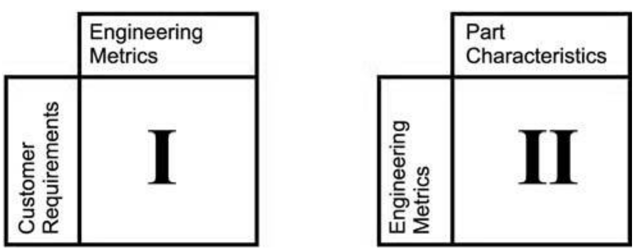

Figure 5.
Traditional QFD houses I and II

Only when these three axes are considered can product development risk be managed. The vision of project QFD is to identify and allocate important resources to use during the project. The best way to determine what is "important" is by seeing how they satisfy customer requirements. The difficulties with this advanced application of QFD are the focus on amorphous systems and processes as well as resolving multiple sources of requirements (voice of customer versus voice of business). One "customer" is the organization itself. As such, project QFD is some times referred to as "boss" or "business QFD" as it helps ensure that the business objectives are aligned with customer needs. Planning resources through organizational requirements ensures that the efforts spent during this project work towards organization success. As important as it is to satisfy user requirements, the project must make business sense to the organization.

Structure

Project QFD is a variation of the traditional QFD that seeks to manage risk and improve product definition and resource allocation. For an amorphous, indirect process, generalized functions are used to characterize engineering metrics and "solution elements" are used instead of parts. Customer requirements are used as keys to generate new system functions. In the modified house I, the project requirements are mapped against project metrics. In house II, the project metrics are mapped against project resources, perhaps organizational tools, DFM methodologies and tools like FMEA, or specific resources such as consultants or information databases. The method of calculating raw scores and relative weights is unchanged from traditional QFD (see Figure 6).

In house I, "project requirements" are the motivation and goals of this project as sought by the management or the organization. Project requirements often include goals such as a "fast time-to-market" or "increased market share." They can also include specific requirements for the product, such as "improve ease-of-use" or "improve ease-of-assembly." As opposed to traditional QFD which looks at the VOC of the end-user, project QFD concentrates on the internal customers of the organization and what likely is needed to meet business goals ("voice of the business"). Ideally the requirements should be phrased towards non-engineers, like accountants or lawyers, in a qualitative manner without using project metric terms. They should answer questions on why the project is taking place.

"Project metrics" are measurable parameters for a project. Simple project metrics include the project budget, measured in dollars, or the time-to-market, measured in weeks, months, or etc. They should be objective, absolute quantities rather than relative or subjective when possible. A cardinal number that is used in counting

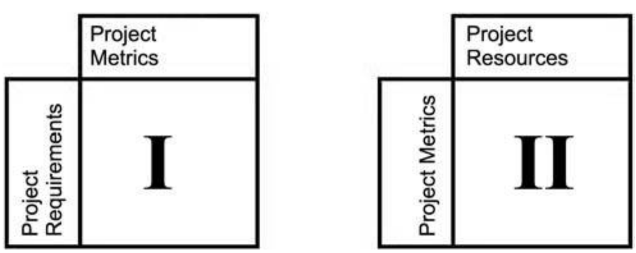

Figure 6.
Project QFD houses

quantity, rather than order (an ordinal number), is preferred for metrics as they are calculable and verifiable independently.

Table I demonstrates house I of a project QFD for a computer server chassis design project. The project team is a small team of outside consultants and the customer is the computer server company liaison.

In house II, the project metrics are then mapped against "project resources". For performing a QFD on an amorphous process rather than a product, the idea is to use broader solution elements rather than parts. Table II shows house II for the chassis design project QFD.

Some project resources and activities should be obvious based on experience or previous projects. A benefit of project QFD comes with doing house II more than once. First, do the analysis with all the resources that are currently used. Then, perform the analysis again and include new methods that have not traditionally been used to illustrate how they might impact the process.

Project CWA

Project CWA draws on value engineering tools like Tanaka (1989) and estimates the "costs" of various solution elements, methods, and activities, with a common scale considering the time, money, or resources required. This analysis facilitates identification of priorities and the activities that may need extra assistance or perhaps outside contracting. Table III shows a sample project CWA for DFM tools in the computer chassis example.

Figure 7 shows the project cost-worth diagram for the chassis example. The elements in the upper left are of high cost and low worth and, therefore, should be simplified or perhaps contracted out. Those activities in the right are high worth and should be emphasized in the project.

