How lessons learnt from using QFD led to the evolution of a process for creating quality requirements for complex systems

Key words: Customers Needs, Requirements, Performance Based Specification (PBS), Quality Function Deployment (QFD), Case Study, Lessons learned, Quality Requirements Definition (QRD), Complex systems.

1.1 Abstract

While the requirements document is an important product, and the importance of good requirements has often been stated, little attention has been given in the systems engineering literature as to the application of published techniques for eliciting requirements for new products. It is likely that this lack will be remedied in the future, and many of those techniques will be adopted and published in the systems engineering literature. However, just reusing those tools for creating specifications for complex systems is as fraught as the reuse of software without investigating the context from where the proposed reusable module was taken from and its suitability for use in the new context. This paper addresses that issue, in the context of Quality Function Deployment (QFD) which has been used in the commercial arena to elucidate and negotiate requirements for new products for at least 20 years. QFD has a lot to offer with respect to new products, but when used to specify the requirements for complex systems, has been found to have a number of deficiencies. This paper summarizes the top six lessons learned from 15 years of experience in using QFD in the elicitation, elucidation and negotiation of requirements for complex systems and documents a process for creating requirements by identifying the customer's needs and transforming them into well-written requirements. The most important contributions made by this paper are the modifications to QFD in the form of the decision table and the evolution of QFD into a process for defining requirements for complex systems named Quality Requirements Definition (QRD).

Note to Editor –please place Table of Acronyms as a Sidebar Panel

Table 1 Acronyms

EQFD	Enhanced QFD
HoQ	House of Quality
IPDT	Integrated Product Development Team
JAD	Joint Applications Development
NGT	Nominal Group Technique
PBS	Performance Based Specification
QFD	Quality Function Deployment
QRD	Quality Requirements Definition
RFP	Request for Proposal

SRR	System Requirements Review
TVDT	Target Value Decision Table
UML	Unified Modelling Language
VOC	Voice of the Customer
VOE	Voice of Engineering
WTP	Willingness to Pay

2 Introduction

Product development processes have achieved a state of some maturity in recent years, but have focused primarily on structuring technical activities from the initiation of the product development to its launch. Consequently, the following major advances are being advocated:

- implementing an end-to-end process from the front end through field operations,
- better integration of business considerations into the end-to-end process, and
- incorporating performance improvements activities into the process.

Holmes and Campbell report that focusing on these issues has improved business performance in two large companies and a small health care start –up [Holms and Campbell, 2004]. However, the current development paradigm for complex products (systems) is characterized by large cost overruns, schedule slips, and dramatic performance deficiencies. The reasons for these failures are varied however a major contribution to the failures is poor requirements [Carson, 2001, Goldsmith, 2004, Hooks, 1993, Jacobs, 1999, Kasser, 2000, Kasser and Schermerhorn, 1994]. Now this does not mean that the problem of translating customer needs to requirements has not been addressed since a number of tools have been developed and documented. These include interviews [Alexander and Stevens, 2002], Joint Applications Development (JAD) [Wood and Silver, 1995], scenario building, user/customer interviews, questionnaires, customer visits, observation, customer value analysis, use cases, contextual inquiry, focus groups, viewpoint modeling [Darke and Shanks, 1997], and QFD [Clausing and Cohen, 1994, Hauser and Clausing, 1988]. However, the paradigm is still less than optimal since for example, often in

- **Government development cases** - the paradigm still produces products that do not perform as needed, or projects that are cancelled or suffer major cost and schedule overruns.
- **Commercial development cases** - the paradigm produces products that are consigned to the scrap heap or junk pile.

Moreover, in addition to poor performance requirements, sustainment requirements are often conspicuous by their absence (after the fact) and poor supply chain requirements often result in equipment that cannot be transported to destinations, or cannot easily be installed or shown to the potential customer. In these instances, distributors or retailers tend to market a competitive product that can be easily installed or shown to potential customers. These non-performance requirements are as critical as the performance ones since if the product does not get to the market, it cannot be sold.

It is likely that this situation will be remedied in the future, and many of the published tools and techniques for requirements elicitation will be adopted and published in the systems engineering literature. However, just reusing those tools for the development of requirements for complex systems is as fraught as the reuse of software without investigating the context from where the proposed reusable module was taken from and its suitability for use in the new context. The danger of such software reuse was demonstrated in the failure of the maiden flight of the Ariane 5 launcher on 4 June 1996.

Clausing suggested enhancing QFD to deal with complex products that are conceptually dynamic [Clausing, 1994]page 60) and to include concept evaluation and selection in an enhanced QFD (EQFD) process [Clausing, 1994, Clausing, 1995, Cohen, 1995];. Blanchard and Fabrycky suggest that QFD is an excellent tool to be applied in the determination of Technical Performance Measures [Blanchard and Fabrycky, 2006] page 76). As such, QFD is one of the tools that is likely to be adopted by systems engineers for requirements elicitation and elucidation. However, more than 15 years of experience in using QFD and enhanced QFD [Clausing, 1994] has indicated that QFD is indeed an excellent tool but it must be extended for use in developing requirements for complex systems. This paper documents the top six lessons that have been learned during those more than 15 years of experience in developing requirements for complex systems. These lessons learned have resulted in both tools and a process, the combination of which can quickly provide a good set of requirements. This combination was first used to improve the tools and the existing processes and later formed the basis for the QRD process incorporating an extended QFD currently used in the activities performed in developing requirements for complex systems.

In the course of evolving QFD into QRD almost 200 published applications of QFD were studied and research was conducted into the special characteristics of QFD when applied to the development of requirements for complex systems. This research identified issues with QFD in applications to developing the requirements for complex systems as well as some ideas and recommendations on how to deal with them. The research concluded that awareness of the problems and implementation of the recommendations on how to handle these problems discussed in this paper can contribute to smooth and successful application of QFD, despite the presence of these dimensions of complexity [Hari, 1993, Hari and Zonnenshain, 1993].

Since systems engineering terminology sometimes depends on the position of the systems engineering activity in the Hitchins-Kasser-Massie two-dimensional framework of systems engineering [Kasser and Massie, 2001], Table 2 contains a list of words and their specific meanings in the context of this paper. The remainder of the paper describes the tools, some modifications to the tools, and the QRD process. Thus

