Designing Products and Services to Meet and Exceed Customer Expectations using Quality Function Deployment (QFD) and House of Quality (HOQ): Applications in Six Sigma and Design for Six Sigma (DFSS)

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Abstract

Six Sigma and Design for Six Sigma (DFSS) integrate engineering design and statistical methods to predict and improve quality before production. DFSS is a way of understanding the key product characteristics to design and build successful products. The success of companies depend on designing, developing and launching new products of superior quality, getting to the market quickly (reduced cycle time), bringing innovation in products, and understanding the customer's needs and requirements. Research shows that approximately 5% of all new-product ideas survive to production, and only about 10% of these are successful. Therefore, actively building quality in every phase of the product development process and predicting and optimizing critical quality characteristics are keys to ensuring product success. Design for Six Sigma (DFSS) is a systematic method to build quality and key customer requirements in all stages of product development. These key quality characteristics (CTQs) and customer requirements can be measured, verified, and optimized. DFSS is an approach to meet or exceed customer needs, requirements, and expectations using the voice of customer (VOC). This research focuses on one of the major tools — Quality Function Deployment (QFD) and House of Quality (HOQ) — used in Design for Six Sigma and also in Six Sigma to design products and services to meet and exceed customer requirements by identifying and addressing CTQs and the voice of customer (VOC) early in the design phase. This research suggests a systematic approach to QFD required in determining the expectations or the *voice of customers* that needs the answer to the following questions: What does the customer really want? What are the customers' expectations regarding the product and how the expectations and requirements can be met by the company to achieve customer satisfaction? Different types of customer information are gathered: solicited and unsolicited, measurable (quantitative) and subjective (qualitative). Through this research we suggest steps to design a software system to successfully design and deploy QFD and House of Quality methodology.

Keywords
Six Sigma, Design for Six Sigma (DFSS), Quality Function Deployment, Critical to Quality Characteristics (CTQs), Voice of Customer (VOC), Lean Manufacturing Decision Support System, Decision Models, Multivariate Statistics.

1. Introduction

The main objective behind the house to quality is to translate *the voice of customer* into design requirements that tells an organization how to incorporate customer requirements in the design phase to meet or exceed customer expectations. By the *voice of the customer* we mean the customer expectations regarding a product. Quality function deployment (QFD) is a systematic approach to design products and services based on a close awareness of customer desires and expectations. A considerable amount of effort is required to determine these expectations or the *voice of the customer* that needs the answer to the following questions: What does the customer really want? What are the customers' expectations regarding the product and how the expectations and requirements can be met by the company to achieve customer satisfaction? Different types of customer information are gathered: solicited and unsolicited, measurable (quantitative) and subjective (qualitative).

The primary tool used in quality function deployment (QFD) is the house of quality (HOQ) that translates the voice of customer into design requirements. The HOQ is a major tool in quality planning. It is one of the major tools in Design for Six Sigma (DFSS) to design quality into the earliest phase of product design.

The steps are outlined in Figure 1. This figure shows the basic structure and different sections of the house of quality. The structure of QFD resembles a house thus the name *house of quality*.

2. Structure Of The House Of Quality

The House of Quality Matrix consists of the following main steps:

1. Determine the customer requirements (these are the WHATs- what customer needs and requirements should be addressed).
2. Identify the technical requirements (these are the HOWs – or the voice of the organization/engineer that will show how the company will meet the customer's needs and requirements).
3. Establish the relationship between the customer requirements and the technical descriptors – this is in the form of a relationship matrix that shows the relationship between WHATs and HOWs.
4. Determine an interrelationship matrix that shows the relationships between any pair of technical descriptors- this interrelationship forms the roof of the House of Quality matrix.
5. Conduct an evaluation of the competing products – this step involves comparing the company's product/service to the competitive or best in class products/service and comparing each customer's requirement to competing products.
6. Identify and determine a priority list of customer requirements by calculating the absolute weight for each of the customer requirement (this step also requires evaluating the customer requirements in order of customer importance, establishing target value, calculating scale-up factor, and determining sales point).
7. Evaluate technical descriptors, develop targets, and determine the absolute and relative weights of technical descriptors.
8. Determine a priority list that shows which technical descriptors (requirements) needs to deployed to meet and exceed customer needs and requirements.