Generally, the cost of the resource would involve either the dollar cost or the time spent implementing and using the resource. The CWA doesn't specify on what scale these resources should be compared, though if one wishes to put money and time on the same scale, one possibility is to use the hourly labor rate as a conversion factor. Getting a "gut check" can be effective enough as the values in the QFD are not that exact either. As long as it is ordinal, the quantitative values are not as important as trends of relative worth.

Guide for project activity

There is often confusion in the distinction between requirements and metrics. Since the choice of these is so critical in QFD, it is important to properly differentiate them. The project requirements should be interpreted as organization's desires for the project. These are the project objectives that were likely determined by project leaders or organizational management. They should not specify particular parts or features, rather concentrate on project priority attributes, such as things that affect the feature subset, time-to-market, or cost of the project, and how the project fits within the organization's portfolio.

When teams have difficulty identifying project requirements, it is suggested they start by considering the priorities in the project priority matrix and then create phrases using a clear, concise grammar with an action verb-noun format. A sampling of key words is shown in Table IV below, an extract from Sarbacker's (1998) work in value

Table I. Project QFD house I chassis example

		Liaison Metrics							
Customer requirements	Customer weights	One chassis, % commonality	Development time	Tooling cost	Chassis inventory	Mfg cycle time	Service cost/warranty period?	Order fill rate	No. of variety
Faster development cycle of server	1	9	9						9
Cheaper to develop	1	9	9	9					
Give customer what they want any time	1	9			9	9		9	9
Cheaper to manufacture (tooling, inventory, throughput)	1	9		9	9	9			
Easy to support service	1	9			9		9		9
	Raw score	405	162	162	243	162	81	81	243
	Relative weight (%)	36	14	14	21	14	7	7	21

Table II.
Project QFD house II chassis example

Liaison metrics	Phase I relative weights (%)	dfM tool characteristics: CVCA	Value graph	Function-structure map	QFD	Cost worth analysis	Cost analysis	Scorecarding	FMEA
One chassis, % commonality	26	1	1	9	9	1		9	1
Development time	11	1	1	9	9			9	
Tooling cost	11	1	1	9	9	9	9	9	
Chassis inventory	16	1	1					9	1
Mfg cycle time	11	1	1	1	1	9	9	9	
Service cost/warranty period?	5	1	1		1	9		1	9
Order fill rate	5	1	1		9			1	
No. of variety	16	1	1	9			9	9	9
	Raw score	1.0	1.0	5.8	4.9	2.6	3.3	8.2	2.3
	Relative weight ($)	3	3	18	15	8	10	25	7

Tool	Cost or time	Relative worth (%)	Tool relative cost (%)	Cost/worth
CVCA	1	3	2	0.62
Value graph	6	3	12	3.72
Function-structure map	6	18	12	0.64
QFD	5	15	10	0.63
Cost worth analysis	3	8	6	0.71
Cost analysis	10	10	19	1.87
Scorecarding	3	25	6	0.23
FMEA	10	7	19	2.67
DFV	8	10	15	1.60
Total part cost	52	100	100	

Table III. Chassis project cost-worth example

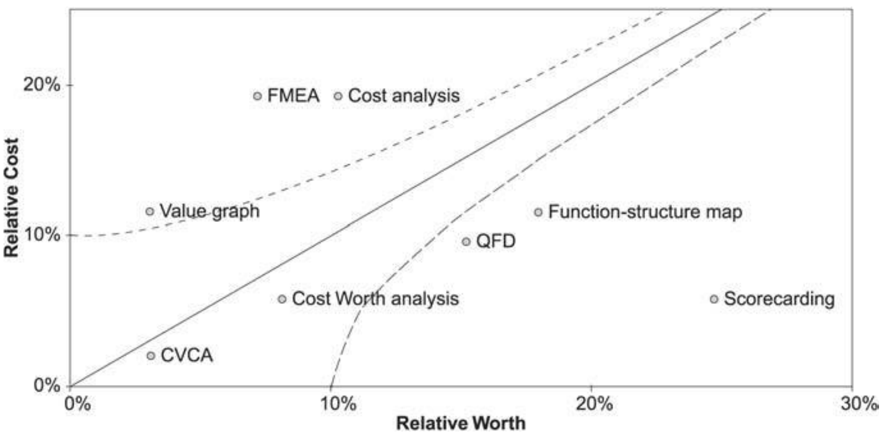

Figure 7. Chassis project cost-worth diagram

Action verb	Noun	Example
Increase	Design or process parameter	Increase drive speed to 20 mph
Decrease	Design or process parameter	Decrease drive speed to 10 mph
Implement	Design or process change	Implement digital control
Eliminate	Design feature or process step	Eliminate linkage adjustment
Substitute	New design or process for current design or process	Substitute 304 stainless steel for nickel alloy