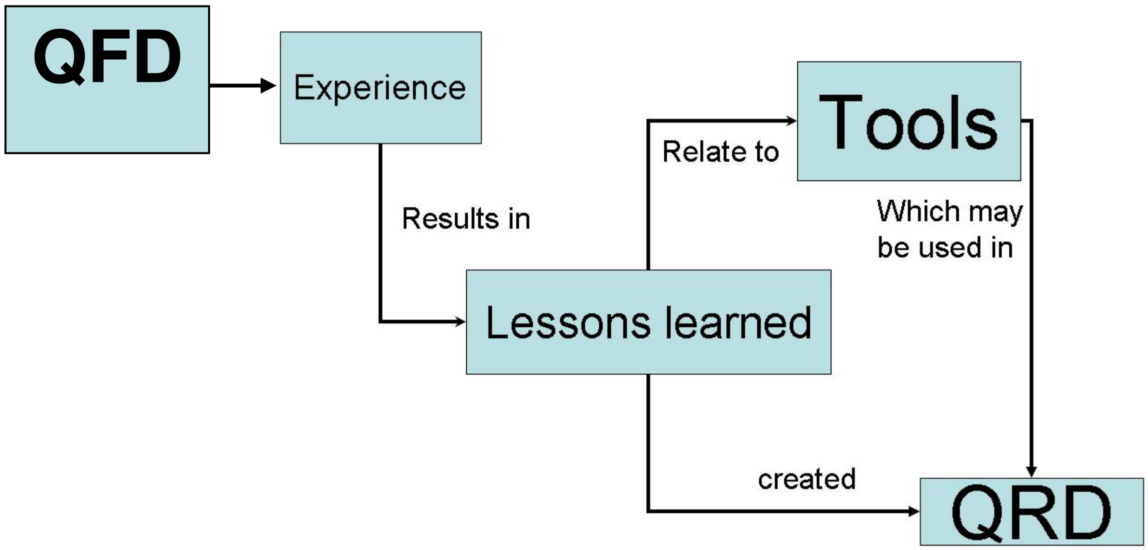

Figure 1 The relationship between experience, tools and the QRD multi-methodology

- Section 3 presents a baseline of the requirements development processes in both government and commerce for simple products and for complex systems.
- Section 4 presents a summary of the lessons learnt during the development of QRD.
- Section 5 presents the key conclusions from the research which analysed the contribution of QRD through real commercial and government projects workshops, interviews and design laboratory experiments.

Note to Editor: Please place following Table as a sidebar

Table 2 Definitions of terminology used in this paper

Customer – an entity that purchases or influences the decision to purchase the new product once implemented. Traditional systems engineering has been used in situations where the customer is known, namely a government agency. In the commercial arena, the customers for a product may not exist until the product is developed and marketed. These customers may be considered as desired customers.
Goal - Something a customer wants or would like.
Methodology – A specific implementation of a process (how the process is implemented).
Need - Something that solves a customer's problem (stated in non-quantifiable terms, may be incorrectly and/or incompletely articulated; stated in solution language rather than problem language). Moreover, what the customer thinks they need may not be the solution to the real problem.
New product definition – A complete set of requirements for a yet to be developed complex system or product as approved at the stage gate immediately before the design stage of the development process.

Process - A generic sequence of events of what has to be done to create a product.
Product, system – Used interchangeably to describe the tangible artefact that is the output of the production or development process.
Real Need – Something the customer needs to solve their problem. However, the customer may not know what they need or be able to articulate that need.
Requirement - "A statement that identifies a product or process operational, functional, or design characteristic or constraint, which is unambiguous, testable or measurable, and necessary for product or process acceptability (by consumers or internal quality assurance guidelines)"[IEEE, 1998].
Requirement request – A draft requirement that has not yet been accepted as a requirement. This is an intermediate product in the transformation process of needs to requirements because the initial set of requirements is not accepted until the stage gate System Requirements Review is complete.
Specification – A document containing a collection of requirements.
Stage Gate Review – a milestone review at the end of a stage of the system development life cycle. These are generally known by the stage of the process they end, i.e. System Requirements Review, System Design Review.
Stakeholder – An entity with an interest in the definition of the new product. Examples of stakeholders are users and wholesalers.
Translation process – The process of translating needs to requirements. Note one need may generate several requirements, while one requirement may be traced back to several needs.

3 The requirements development process

In both government and commerce, the early part of the product (complex system) development life cycle, the requirements development process is concerned with the development of a new product or system. This process has been called the definition of requirements for new products, the definition of requirements for complex systems and various other names. In this process, needs are identified and converted to requirements. This simple statement hides a complicated situation since while the process is generally shown as a sequential series of steps, in reality it ends to be iterative, or multi-phased and difficult to control [Kasser, 2002]. No wonder poor requirements have been cited as a major cause of cost and schedule overruns in the acquisition of Defence and information systems for at least 15 years. Thus it should not come as a surprise that the performance requirements generated by the current process are often expressed in solution language not in problem language, and tend to be incomplete, incorrect, and badly written [Carson, 2001, Goldsmith, 2004, Hooks, 1993, Jacobs, 1999, Kasser, 2000, Kasser and Schermerhorn, 1994] and there have been many attempts to improve the process.

In order to improve the requirements creation process, one needs to know what is wrong in terms of things that are being done badly, incorrectly, or not at all. For this reason process improvement initiatives begin by establishing a baseline and then often compare the baselined process with a conceptual model of an ideal process. The resulting gap analysis provides the information necessary to create a plan for achieving an improved process conforming to the desired standard or model [Kasser, 1995]. The current baseline seems to be:

- Tools for requirements elicitation exist, have been published, but somehow don't seem to be used in mainstream systems engineering.
- There is a high degree of probability that those tools will soon be adopted.
- There is a need to determine if the tools need adapting before being adopted for eliciting the requirements for complex systems.
- As a consequence, systems engineers need to be sensitised to the perils of adopting tools designed for determining the requirements for simple systems without determining their fitness for use in determining the requirements for complex systems.

This paper addresses that need in the context of QFD and discusses the evolutionary adapting and extending of QFD which resulted in the evolution of a process for defining requirements for complex systems named QRD in the context of the top six lessons learned over 15 years of working with different projects of different degrees of complexity.

4 Lessons learned from the current paradigm

QFD is a useful tool for developing the requirements of new products, and its benefits are well documented [Clausing and Cohen, 1994, Cohen, 1995, Hauser and Clausing, 1988, King, 1989]. However, when used for the development of requirements for complex systems it needs to be extended as the following summary of the six most important lessons learnt using QFD shows.

1. QFD is a time-consuming process and difficult to apply in developing the requirements for complex systems as discussed in:
    - Definition of Space vehicle engine in Pratt & Whitney [Lecuyer, 1990]
    - Definition of Hybrid components in Hughes [Bersbach and Wahl, 1990].
    - Definition and Concept selection of Space Launcher System for the Air-Force Space Command [Weiss and Butler, 1992].
2. The process that produces the definition of a complex system contains more activities than QFD.
3. QFD does not support making Target Value Decisions for complex systems. This information is necessary to make the informed critical decisions required to produce the performance based specification (PBS) [Stanberry, 2004].
4. The methodology for definition of a complex system must be tailored to the unique characteristics of each product, organization and culture. There is no "silver bullet" – that is there is no single methodology that can support the entire process of defining the requirements for complex systems.
5. QFD cannot be used when requirements are stated in specifications incorporated in requests for proposals (RFPs) Moreover, RFPs tend to specify design requirements, including materials to be used and how a requirement is to be achieved, or the methods for its production rather than required performance results and criteria for

verifying compliance [Stanberry, 2004]. This situation decouples the product developers from the customers and limits their ability to satisfy the real needs. In the event this situation cannot be avoided, the team developing the specifications for the new-product needs a way to determine the original performance needs of the customers.