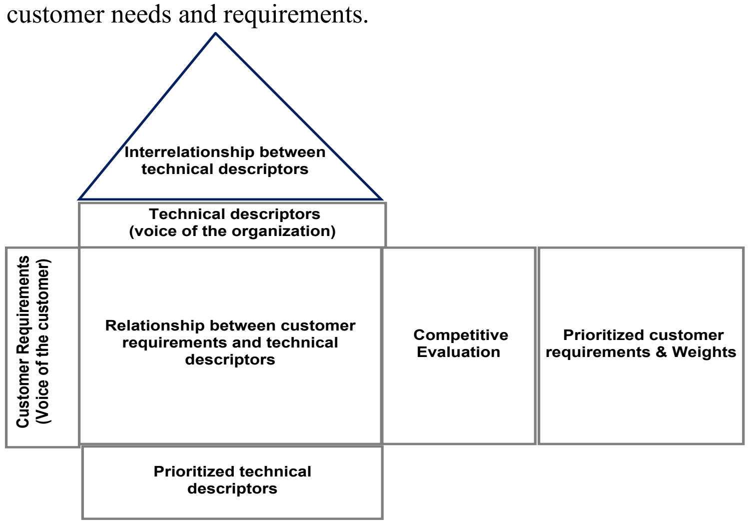

Figure 1. The Basic Structure of House of Quality

Figure 2 shows the overall structure of the House of Quality matrix. The figure shows the complete matrix with different steps outlined above and illustrates the development stages of the House of Quality and the Quality Function Deployment (QFD) process. Initially, the matrix may look confusing at first but when the individual parts are examined and studied separately, the overall process is much more simplified. In the example below, we will explain each part of the matrix and show how it fits into the overall structure.

The QFD process uses the House of Quality matrix. It is a customer driven planning process to incorporate the customer requirements in the design, manufacturing, and marketing phases of the product and build the product that will meet and exceed customer requirements. This approach was developed by the Japanese to meet the customer requirements.