Table IV. Action verb-noun grammar

feasibility evaluation method. When possible, the product design goals should be formulated include pairings of action verbs and nouns like “increase market share”. However, projects involve more than only engineering approaches, so not all requirements will be in this form. The team should then look at these phrases and try to answer why they are trying to accomplish this. These project requirements should not sound like the solutions but rather the high-level project goals and challenges, like “make cheaply”, “produce better quality”, and “meet new demand”.

Project metrics are tied to the "functions" of the systems. They should be interpreted as project success or progress measurements. These values should not only be quantifiable with units but also numbers that clearly give a picture of what is better (i.e. be ordinal). These numbers should measure the different project priority attributes. For example, different project metrics include product/project completion (percentage or man-hours), time spent (hours, months, or years), or money spent like dollars (Chao and Ishii, 2004). Often, the project requirements and metrics are very closely related. For example, a customer requirement of fast time-to-market relates very closely to the metrics of development time and production time. Working iteratively and looking at the requirements is a good way to brainstorm ideas for metrics, and vice versa.

The solution elements considered in house II are usually project resources but are not limited to design tools, methodologies, and activities. For example, some projects may need "supply chain analysis and design" or "salesmen training." For applications of project QFD in the Stanford mechanical engineering master's level course ME317, the students considered DFM tools in the modified QFD phase II, like benchmarking, cost analysis, FMEA, QFD, robust design, and scorecarding. Other resources that can be listed include other design teams and consultants, software packages, international standards, or government regulations. The solution elements can broadly be anything to achieve the functions, such as process modules for a platform. More extensive use of morphological analysis with the requirements and functions can help generate new system functions and solution elements.

Industry case study

This industry-based case study deals with an AC drive controller project in the drives group at a large, multi-national organization, which will be referred to in this example as "XYY". The "ACDC8" was developed at the Finland Drives (FIDRI) business area unit in the automation technology division of XYY.

The project "Avocado" dealt with the frame sizes R7 and R8, which include powers from 100 to 500 kW. Shown in Figure 8, the R7 and R8 frame sizes are important for the group because they need complete wall-mountable or free-standing product series up to 500 kW, and traditionally, XYY has had a large market share and relatively good margins in this area. Typical applications include fans, cranes, and pumps for industrial use. In general, customers are usually large, very conservative, industrial companies who are not necessarily willing to take on the very newest products. At the very least, they require backward compatibility in many cases.

One objective of the study was to determine the usage of different solution elements at XYY companies. One standard that had been established across XYY, and used at FIDRI, was the gate model. The gate model is an operational roadmap for driving product development from idea to launch. In this product planning methodology, the product development process is divided into a series of activities with decision points, or gates, at the end. Each stage contains a set of defined tasks, and the gates are the decision points at the end of each stage where the team must decide whether to continue the project, rework it, or kill the project. These gates, depicted in Figure 9, not only act as "quality control" checkpoints but also help synchronize the project. The results of project QFD would be used to help problems with identifying the right criteria and methodologies to use in the gate meetings.