6. The requirements elicitation and elucidation phase of the product development life cycle should be terminated and formally approved by a stage gate review (e.g. a System Requirements Review (SRR) presented to the stakeholders and senior decision-makers such as the stage gates incorporated in the PRINCE 2 methodology [Bentley, 1997].

This paper now discusses these lessons learnt in some detail assuming that the reader has some knowledge of QFD.

4.1 Lesson Learnt: QFD is a Time-Consuming Process and Difficult to Apply for Complex Systems

The most important lesson learned is that the perception that QFD is time consuming and difficult to use for developing requirements for complex systems was true. This due to the nature of the House of Quality (HoQ), the matrix tool used in QFD to translate customer's needs into product characteristics[1]. In general the literature on QFD applications with large HoQ matrices is sparse and tends to discuss unique applications such as the Master HoQ [Cohen, 1995] which discussed a HoQ containing 7500 cells and concluded that the effort was worthwhile. Akao's book on QFD also provides a very informative variety of Japanese applications of QFD with very detailed matrices, and many levels and types of deployments [Akao, 1990].

On the other hand there are examples in the literature that discuss the time consuming nature of QFD in the definition of requirements for complex systems [Bersbach and Wahl, 1990, Lecuyer, 1990, Weiss and Butler, 1992]. This is because it was found that when QFD is applied to complex system products and multi-level hierarchical systems consisting of subsystems, assemblies, subassemblies and many parts, the House of Quality (HoQ) [Clausing and Cohen, 1994] can't cope with the many needs of the customers and the large number of characteristics [Hari and Zonnenshain, 1993]. Moreover, [Cohen, 1995] p 244) also describes one of his QFD projects with 110 customer needs and 155 quality characteristics which required overwhelming and unacceptable time and patience.

Remedy: Modify the House of Quality

We modified the HoQ to shorten the process as discussed below.

[1] The product characteristics also known as Measures of Performance, are attributes expressed in technical terms (Voice of Engineering (VOE)) which are used to measure the performance of the product. Examples are range, accuracy, weight, reliability, cost, or time to market.

We reduced the number of rows to no more than 15-20 system level needs[2]. We reduced the number of columns in the HoQ to no more than 20 – 25 product characteristics (columns), these being the most important, difficult, or controversial decisions. These are selected in the preparation process for the QFD workshop by the representatives of the Voice of the Customer (VOC) together with the representatives of the VOE.

Our experience which reinforces the literature discussed above has shown that QFD workshops which discuss large matrices and take a long time to complete are impractical and not effective. In practice, most of the workshops that had not had a pre-workshop reduction of the size of the HoQ to less than about 20 rows by 25 columns were never completed because the participants gave up after becoming exhausted by the process.

Risk management is performed at the SRR which takes place at the end of the process. The process of preparing for the SRR provides a final quality check that a critical parameter has not been overlooked in the process of reducing the number of rows.

By intelligently modifying the HoQ we shorten the process by focusing the team effort on the important decisions produced by the QFD process without sacrificing any of its benefits. For example

- By limiting the number of columns, we focus the team on the most important and hard to decide decisions thus saving the time currently spent in discussing correlations with trivial characteristics. This approach gives us the most important benefits of the process making it a more efficient and agile process which can then be applied even to very complex systems.
- By discussing only those contradictions which actually constrain the decisions about the target values we reduce the time to perform the QFD since building the traditional QFD HoQ is very time consuming (taking 4-8 hours for 25 columns) because we have to discuss every combination of every characteristic.

We also added a column entitled "other characteristics" to the HoQ. This column also helps to reduce the total number of columns by not including every characteristic in the matrix while simultaneously not ignoring them later when we complete the specification. Any characteristic which is included in the modified HOQ goes through the whole process of correlation analysis with all the customer’s needs, then it is discussed in the decision table, compared with competitors, significance analyses and more, while "an

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[2] The reduction in the number of rows is where expert knowledge is applied to shorten the process. This is a tried and true approach. For example, in decision making, when developing options for alternative courses of action, those with a priori knowledge of a low probability of success are trimmed from the decision tree in the construction phase. Similarly, the standard binominal process for finding a fault in an electrical circuit is to start about half way along the circuit and test for voltage, signal or some indication that the fault is down stream from the test point. Depending on the result the tester either goes to a point back half way back to the start, or half way forward to the end to try again. This process continues until the fault is located, whereupon the faulty component is repaired or replaced. Yet when a light bulb fails to illuminate, the standard process for identifying and fixing the problem has become to apply the a priori knowledge of component reliability and replace the bulb before testing any of the remaining components of the circuit. This concept of applying a priori knowledge is applied to reduce the number of parameters of interest hence the number of rows.

easy to decide characteristic" which is written down in the "other characteristics column goes directly to the specification skipping all the process and the time it requires.

The Integrated Product Development Team (IPDT) documents any product characteristic which contributes to satisfying a need and is not included in the 20-25 characteristics in the “other characteristics” column for discussion. This minimizes the time spent discussing trivial decisions, yet ensures those characteristics are not forgotten later.

We removed the roof (the analysis of the correlations among the product characteristics) because it is time consuming, and provides little benefit. Instead, it was decided to discuss only correlations that actually affect the decision on target values and to include this discussion in the Target Value Decision Table (TVDT) discussed in Section 4.3. Thus, one additional column in the TVDT performs the essence of the analysis.

We trimmed the Customer Needs Hierarchical Tree. The Customer Needs Hierarchical Tree is a visual structure of the customer’s needs arranged in a tabular format in a hierarchical order. The reason we use a tree is because the effort of capturing the VOC and other requirement requests may produce a large number of customer’s needs, at various levels of detail. Moreover, some detailed needs may also be manifestations of higher level needs. For example, the top-level needs for a portable light source may be summed up qualitatively as lightweight, reliable, and easy to handle.

To prioritise the needs of the customers we evolved an approach that used the simplest method of calculating importance in order to communicate the different views and interests of the various customer’s representatives, to share their knowledge on each other priorities and concern and to quickly reach an acceptable consensus. We tried various methods of prioritisation including Analytical Hierarchical Process (AHP) [Saaty, 1990], Nominal Group Technique (NGT) [Memory Jogger, 1985] and found NGT to be the most cost effective, since you can usually reach an agreement on prioritisation on about 20 needs with in 1-2 hours while AHP would generally take at least twice as long. We preferred splitting 100% of customer satisfaction among the customer needs as a method which reflects the opinions in the team better than the traditional 1-5 scale. This approach supports the hierarchical structure of the customers needs and creates more of a significant difference between the most important customer’s needs. As a result we get more significant variations in the characteristics of the products which emphasise the most important decisions clearly. For example in the flashlight case study shown in Figure 2 the fact that the volume of the flashlight is 16 times more important than the time to change the battery reflects the customer’s preference for a competitor’s product since this characteristic is a “most important need”.