Structure of House of Quality Matrix

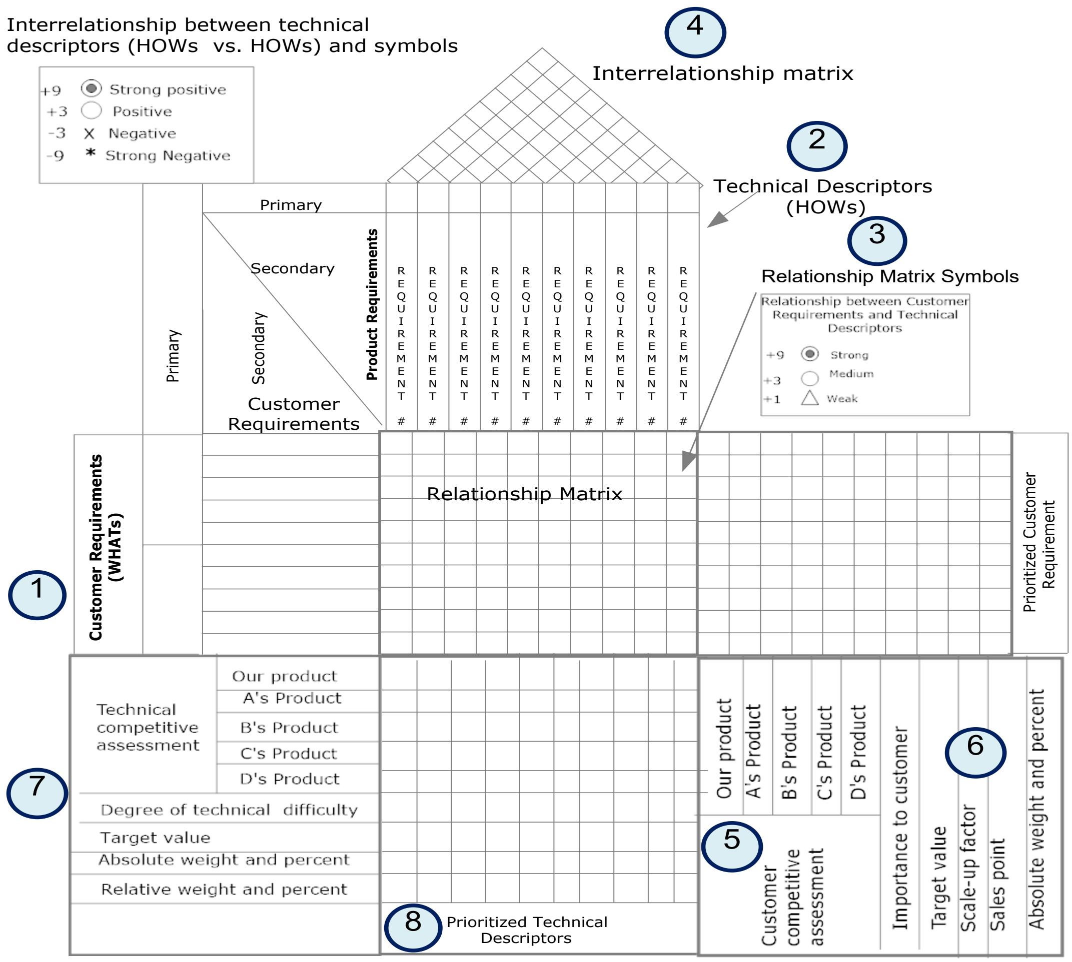

Figure 2. House of Quality Matrix

3. Companies Using Qfd

Quality Function Deployment was developed by Yoji Akao in Japan in 1966. By 1972, the QFD was successfully implemented at the Mitsubishi Heavy Industries Kobe Shipyard. Toyota has been using the QFD since 1977 with impressive results. Between 1977 and 1979, Toyota realized a 20% reduction in the start-up costs on the launch of van which further decreased to 38% from 1977. A further reduction of 61% was realized in the start-up cost of launching the same van by 1984. In addition, approximately 33% reduction in development time was realized with a significant improvement in quality (Evans and Lindsay, 1996). QFD has been used in the United Sates since 1986. The first users were Xerox and Ford. Since then, QFD has been used by several companies including GM, Mazda, Hewlett-Packard, Motorola, IBM, AT&T, GE, and many others. The Cadillac model of 1992 was entirely planned and designed using the QFD approach. Akao, the developer of QFD described the approach as "QFD is a method for developing a design quality aimed at satisfying the consumer and then translating the consumer's demand into design targets and major quality assurance points to be used throughout the production phase. ... [QFD] is a way to assure the design quality while the product is still in the design stage." As a very important side benefit he points out that, when appropriately applied, QFD has demonstrated the reduction of development time by one-half to one-third (Akao, 1990).

4. Major Goals And Application Areas

The 3 main goals in implementing QFD are:

1. Determine spoken and unspoken customer wants and needs and prioritize them (determine WHAT the customers want in a product).
2. Translate the customer requirements into technical requirements – the technical requirements are the HOWs by which a company will respond to the customer requirements or WHATs.
3. Build and deliver a quality product or service that meets and exceeds customers' expectations.

Since its introduction, Quality Function Deployment has helped to transform the way companies design and manufacture products or design the service systems. QFD has been instrumental in
• Planning and developing new products
• Designing new product /modifying existing products
• Determining process characteristics
• Guide the manufacturing and marketing of products
• Making design, manufacturing planning and control decisions of the production/service systems.

5. 5.0 Phases Of House Of Quality And Qfd

QFD uses cross-functional teams and the principles of Concurrent Engineering in all phases of product development. The QFD process is usually divided into four phases (described below). Each phase uses a matrix to translate customer needs and requirements from planning stages to production control (Becker Associates Inc, 2000).

In QFD, the matrix related to each phase represents a more specific aspect of the product's requirements. Relationships between elements are evaluated for each phase. Only the most important aspects from each phase are deployed into the next matrix.

Phase I: Product Planning: This phase is about production planning and involves building the house of quality matrix. It is usually led by the marketing department using customer data and evaluation of similar competitive products (if available). Many companies using QFD only get through this phase. Phase I of QFD documents customer requirements needs and requirements (WHATs), customer competitive evaluation, product measures, and the technical ability of the organization or the technical descriptors to meet each customer requirement. It is very important to obtain good data and customer opinion in Phase I. Obtaining credible and useful research regarding the customer requirements, related product, and competition data are critical to the success of the entire QFD process.