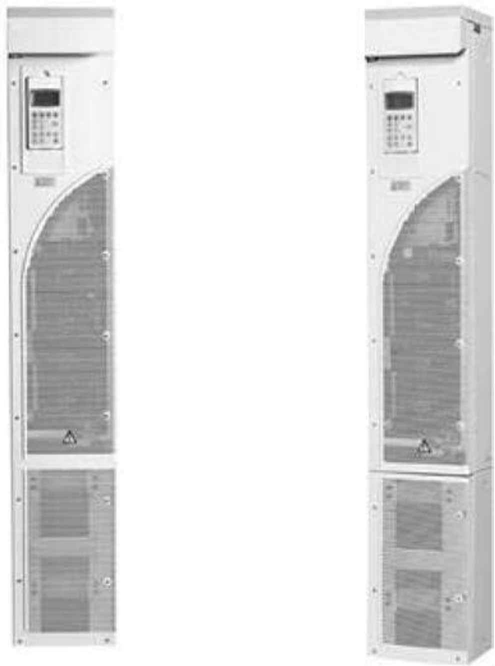

Figure 8.
ACDC8 high voltage drive controllers

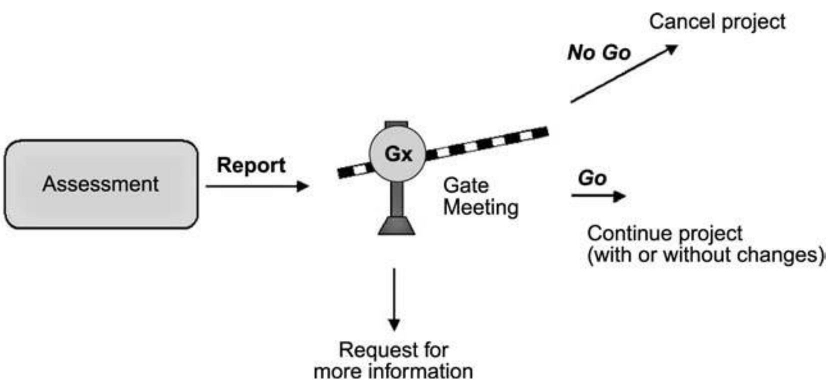

Figure 9.
Representation of XYY process gate

This project QFD analysis was performed by gathering requirements from the perspective of FIDRI management and the platform and project/R&D leaders and flowing them down through project metrics and tools/methodologies. For the QFD, the traditional 0-1-3-9 scale was used.

House I (requirements-metrics)

The project priorities for the Avocado development were to optimize the cost, constrained by the time, accepting the features. XYY believes it to still be the best drive controller currently available in motor control performance, although not necessarily in terms of product size and cost. Due to the competitive nature of the market, it was important to get to the market as soon as possible. The original target was to introduce a new product platform with the ACDC8 family, but the platform development was not successfully implemented within the schedule. Cost reductions would be accomplished primarily through modularity and commonization. In addition, it would offer faster commissioning and programming capability to help offset costs. The main goal of the ACDC8 was not to add new features, although certainly advancements have been made. The basic concept idea was roughly the same as the old concept. Customers of these drive controllers are typically conservative and not always willing to take new and unproven products. Table V organizes these requirements and metrics into the house I of the Avocado project QFD.

House II (metrics-resources)

The key methodologies used by FIDRI on this project were the process planning tools. Perhaps the most important tool used to manage the ACDC8 platform development was the Main Circuit Roadmap. With it, the desired platform variants were mapped against the different models. This was important not only in deciding the products and projects which would need to be pursued, but also helped somewhat with the resource allocation planning. The roadmap was crucial as the ACDC8 development involved replacing of a very large product range and required several different projects.

As mentioned before, the FIDRI group used a modified version of the XYY gate model. The model was a key to keeping the almost independent design teams within Avocado on the same page and keeping the project on schedule. The principle behind the gate model was that each gate would plan ahead to the next one. The initial gates were perhaps the most crucial for the development teams. Gate 0 involved the establishment of the project, and gate 1 set the planning for the rest of the project. However, some felt that the gate model was good more because it provided a common structure and schedule than for any management or decision-making purposes.

Software support was also important. The project was almost paperless in that weekly memos, official documents, change notices, and so on were all electronic and distributed electronically via e-mail. Also, the mechanical and electrical design and simulation tools were instrumental in the technical detailed design. For example, the use of Pro/ENGINEER was key to the mechanical design engineers. Finally, the collaborative and revision control software prevented minor problems. These solution elements are listed in house II of the Avocado project QFD in Table VI.

Project CWA

The next step of the project QFD analysis was the CWA of the different solution elements. Table VII lists tools used at FIDRI, cost in terms of effort, and worth calculated by project QFD.

Figure 10 plots these costs and worths in a two-dimensional graph, with worth on the X-axis and cost on the Y-axis. Elements in the upper left quadrant are tools that are of extremely high cost where efforts should be made to deemphasize the project reliance on them.