The QFD literature [Cohen, 1995, King, 1989] suggests that time be spent quantifying the competitor’s ratings and discussing selling points. In the QRD implementation of QFD time is only spent on the competitor who is perceived as being the best in the market in satisfying this need and presenting technical information about the competitor’s product and reasons why is it perceived by the customers as the best in the market.

Project: Flashlight for the Elderly		Company: Light Light											Workshop Date: **1.1.02**		
House of Quality															
		Product's Characteristics													
	Decision Characteristics	A	C	D	E	F	G	H	I	K	L	M			
No	***Customers' Needs***	Light Intensity	Total Volume	Total Weight	Time to Locate and Operate	Automation Level	Continuous Operation Time	Product Manufacturing Cost	Operations to Failure	Design Level	Time to change batteries		**Importance**	**Reference Products**	**Other Characteristics**
1	**Scenario No. 1: Find light switch or door lock in dark**	▲	○	○	○			▲	▲				10	Now	Light Focus
2	**Scenario No. 2: Primary orientation at home while electrical blackout**	○	○	▲	●		○	▲	▲	○			9	Now	
3	**Scenario No.3: Find my way in dark streets**	●	○	○	○		○	▲	○				5	Now	Environmental conditions: Spalsh resistance
4	**Easy to carry in pocket or handbag**	▲	●	●	○		○	○		○			24	X	
5	**Easy to find and to operate in dark**	○	●	●	●	●		▲		○			8	Now	
6	**The logistic scenario: Easy to maintain (or no maintenance)**					○		▲	▲	▲	●		3	Y	MTTR: User Level
7	**Operates reliably when needed and does not operate when not needed**		○	○		▲	●	○	●	▲			20	Y	
8	**Affordable**	▲			▲	▲	○	●	○	○	▲		13	X	
9	**Looks nice, smooth touch**	▲			○			○		●			8	Y	
10															
	Total importance	149	419	400	310	113	330	308	251	261	38		2579		
	Relative importance	6%	16%	16%	12%	4%	13%	12%	10%	10%	1%		100%		
	Rank	8	1	2	4	9	3	5	7	6	10				

Figure 2 Modified HoQ for a flashlight

A typical modified HoQ for the development of the requirements for a flashlight is shown in Figure 2[3]. The IPDT discusses the relationships between the VOC and the characteristics. They analyse how much each characteristic contributes to each customer need. During the course of a meeting, the IPDT seeks consensus on these evaluations and

[3] We preferred to use a simple example which is definitely not a complex system to make demonstration of our ideas easier to read and follow rather using small font and professional languish which is not easy to follow.

enter the resulting information into the modified HoQ using the following symbols to present the strength of the relationships:

● - Strong contribution. Recommended weighting value = 9.
○ - Moderate contribution. Recommended weighting value = 3.
∆ - Weak or indirect contribution. Recommended weighting value = 1.

The formal output of the modified HoQ is the ranking of the relative importance of the important product characteristics (but all of them are important otherwise they would not be discussed in this stage). The greatest benefit of this step in the process is the communication and detailed discussion between all the disciplines that are represented in the IPDT and especially between the VOC and the VOE.

4.2 Lesson Learnt: The Process that Produces the Definition of a Complex System Contains more Activities than QFD

QFD while a good starting point is not a complete process.

Remedy: Develop and use a process for the development of requirements for complex systems

The remedy for this lack of a complete process was to introduce other activities essential to complete the process of new-product definition. These other activities are:

- the determination of the VOC;
- the determination of the remaining requirements;
- the production of a complete specification document, and
- a Stage Gate SRR.

This process called QRD was architected from process and tool components found to be effective in various methodologies and processes in the same way that the Cataract Methodology was developed [Kasser, 2002]. QRD is a customer-driven, systematic, expeditious, and cost-effective process for defining the performance requirements for complex new products. The value added by QRD to the requirements definition process for complex systems is the integration of QFD into a process which serves to identify, jointly with customers or their representatives, the target-values of the most critical product characteristics which will meet the real needs of the customer at the best value. The QRD process bounds the necessary activities in the following five steps described below:

1. Determination of the VOC.
2. Determination of the remaining requirements (requests).
3. Creation of the definition of the New Product (specification)

4. Production of a complete draft PBS.
5. A stage gate SRR resulting in the approval to proceed with the design of a product that will comply with the signed-off PBS.

Steps 1 and 2 may be performed in parallel, Steps 1 – 4 are sometimes performed in an iterative manner in the case of complicated products. Step 5 is the final step of the methodology. Each step may use different methodologies, processes and tools, as described herein depending on the situation, hence the recommendation for using a Process Architect [Kasser, 2005] to design the appropriate process for a specific situation. Consider each of the steps in turn.

Step 1: Determination of the voice of the customer

In systems engineering, Step 1 tends to be known by a number of names including the requirements elicitation and elucidation process, requirements analysis or the conceptual design process. In this Step the stakeholders and customers are identified and their real needs are determined. Step 1 takes place within the context of a high degree of communication with the customer coupled with knowledge of the user's needs. This step is best performed by an IPDT which analyses and captures the needs. The membership of the IPDT comprises personnel from design, manufacturing, logistics, and marketing. The objectives of Step 1 are:

- to identify the customers and stakeholders;
- to ensure that the definition of the characteristics of the complex new product is driven by, and focused on, the real needs of the customers and users;
- to identify the hidden needs as well as the known needs;
- to create a baseline to justify the product specification;
- to verify that to the best of their knowledge, no critical need is omitted;
- to ensure the product development team understand the real needs of the customers;
- to develop a common language within the product development team to describe the needs, and
- to prioritise the needs.
- to produce a documented VOC.

The output of Step 1 is the VOC expressed in the form of a Customer Needs Hierarchical Tree and other well-organized lists of the needs together with their associated priorities as understood and agreed to with the customers and stakeholders' representatives. The most useful formats for documenting the VOC are scenarios, solutions to problems, or benefits to the entity with the need. This is because customers buy benefits and solutions, not features [King, 1989]. These descriptions of the needs should be:

- Positive statements whenever possible, expressed in qualitative terms, not necessarily in numbers. That conversion happens later.
- Expressed in the customer's language using definitions that are derived from information provided by the customers and are interpreted identically by all stakeholders [King, 1989]. Since different stakeholders have a plurality of opinions,

interests and vocabulary, these descriptions help them to communicate meaning to each other.

Step 1 also contains an activity which determines the priority of the needs. There are a number of techniques for the prioritisation of a large number of needs. As discussed above, we initially tried using AHP [Saaty, 1990], but found that while the method was helpful in performing the task, it was very time consuming. An alternative approach known as NGT [Memory Jogger, 1985] was found to provide the same benefits while being much simpler and faster to use.

Step 2: Determination of the remaining requirements:

This is the step that determines the remaining requirements (in the form of requirement requests). These remaining requirements may come from standards, regulations, and any other source not participating in Step 1. For example, some requirement requests may be inherited from similar systems or from past experience. Applying an object oriented database approach to storing requirements facilitates the inheritance of requirements, but does not necessarily assist in determining the relevance of requirements inherited from a similar system [Kasser, 2003]. These requirement requests must be added to the VOC to complete the set of requirement requests.