***Phase II: Product Design: In the case of product development*:** Phase II is led by the engineering department. The product design should be done using concurrent engineering approach where product design and manufacturing both are involved in the design phase of the product. One of the major objectives of this phase is to design a product based on customer requirements and deliver what the customer needs. The other critical aspect of the design phase is to build quality into every phase of the design process so that costly field failures that may have major cost implications in the future can be avoided. It is easier to correct the mistakes at the design phase than when the product is released. Designing a successful product or service requires innovative ideas. Product design is about conceiving the product idea, specifying the design specifications, designing the product, creating, and testing the prototype and documenting the product features. The features that are determined to be critical and most important to meeting customer needs and requirements are then deployed into process planning phase.

Phase III: Process Planning: Process planning involves designing the processes to manufacture the product. Product and process design should be done simultaneously to ensure that the manufacturing has the capability to build what is designed. In this phase, decisions are made regarding the type of process design that to a large extent depends on the nature of the product, market demand, and forecast. This process planning phase involves flowcharting the manufacturing processes and documenting the process parameters and target values.
Phase IV: Process Control: In the control phase, performance indicators are created to monitor the production process, maintenance schedules including preventive maintenance plans, and skills and worker training requirements are assessed. This phase involves Quality Control/Quality Assurance and deploying Six Sigma quality program to assure the quality of the product, reduce variation, and reduce the cost of poor quality using continuous improvement approach.

6. Construction And Implementation Of House Of Quality And Qfd

The quality function deployment steps and the house of quality matrix will now be explained using an example. The first phase in the implementation of the Quality Function Deployment process involves putting together a "House of Quality."

Steps to the House of Quality

The first step in a QFD project is determining the market segment to analyze and identify the customers. The QFD process is usually led by a team. In the initial stage, the QFD team gathers information from customers regarding the needs, requirements, and expectations they have for the product or service. The data are then organized and evaluated using simple quality tools like Affinity Diagrams or Tree Diagrams. The House of Quality and Quality Function Deployment process is explained below using a case that involves designing a food processor.

Step 1: Customer Requirements - "Voice of The Customer" (Whats)

This step involves determining what the customer needs or expects in a particular product. The list of customer needs is referred to as the WHATs or a list of what the customer wants. Initially, the list of customer requirements may not be clear and thus the requirements may be general in nature. The customer requirements may be divided into primary and secondary requirements. The secondary requirements are more detailed and are derived from the primary list. A primary customer requirement may consist of several secondary customer requirements.

Example: Customer Requirements for a Food Processor

This company manufactures different models of food processors. One of its food processors model is experiencing problems. The sales and revenue for this particular model has declined and the product is facing warranty issues and customer complaints. Because of the recent quality problems and decline in sales for this product, the quality and product design departments want to modify and reintroduce the product in the market. This will require product redesign as well as production line overhaul. The company has an excellent reputation for quality products and recently they have initiated the Design for Six Sigma (DFSS) efforts that has significantly helped incorporate customer requirements and quality issues in product design and manufacturing stages. The Six Sigma team strongly recommended using quality function deployment in the redesign effort of this food processor unit. The team wants to begin the redesign process by first listing the customer requirements or WHAT the customer needs or expects in the product. This will also help the team incorporate some of the features missing from the earlier product.

The Six Sigma team has identified *performance and features*, *aesthetics*, and *operations and maintenance cost* as the primary customer requirements. Related to each of these primary requirements, the secondary requirements are shown in Figure 3. The team felt that it was not necessary to breakdown the customer requirements to tertiary level. Note that the customer requirements can be broken down into primary, secondary, and tertiary requirements.

Step 2: List Technical Descriptors Requirements (Hows)

Once the customer requirements and expectations are known, the next step in the QFD process is to determine the engineering characteristics or the technical descriptors that affect one or more customer requirements. This step in the process helps identify how the customer requirements can be met.

Customer Requirements (WHATs)

Customer Requirements (WHATs)	Primary	Secondary
	Performance & Features	Light weight
		Strength and durability
		Reliability
		Easy to operate
	Aesthetics	Look and appearance
		Nice finish
	Operation, storage, maintenance cost	Easy to assemble and disassemble
		Low total cost of ownership
		Low parts cost
		Compact easy to store
		Easy to clean

Figure 3. Customer Requirements (WHATs) for the Food Processor

Technical Descriptors (Hows) For the Food Processor Problem

Figure 4 shows the technical descriptors corresponding to the customer requirements in the previous step. In this case only the primary and secondary levels are needed to make each of the items in secondary level actionable and therefore, no tertiary level is needed.