XYY was interested in implementing more structured methods in their product development. To demonstrate how design methodologies could benefit the project,

Table V. Avocado project QFD house I

		A	B	C	D	E	F	G	H	I	J	K	L	M
Estimated market share increase														
Existing ACDC6 replaced (%)		+												
TTM		+	+											
Commonality (%)		+	+	+										
Development time		+	+	+	+									
Training time		+		+										
Mfg cycle time		+		+										
Service/warranty/concession costs		+				+	+							
Order fill rate		+				+	+							
No. of models		+	+		+	+	+	+	+					
No. of different parts					+	+	+	+	+					
Profit					+	+								
No. of existing ACDC6 replacable		+	+								+			
	Preferred	+	+	–	+	–	–	–	–	+	+	–	+	+
		Project metrics[a]												
Project requirements	Organization weights	A	B	C	D	E	F	G	H	I	J	K	L	M
Decrease cost	9	3	3			3		3	1	9	3	9	9	3
Decrease size	9	3	3			9		3	1	3		3	3	3
Improve ease of use	3	3	9	3		3				3	3		3	9
Improve ease of production	3		1	9	3	3	3	3	3		3	3		
Improve field quality	3	3	9	3		9	3		3					3
Improve performance and functionality	3	3	3	3		3	9		9		3	1		3
Decrease the number of components	3	1	1	3	9	3		3	3		9	9	3	
Increase commonality of components	9	1	1	3	9	3	1	1			3	9		
Use commonly available components	3			3	9	3		1	1		3	9		
Improve throughput	1	1	1	3	1			1			1	1	9	
Be able to use second source suppliers	1	1		9	3				1		3		3	
Reach market quickly	9		3	9	1	9	3	1		3	1		3	3
	Raw score	49	84	45	22	87	37	23	46	45	43	58	60	63
	Relative weight (%)	8	14	7	4	14	6	4	8	7	7	9	10	10

Note: [a] A = estimated market share increase; B = existing ACDC6 replaced (%); C = TTM; D = commonality (%); E = development time; F = training time; G = mfg cycle time; H = service/warranty/concession costs; I = order fill rate; J = no. of models; K = no. of different parts; L = profit; M = no. of existing ACDC6 replacable

Table VI.
Avocado project QFD house II

Project metrics	Phase I relative weights (%)	XYY resources A	B	C	D	E	F	G	H	I	J	K	L	M
Estimated market share increase	5	1			3		3	3	9		3		1	1
Existing ACDC6 replaced (%)	8		3		1	3	3	3	9					
TTM	10	3	3	9	9			3	1	1	3	1		
Commonality (%)	8	9	3			3	3	3		3				
Development time	15	9	3	9	9	3	3	3		1	3	3	3	3
Training time	4	3	3	1						3	3	3	1	1
Mfg cycle time	5		3		3	1				3				
Service/warranty/ concession costs	4	3	9	3		1				3	9	3	1	1
Order fill rate	7								9					1
No. of models	7	3	9		3	1	1	3		3	3			
No. of different parts	13	3	9			9	1			3	3			
Profit	8	3	1					3	9				1	3
Existing ACDC6 replacable (%)	6	9	9	3				3		1				
	Raw score	4.0	4.3	2.5	2.8	2.3	1.3	2.0	2.7	1.5	1.9	0.8	0.7	0.9
	Relative weight (%)	15	15	9	10	8	5	7	10	6	7	3	2	3

Note: A = Engineering know-how; B = ACDC6 experience; C = Main circuit roadmap; D = VAKKA (gate model); E = Pro/ENGINEER; F = Statement of product need (SOPN); G = Management oversight; H = Marketing studies; I = Simulations and testing; J = Design reviews; K = Failure documentation; L = Other BAs; M = Consultants

Tool	Cost or time	Relative worth (%)	Tool relative cost (%)	Cost/worth
Engineering know-how	18	15	23	1.54
ACDC6 experience	6	15	8	0.49
Main circuit roadmap	3	9	4	0.41
VAKKA (gate model)	6	10	8	0.75
Pro/ENGINEER	9	8	11	1.38
Statement of product need (SOPN)	1	5	1	0.27
Management oversight	1	7	1	0.17
Marketing studies	3	10	4	0.39
Simulations and testing	9	6	11	2.04
Design reviews	9	7	11	1.60
Failure documentation	3	3	4	1.33
Other BAs	3	2	4	1.59
Consultants	9	3	11	3.48
Total tool cost	80	100	100	