One of the tools used in Steps 1 and 2 is a Customer Needs Hierarchical Tree, an example of which is shown in its spreadsheet implementation for a flashlight in Figure 3. Note how the easy to maintain need (Item 4) contains the detailed needs of being able to change (replace) the battery and bulb, and the readily available spare parts: namely different levels of needs.

The tree is populated in Steps 1 and 2. In Step 1 we document the VOC; in Step 2 we document the external and interface requirement requests as if they were the needs of different customers.

As the tree is populated, the needs should be arranged in such a way that it will be easy to see the whole hierarchical picture. The visual structure of the tree also helps to check its completeness. For example, customers sometimes describe some needs in a too general description and that can be seen easily in the tree so the IPDT can go back to the customers and ask for more detail in the respective branch. On the other hand sometimes the information in some branches is over detailed and the team will not be able to process it later, so after studying the essence of these details the team can trim the tree (adjust needs between primary, secondary and tertiary levels) to a manageable size. Our experience in dozens of workshops some of them for developing requirements for very complex systems shows that the effort of arranging the tree and then trimming it never exceeded more than one working day.

	Project: Flashlight for the Elderly		Company: Light Light		Workshop Date: 1.1.02	
	Customers Needs Analysis					
	Mission Definition: Develop an independent, portable, lighting means for regular use by senior citizens					
No	Primary Need	No	Secondary Need	No	Tertiary Need	Remarks
1	Sufficient light in the reference scenarios	1.1	Scenario No. 1: Find light switch or door lock in dark			
		1.2	Scenario No. 2: Primary orientation at home while electrical blackout			
		1.3	Scenario No.3: Find my way in dark streets			
2	Easy to carry in pocket or handbag	2.1	In pocket			
		2.2	in handbag			
3	Easy to find and to operate in dark	3.1	In dark			
		3.2	In handbag crowdedness			
4	The logistic scenario: Easy to maintain (or no maintenance)	4.1	Easy to change battery			
		4.2	Easy to change bulb			
		4.3	Available spare parts			
5	Operates reliably when needed and does not operate when not needed	5.1	For long time			
		5.2	After long breaks			
		5.3	In rainy conditions			
		5.4	Falling resistance			
		5.5	No false operation			
6	Affordable	6.1	Within my Budget			
		6.2	In the required location			
		6.3	In the right time			
7	Looks nice, smooth touch	7.1	Aesthetic look			
		7.2	Smooth touch			
8	Improve security and safety feeling	8.1	Physical defense			
		8.2	Alarm			
		8.3	Call for help			

Figure 3 Customer Needs Hierarchical Tree for an independent, portable, lighting means for senior citizens

Step 3: Creation of the definition of the New Product

Step 3 the transformation phase, is the heart of the QRD multi-methodology. It is where the communication between the representatives of the VOC and the representatives of the VOE takes place. This step is usually performed as a very intensive teamwork exercise in the form of a facilitated workshop in which the few most important Target Value Decisions are agreed upon by all the participants in the process and reflects the mutual understanding of all the side interests and limitations. This workshop is very similar in format to those used in JAD [Wood and Silver, 1995] sessions.

Step 3 transforms the VOC produced in Step 1 and the other requirement requests identified in Step 2 into target values for the most critical requirements (the initial definition of the complex new product) and their impact on the manufacturing process. This transformation process, described from the information flow perspective, contains the following steps [Kasser, 2000]:

- Prioritise each element of the VOC and external requirement (done in Step 1).
- Determine if a contradiction exists with other requirements and if so, resolve it.
- Determine coupling and dependencies (correlations) with other requirements and perform trade offs as needed to resolve them.
- Perform an impact assessment using an IPDT. The impact assessment must:
    - Estimate the cost/schedule to implement. (at this point it is a rough estimate)
    - Determine the cost/schedule drivers - factors that are responsible for the greatest part of the cost/schedule.
    - Perform a sensitivity analysis on the cost/schedule drivers.
    - Determine if the cost drivers are really necessary and how much modification can be made by negotiating the requirement with customers based on the results of the sensitivity analysis.
    - Make the decision to accept, accept with modifications, or reject the requirement request.
    - Notify the originator of the decision.
    - Document the decision(s) in the requirement repository.
    - If the requirement is accepted, allocate the implementation to a specific development Build and modify the Work Breakdown Structure (WBS) appropriately.

Step 3 thus builds a modified HoQ documenting the most important decisions leading to the initial PBS. Decisions about target values are made on the basis of a sensitivity analysis which may require the final target values to be negotiated with the customer. The sensitivity analysis may discuss not only the effect on performance but also on other attributes (main concerns of the production organization) such as the risk and difficulty of achieving the target values, the effect on cost, time to market or on conceptual considerations. The discussions in this step of the process may also have to consider some aspects of the design and implementation process. While the output of the stage are requirement requests stated in terms of “what has to be done to implement the requirement”, rather than “how it is to be implemented”, the design team must, in this step of the QRD process, determine that there is at least one way of implementing the requirement to prove feasibility of implementation. After all, there is little point in drafting a requirement that cannot be met.

The initial decisions on the target values are followed by an impact assessment on the main concerns of the organization. These concerns include risk, difficulty of achieving the target values, the effect on cost, time to market and other conceptual considerations. Finally, action items are assigned to the appropriate IPDT members to verify achievement of the target values.

At this point the IPDT can create the basis for the design quality measurement (DQM) system. The measurement system is based on Customer Satisfaction Rating (CSR) functions, linked to the target values [Hari ;Weiss and Zonnenshain, 2001]. A similar type of rating for proposals has been introduced by the US Defense Department in the form of "utility graphs"[DOD].

Step 4: Production of a complete Performance Based Specification

Once Step 3 is complete, a small group of individuals completes the PBS document because most of the remaining requirements are derived from the decisions made in Step 3 or are obvious to the team working on Step 4. If necessary this group can communicate with the appropriate stakeholders to clarify any obscure points or revisit decisions.

Step 5: The Stage Gate Review

The QRD process ends with a stage gate review such as that mandated in the PRINCE 2 methodology [Bentley, 1997]. This is a formal SRR with the participation of the senior decision-makers such as top management and customers' senior representatives. The purpose of this review is not to discuss problems and make decisions, but:

1. to document consensus that the product when produced conforming to the PBS will meet the VOC and
2. verify that adequate resources have been appropriated to produce the product [Kasser, 1995], and
3. provide a final quality check that a critical parameter has not been overlooked in the process of reducing the number of rows in the HoQ as discussed in Section 4.1.

Many current SRR and similar reviews provide a forum for stakeholder discussion and demonstration of the plurality of viewpoints. At times the differences can be so great that the project is in danger of cancellation. In the QRD process, these discussions take place, and the decisions are made in the steps leading up to the SRR. Then because all the information for the review has been decided and documented in the previous steps of the QRD process, the SRR is very focused, well-organised and takes only a few hours similar to that discussed by [Kasser and Mirchandani, 2005].

4.3 Lesson Learnt: QFD does not Support Making Target Value Decisions and Implication Analyses for Complex Systems

When used for defining requirements for complex systems, QFD has been found to be incomplete and often does not produce the necessary information needed to make the informed critical decisions needed to produce specifications. For example:

- QFD is not suited for performing a sensitivity analysis on the consequences of decisions;
- QFD does not incorporate the ability to discuss affordability or "willingness to pay" (WTP) issues with the customer; and
- QFD does not contain the provision to produce an action-plan and a high level verification-plan.

Remedy: Add a Target Values Decision Table

The remedy for the incompleteness of QFD in the context of developing requirements for complex systems is to incorporate a Target Value Decision Table (TVDT) into the QRD process. The TVDT contains the quantitative or semi quantitative target values for the most important design characteristics, trade offs, dependencies and relevant performance of competing products obtained through competitive benchmarking. The TVDT is used to facilitate decisions that will position the new complex product relative to the competitors in the market. A typical TVDT for a flashlight[4] is shown in Figure 4. The TVDT and the process of filling in its data are considered by most of the IPDT members participating in the workshops as:

- the most important part of the process;
- building the consensus, and
- the most important extension to the traditional QFD process.

	Project: Flashlight for the Elderly						Company: Light Light				Workshop Date: 1.1.02		
					Decisions Table								
	Product Characteristics		Trade - offs	Ref. Products			Target Values	Implication					
No	Units / LIST	W	Charact.	Now	X	Y	Ver. 1	Diff	$	TTM	Conceptual	AI	Remarks
1	Total Volume (cc)	16%		220	80	75	40	○	○	△		1	
2	Total Weight (grams)	16%	1 (vol)	220	75	70	60	○	○	△		1	
3	Continuous Operation Time (min)	13%	1 (vol), 2 (wgt)	40	20	20	20	●	○	○	New bulb or battery concept	2 3	
4	Time to Locate and Operate (sec)	12%	1 (vol), 2 (wgt)	10	14	12	8	○	△	△	W/O additional volume (key holder ?)	4	
5	Product Mfg Cost ($)	12%	1,2,3,4	3$	2$	1.6$	1.3	○		○		5	
6	Design Level (scale 1-5)	10%	4,5	3	3	2	4	○	○			6	
7	Operations to Failure	10%	5	500	400	500	500	△	△	△		7	
8	Light Intensity (Lux)	6%	1,2,3,6	300	300	400	200	△	△	△		8	
9	Automation Level (List 1)	4%	3,4,5,6	2	2	2	1	△	△	△		9	
10	Time to change batteries (sec)	1%	5	25	30	60	25	△	△	△	Disposable	10	

Figure 4 Example of a Target Value Decision Table (TVDT) for a flashlight

The TVDT is presented on a large screen during the meeting in which the decision-making process takes place and is filled in incrementally by the members of the IPDT as the meeting progresses. The process of completing the TVDT contains the following steps as discussed below.

1. The preliminary step.
2. The requirements negotiation and sensitivity analysis discussion.

[4] While a flashlight is not a complex system, it does have a number of possible configurations and as such is a suitable example for this presentation on the QRD process.

3. The second (technical) benchmark.
4. Implication Analyses.
5. Discussion on WTP.
6. Creation of an Action Plan.

The preliminary step

The product characteristics and their relative importance (weighting) are transferred from the modified HoQ according to the ranking order, the most important one being at the top.

The requirements negotiation and sensitivity analysis discussion

The discussion on each product characteristic starts with an introduction by the senior VOE representative (usually the system engineer) of the characteristics, the range of debate and possible implications. Then trade offs against the more important (previous) decisions are raised, and only the identification number or the name of the conflicting characteristics are noted in the trade off column. The idea behind this step is that in case of a conflict between two characteristics, the customer will prefer better performance in the more important (higher priority) characteristics and will be willing to compromise on the less important ones thus aiming at the best value that can be achieved.

The second (technical) benchmark

The second (technical) benchmark takes the form of a meeting in which the relevant information about the reference products for the decision on each target value is presented. The best in class is emphasized. Then a short discussion on where this product should be aimed is conducted. Completion of the contents of the Target Value column is the formal goal of the meeting. These decisions sometimes require deep discussions, bringing into consideration all the information that has been shared and learnt up to this point. The decisions are usually based on the contribution from the various experts who should be represented in the room. Sometimes this column is split into more than one column in instances such as where decisions are being made on the characteristics of several versions or releases of the new complex product.

Implication Analyses

Next, a discussion on the implications of the Target Values Decisions takes place. The team tailors the implications columns according to their concerns. Some implications are frequently analysed such as the technical difficulty of achieving the target value, the effect on cost and time to market and the implication on the concept selection.

Discussion on Willingness to Pay (WTP)

WTP articulates the flexibility of the cost to the customer by defining the readiness of customers to pay additional costs for some benefit. However, QFD does not incorporate the ability to discuss affordability or WTP issues with the customer [Smith and Nagle, 2002].. The determination of the WTP of the customer allows the product developers to satisfy the customers' needs according to the customer willingness to pay for them (needs satisfied completely, partially or not ~~al~~ at all). In the QRD process we developed and now use the following three levels of WTP in Step 1 and Step 3:

- **Essential:** This level of need is the reason why the customer will buy the product. He relates most of the cost to this need and is ready to pay for it. An example of an essential need is the ability of a car to transfer the customer quickly from one location to another. The customers will agree to pay some tens of thousands of dollars for this benefit.
- **Beneficial:** The customer needs it but is not willing to pay for meeting the need[5]. The amount of money he would like to pay ~~it~~ is less than the amount of money the supplier demands. If the customer cannot pay the total cost of a beneficial need he will have to discuss with the supplier what partial benefits he can get for the amount he would like to spend. An example of beneficial need is the desire of the customer to control the temperature inside his car. He might accept paying a few hundred dollars but would not be willing to pay a thousand dollars.
- **Luxury:** Satisfaction of this need will satisfy or even delight the customer but he will not agree to pay anything for it, or he will only agree to pay some insignificant amount of money. An example of a luxury need is an automatic lowering of the volume of the car audio system upon an incoming cell-phone call. It is nice to have such a feature in the car but the customer would not agree to pay more than few dozens of dollars for it or will even expect to get it free of charge.

The essential needs are obviously the most important needs (high priority) while the luxury needs tend to be low priority and will be satisfied only up to the extent of the WTP for them.

Creation of an Action Plan

Finally, all allocated action items are documented; relevant action items could be:

1. tasks required for completion of Step 3,
2. tasks to be performed after completion of Step 3 (the workshop) and before completion of the specification document (Step 4),
3. tasks scheduled for discussion during the SRR (Step 5) or even
4. tasks for the system engineer to analyse or to monitor during later design stages.