Table VII.
Avocado project CWA

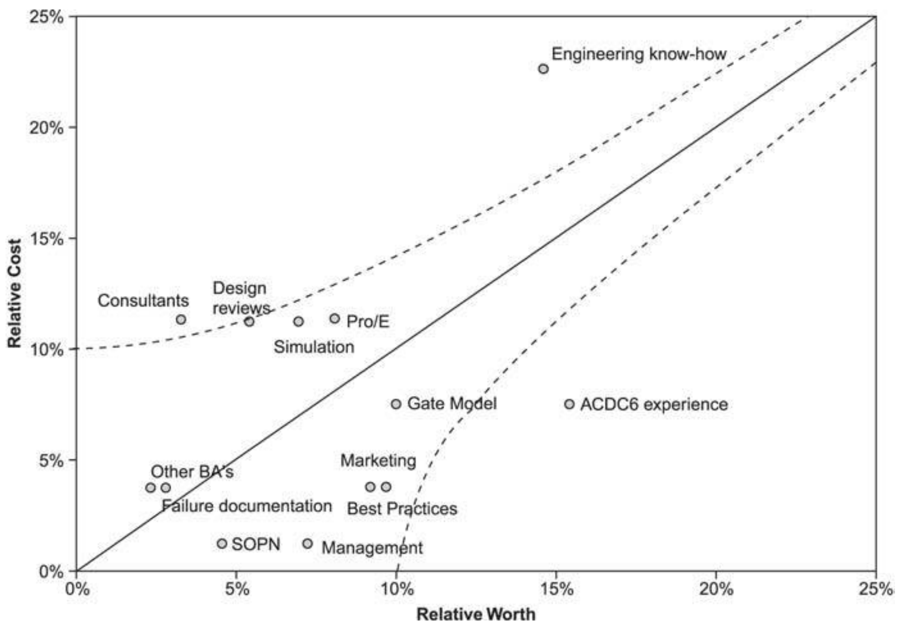

Figure 10.
Cost-worth diagram of Avocado project with FIDRI solution elements

another project QFD and CWA included selected DFM methods. Table VIII and Figure 11 show these results.

For example, scorecarding is a tool to relate quality into technical and product definition. Whereas QFD "flows down" the customer requirements to part attributes or process parameters, scorecarding is a six sigma approach which "rolls up" to evaluate performance satisfaction by providing a snapshot of how the company is doing. By determining a transfer function between process control factors and noise factors and

Table VIII.
Avocado project CWA with DFM tools

Project resource	Cost or time	Relative worth (%)	Tool relative cost (%)	Cost/worth
Engineering experience	9	7	15	2.26
Main circuit roadmap	6	9	10	1.12
VAKKA gate model	6	9	10	1.09
ACDC6 experience	9	11	15	1.36
Gantt chart	1	6	2	0.31
Collaborative software	1	6	2	0.29
Marketing analysis	6	9	10	1.09
Risk management	1	3	2	0.49
Platform analysis	1	7	2	0.23
Benchmarking	3	2	5	2.19
CVCA	1	1	2	2.17
QFD	3	7	5	0.69
FMEA	3	5	5	1.05
Knowledge management	6	5	10	1.98
Scorecarding	3	12	5	0.43
Total tool cost	59	100	100	