4.4 Lesson Learnt: The Methodology for Definition of a Complex System Must be Tailored to the Unique Characteristics of Each Product, Organization and Culture.

QRD is the generic name of a meta-process for achieving or at least maximising the probability of achieving a complete set of verified and validated requirements. It can be implemented using any appropriate methodology, process or tool that does the job.

[5] He may not have the budget.

However, these methodologies and processes will need to be tailored, namely customised or combined with other methodologies and processes.

Remedy: Architecture of the New Product Definition Process

The remedy is that one must choose specific tools and practices for executing the project. Knowledge of the capability of tools and techniques is only part of the knowledge required to apply them successfully. The knowledge needed to tailor them to the unique needs of each situation is essential but unfortunately to date this knowledge is rarely taught in courses even though a few of these methodologies have been documented in the literature, see [Avison and Fitzgerald, 2003] [Checkland, 1993] [Flood and Jackson, 1991] for examples. There are also a number of methodologies for the market research and customer inquiry processes that can be used in Step1 of QRD to capture the customers' needs. These include scenario building, user/customer interviews, questionnaires, customer visits, JAD sessions, observation, customer value analysis, viewpoint analysis, use cases (and other Unified Modelling Language (UML) techniques), contextual inquiry, focus groups, hierarchical customer needs trees, WIP analysis, and NGT.

The QRD process must also be tailored for the type of system being developed. Different types of problems require different approaches to solving, and using the appropriate one is critical to project success. One way of classifying problems was discussed by [Shenhar and Bonen, 1997] who presented a two-dimensional taxonomy in which systems are classified according to four levels of technological uncertainty, and three levels of system scope. These three layers correspond roughly to the three lower layers of the Hitchins five-layer model [Hitchins, 2000]. Shenhar and Bonen then described the differences found in systems engineering styles in various areas, such as system requirements, functional allocation, systems design, project organization, and management style. They also claimed that adopting the wrong system and management style may cause major difficulties during the process of system creation. [Shenhar and Bonen, 1997] suggested the following distinction which can be used as a guide to determine which methodology and process is appropriate for specific situations.

- **Type A — Low-Tech** Projects which rely on existing and well-established technologies to which all industry players have equal access. The system requirements of Low-Tech Projects are usually set by the customer prior to signing the contract and before the formal initiation of the project execution phase.
- **Type B — Medium-Tech Projects** which rest mainly on existing technologies; however, such systems incorporate a new technology or a new feature of limited scale. Their requirements are mainly set in advance; however, some changes may be introduced during the product development phase. This process often involves a joint effort of the contractor and customer. It may also require the involvement of potential customers in the process.
- **Type C—High-Tech Projects** which are defined as projects in which most of the technologies employed are new, but existent — having been developed prior to the project's initiation. System requirements are derived interactively with a strong

involvement by customers or potential users, and many changes are introduced during the development phase.
- **Type D—Super-High-Tech Projects** which are based primarily on new, not entirely existent, technologies. Some of these technologies are emerging; others are even unknown at the time of the project's initiation. System requirements are hard to determine; they undergo enormous changes and involve extensive interaction with the customer.

Now, the real world will generally require that the text-book methodologies and processes will need to be tailored, namely customised or combined with other methodologies and processes. One must choose the specific tools and practices for executing the project. Knowledge of the capability of tools and techniques is only part of the knowledge required to apply them successfully. The knowledge needed to tailor them to the unique needs of each situation is essential but unfortunately to date this knowledge is rarely taught in courses and documented in the literature. Designing an appropriate mixture of methodologies, processes and tools for use in any specific organisational situation is a job that needs the specialised skills of a Process Architect [Kasser, 2005] who understands the methodologies, processes and tools as well as the organisation and the domain of the product.

In Step 2, the requirements specifications often document detailed functional requirements but tend to underestimate or completely ignore non-functional requirements such as Human-System interface requirements. Documented processes that help gather these requirements (as requirement requests until accepted in Step 5 of QRD) include:

- AMMETH, a proposed seven step methodology [Guida and Lamoerti, 2000] which addresses the important issue of identifying the requirements for advanced human-system interface in the context of a disciplined requirements engineering process and, helps carry out the requirements analysis of human-system interfaces in a disciplined and effective way.
- A process to elicit non-functional requirements and show how to integrate them into the class, sequence, and collaboration diagrams of UML and how Use Cases and scenarios can be adapted to deal with Non-functional requirements [Cysneiros and Leite, 2004].
- Checklists for identifying these requirements such as [DSMC, 1996].

As a further example, [Kasser and Mirchandani, 2005] describes a case study of a situation in which a soft-systems methodology coupled with an object-oriented approach for viewing the requirements was used in a complex environment to gather an initial set of requirements. By considering the cost, priority, and risk attributes of the requirements, as well as clarifying the wording of the requirements for verifiability, an optimal product architecture and development process was achieved in a relatively short period of time compared with the standard systems engineering process. Moreover, the PBS presented at the SRR was deemed complete and comprehensive by the customer. In this instance, Steps 1 and 2 were performed in parallel, and Step 3 was performed by visiting the stakeholders in turn and going through the process of requirements negotiation and analysis without using QFD, the performance requirements were agreed to by all the stakeholders, the only area of requirements needing negotiation being the installation (supply chain) requirements.

4.5 Lesson Learnt: QFD cannot be Used When Requirements are Stated in Specifications incorporated in Requests for Proposals.

Some customers prefer to list their requirements in specifications documents incorporated in RFPs. Moreover, these documents tend to specify design requirements, including materials to be used and how a requirement is to be achieved, or the methods for its production rather then required results and criteria for verifying compliance [Stanberry, 2004]. This situation separates the product developers from the customers and limits their ability to satisfy the real needs. In the event the situation cannot be avoided, the IPDT needs a way to determine the original performance needs of the customers.

Remedy: Requirements Analysis

The QRD implementation of Requirements Analysis is based on the spreadsheet implementation of a form of the type shown in Figure 5. It is a reverse engineering process which goes through the requirements document with the customers or with the representatives of the VOC analysing each requirement in turn using the Requirement Analysis Form in order to find the customer's real need. Good questions to ask the customer in this dialogue are

- "why do you want this requirement?" and
- "how will you know when the requirement is met?"

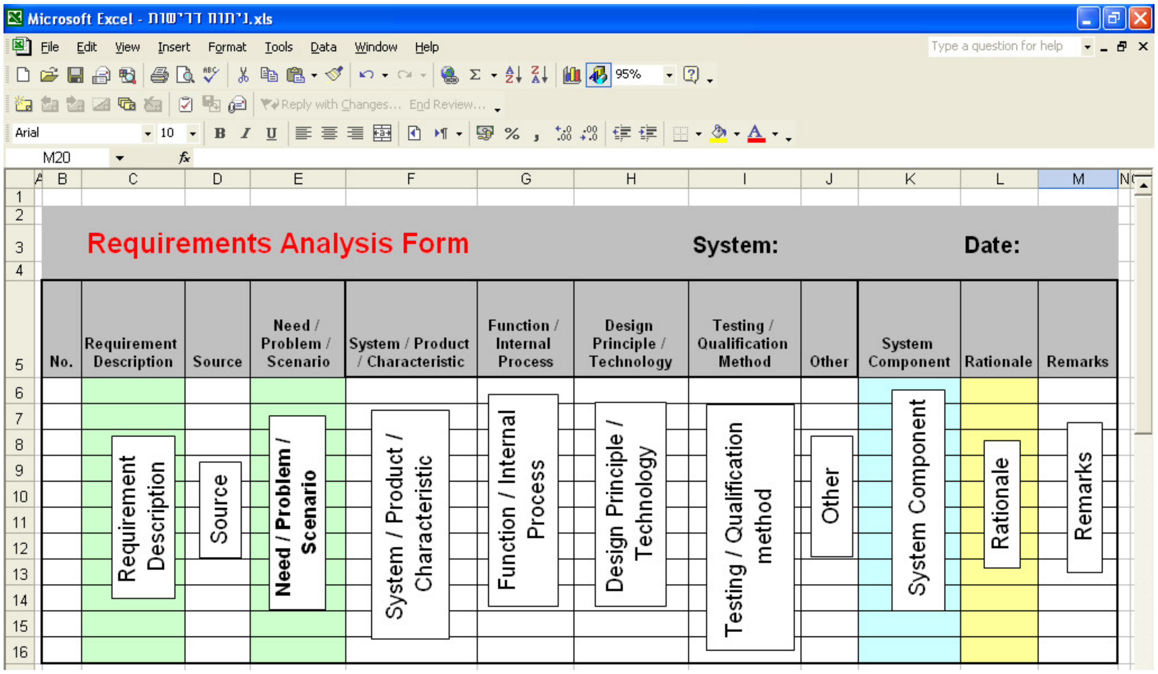

Figure 5 **QRD Requirement Analysis Form**

Requirements Analysis is an activity performed to determine the VOC in Step 1 of QRD, It comprises the following steps:

1. Copy the original identification number and requirement text from the requirements document or database to the Number and Requirement Description columns in the form.
2. Identify and document the source of the requirement
3. Analyse and categorise the nature of the requirement and enter them in the appropriate column. Possible categories are:
   - Need/Problem/scenario
   - System/product characteristic
   - Function/Internal Process
   - Design Principle/Technology
   - Testing/ Qualification Method
   - System Component, part, subsystem, configuration, or even the entire architecture
   - Priority
   - Others as appropriate to the situation.
4. Discuss the rationale for each requirement and enter it in the Rationale column.
5. If the requirement is other than a Need/Problem/Scenario, discuss the need behind the requirement with the customer representative. Once the reason behind the requirement request is found (real need), the information is documented in the appropriate column in the Requirements Analysis form.

4.6 Lesson Learnt: A Stage Gate Review is required to approve the specification for the new product

Any process for the definition of the specification for a new product should be terminated and formally approved by a stage gate review (e.g. a SRR) presented to the stakeholders and senior decision-makers.

Remedy: Incorporate a SRR into the process

A SRR is incorporated into the process as discussed in Step 5 of QRD. This is not the traditional SRR in which decisions may be debated and action items allocated to perform further work. All these activities will have already taken place in the earlier stages of the QRD process. This SRR serves to document that consensus exists amongst the stakeholders that the requirements document the need and the decision to proceed to the next phase is seen to be made. The agenda for the QRD SRR covers the following QRD process-products (as appropriate):

- Potential customer~~s~~ segments, the chain of customers and shareholders in any segment (e.g., users, maintenance, purchasers, transporters, installers) and their principle needs.
- Customers' needs: The main reference scenarios, the main problems for solution and required benefits, needs analysis and priorities.
- Results of the WTP analysis.
- The main competitors which the customer considers as the best in the market.
- Cross-checking between the needs and the characteristics.
- Target values for the requirements.
- Priority of the requirements.
- A comparison of the target values that were agreed upon in relation to the best competitor and evaluation of their technological maturity.
- Requirements that have been clearly consolidated and formulated comprehensively and precisely, in such a way that they will enable the following design and production stages of the System Development Life Cycle to be performed with minimal waste.
- Level of difficulty in achieving the target values.
- The most significant tradeoffs and the correlation between the functional and performance requirements and other (object-oriented) properties such as cost, risk, and priority.
- The product life cycle: Forecasted events, mission profile, expected environmental conditions, initiated activities which may happen during the life time of the product, possible situations that the product may experience during its life time until disposal.
- Options for future upgrades (including functional, physical or conceptual), provision for additional or extended functions.
- Means of immunization and protection against intentional or unintentional disturbances.
- Capability of upgrading the system's durability for operation in significantly different environmental conditions for which it was designed, and which may be required in the future.

- Rationale for the target values for quality, reliability, availability, safety, and maintainability.
- Rationale for the target values for life cycle cost components.
- Cost Modularity analysis.
- Relevant requirements for aging and life time of the designed life cycle of the system.

5 Research Results:

The evolutionary extension of QFD into QRD has been evaluated through process workshops in active projects, interviews and design laboratory experiments over 15-years. Some 500 designers participated in the various workshops where they were introduced to the process and experienced it to some extent. Questionnaires and Kiviat charts were used to express the designers' views on the contribution of the process to the new-product definition effort. The data produced as a result of the workshops was subjected to statistical analyses including T tests, F tests, Multivariate Analysis of Variance (MANOVA) test, Wilkins' Lambda test, and Dunkan's test [Hari, 2000]. The Key conclusions from the research were:

- Few of the development team members and customers representatives (36%) are satisfied with their current new-product definition processes for complex systems. A new integrated process or road map such as a customized QRD process is required
- The satisfaction with the new-product definition process for complex systems was increased by 60% to 96% as a result of the application of QRD.
- The metrics for customer satisfaction measurement that were found to be most frequently used by the design teams were: functional product characteristics, user-friendliness, reliability, cost, and time to market. These five metrics measured more than 80% of the customer satisfaction.
- Applying expertise to reduce the number of factors to be considered in a QFD analysis not only applies to complex systems but can also be used for developing the requirements for simpler systems when time is limited.

6 Summary

This paper has discussed the lessons learned in the evolutionary process of adapting and extending QFD over more than 15 years into the QRD process which:

- Is based on lessons learnt from success and failure case~~s~~ studies, improvements and modifications
- Has been validated via the many workshops.
- Brings to the systems engineering process a tried and tested approach for converting customer’s needs to both functional and performance-based requirements as well as the other attributes of the requirement in the product and process domains that allows the product to be produced more rapidly and correctly than is typically done using other methodologies for developing the specifications for new products based on QFD.

Finally, it should be noted that

1. In order to succeed in application of QFD to complex system one must tailor it and to know how to do it
2. QFD can be applied to complex system if the remedies recommended in this paper are applied.
3. By quickly identifying the most critical (high priority) design requirements you can convince organizations to apply this methodology.

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