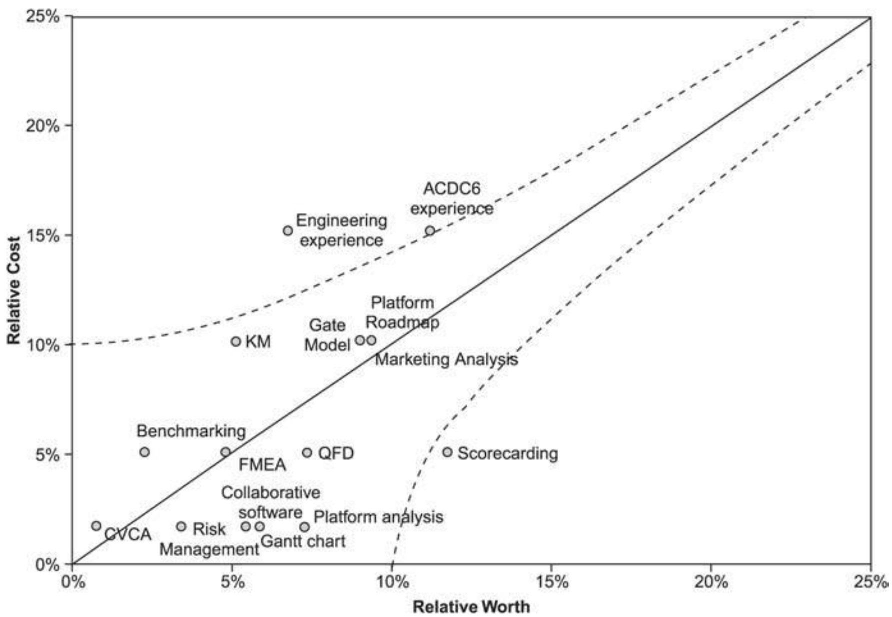

Figure 11.
Cost-worth diagram of Avocado project with additional DFM tools

relating them to the project objectives and measures, a project can better emphasize quality. Though these tools seem quite simple, they are very specialized and can be completed in less time by focusing the analysis on key aspects of the projects. An additional benefit of these tools is that they make the analysis transparent and easily documentable for other design members or even future projects.

A case study across the organization, including FIDRI and other XYY business area units, showed that XYY's businesses and products extended across a spectrum of both hardware and software and new and mature technologies. However, across the organization there was a common need for improvements in risk management, product definition, time and resource allocation, team collaboration, and communication. Project QFD can help with all these issues. Though XYY does use the gate model, further development of the product development process is necessary. There was a lack of standardized design methodology or strategy and an over-reliance on engineering experience. XYY needed help identifying the role of structured tools in product development. Different business areas required different types of tools. Project QFD was identified as one of the key product definition tools which could help the organization across the entire spectrum.

Survey using industry-provided design projects at Stanford University

The project QFD method has been used in both industrial (like GM and Toshiba) and academic environments, particularly in the master's level class ME317 Design for Manufacturability at Stanford University. This class was used as a testing ground for the application of project QFD over the last three years.

ME317 (http://me317.stanford.edu) addresses systematic methodologies to define, develop, and produce competitive products. The methods cover characterization of user values, DFM, and other life-cycle values such as reliability, serviceability, and environmental compatibility. It is a six-month long, team project course with students in four countries. The first quarter, ME317A, addresses key issues of competitive product development. In the course project, student teams identify opportunities for improvement and apply structured methodologies to develop a comprehensive product definition. Following the product definition process covered in ME317A, ME317B focuses on quality implementation of the product definition. In the course project, groups of students apply structured methods to optimize the design of an improved product and plan for its manufacture, testing, and service. The methodologies covered include tools such as value engineering, product definition, concurrent engineering, QFD, design for assembly, design for variety, process and materials selection, design for producibility, concept generation: morphological analysis, concept selection: Pugh's method, design for robustness, design of experiments and taguchi method, statistical process control and six sigma process, poka-yoke, and risk management.

While project QFD was not a course requirement, many teams used the method to plan their project tasks. The analysis began by asking the team who the "customers" of their project are and what their VOCs are. Then, the teams proceeded with the application of QFD with the assistance of the ME317 teaching staff and MML research assistants. For the "cost" of applying each tool, the staff worked with the team to come up with a rough estimate of the time required to apply the tools or accomplish the tasks and rated them ordinally.

The first year the students performed project QFD near the end of the first quarter of 2001 in this two-quarter sequence. Three of the seven project teams used project QFD. Though many factors were involved, it is notable that the teams that used the project QFD had a higher average score on their final grades than the teams who did not. In 2002, nearly every team used the tool. The students worked with companies such as Sun, GM, BAE, Medtronic, and St. Jude Medical. Afterwards, the students offered their views of the tool and rated the effectiveness of the tool in a few key areas:

- the project QFD analysis helped us understand our project requirements;
- the project QFD documentation provided was sufficient to perform the analysis;
- guidance from the teaching staff was necessary to perform the analysis;
- it was difficult to perform the phase II analyses because we were unfamiliar with the DFM tools;
- we discussed the project QFD results with our liaison and/or coach;
- our project resource allocation reflected the project QFD CWA results; and
- performing the project QFD helped us in the project and final report.

The students answered each on a scale from "strongly agree" to "strongly disagree", quantified as in Table IX and then plotted.

Figure 12 shows that on five of the seven questions, the students overall agreed with the statement. The remaining two had both "agree" and "disagree" and averaged to zero.

The students largely agreed that the tool was very useful and really helped with the product definition of their project. Though more resources and documentation were made available to the students, because this tool is applied early in the project while they were still learning DFM methods, the application of house II of project QFD was still challenging for some projects. Not only were they still learning what the different tools were, but they did not have a good grasp of what was involved in applying the solution elements. They relied largely on the project team coaches and the teaching staff. In an industry setting or one where the team members are more familiar with the tools, this is less of an issue.

Conclusions

As with traditional QFD, project QFD is a design for six sigma approach that helps assign and relate project resources and solution elements. For an amorphous, indirect process, generalized functions are used to characterize engineering metrics, and "solution elements" substitute the parts. By starting with what the organization deems as important, the voice of the business is captured in the customer value chain. A company can sell many units at a loss simply to make the consumers happy, but decisions must make sound business sense. Though QFD tools are not always well accepted, they can play a role in not only analyzing the organizational requirements and resources but also are a good forum to discuss, document, and share product definition view. Companies like GE have to work with a number of internal VOCs as

Agreement	Quantitative value
Strongly agree	2
Agree	1
Neither agree nor disagree	0
Disagree	−1
Strongly disagree	−2
Not applicable	Not averaged in

Table IX.
Quantitative agreement rating scale

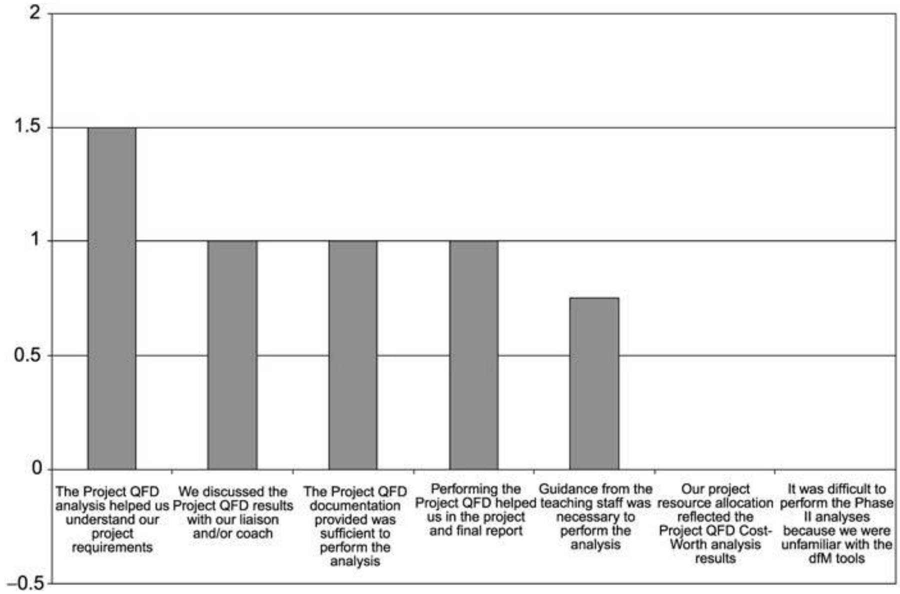

Figure 12.
Project QFD survey averages

well as those of external customers. Project QFD helps error-proof design by clarifying project goals and achieving organizational alignment.

Continued research is taking place on further design process error-proofing applications of this tool, mainly for project risk management as a way to prioritize risks and allocate resources during reviews. Support for this work comes from industry and government agencies such as GE, ABB, and NASA to work within their product development process life-cycle models and phase or gate reviews. These organizations identified project QFD as a key product definition tool that could help deploy solution elements and resources. Even when technical engineering peer reviews cover all subsystems, they are not always done in a consistent fashion or are too shallow technically. For example, at NASA, the areas to be peer reviewed are chosen through a negotiated agreement between the review chairperson and the project manager. Some of the criteria used to decide subsystem review allocation include: technological readiness level, complexity, criticality to overall performance of the total system, breadth of the technical area over the entire project, information on the subsystem at a previous review, and past history of trouble. The project QFD method can help plan the sub-system reviews based on such criteria.

An electronics company in Japan has already used the tool successfully in projects for Internet phones and semiconductors and in platform and business model development. In addition to being part of ME317, projects in the advanced DFM course, ME417 Total Product Integration Engineering, at Stanford have used project QFD as a guide in new tool development and explored new applications of it, such as for product portfolio alignment. The method and supporting material is going through continuous refinement as they encounter more examples.

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