Note that some technical descriptors may affect more than one customer requirement. This will be shown in the next step where a relationship matrix between WHATs and HOWs will be developed.

Step 3: Develop a Relationship Matrix Between Customer Requirements (WHATs) and Technical Descriptors Requirements (HOWs)

The next step in developing the house of quality is to determine the relationship between the customer requirements and technical requirements and show the relationship in a matrix form.

Technical Descriptors (Hows)

	Technical Descriptors (HOWs)											
Primary	*Material*		*Mfg. Process*			*Manufacturing,assembly, servicing*						
Secondary	Aluminum	High impact plastic	Injection molding	Plastic molding	Machining	No. of parts to assemble/disassemble	Modular design	Labor complexity	One year service/warranty cost	Dis-assembly & re-assy time to clean	Ease of replacing parts/subassembly	Manufacturing cost/time

Figure 4. Technical Descriptors (HOWs) for the Food Processor

Establishing the relationship between the customer requirements and the technical descriptors (WHATs and HOWs) requires special attention because the relationship may be complex, and one or more customer requirement may affect more than one technical descriptor.

The relationship matrix as shown in Figure 5 is now developed by the QFD team. This relationship matrix depicts the degree of association between each customer requirement and each technical descriptor. A set of symbols are used to show the degree of relationship between the customer requirements and technical descriptors.

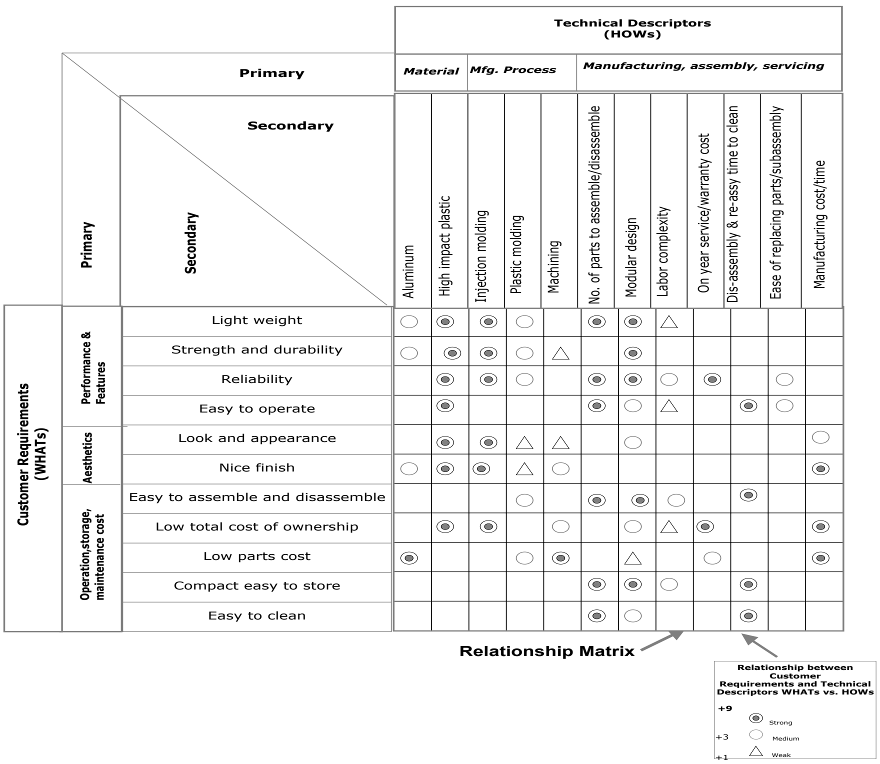

Figure 5. Relationship Matrix Showing the Relationship between Customer Requirements (WHATs) and Technical Descriptors (HOWs) for the Food Processor

Step 4: Develop an Interrelationship Matrix Between Technical Descriptors (Hows)

The interrelationship between each of the technical descriptors is determined using a correlation matrix displayed at the roof of the house quality. The correlation matrix is attached to the technical descriptors and is a triangular table. The symbols used in this matrix are explained below.

Symbol	Relationship
◉	A strong positive relationship (or, nearly perfect positive correlation)
○	A positive relationship (or, positive correlation)
X	A negative relationship (or, negative correlation)
*	A strong negative relationship (or, nearly perfect negative correlation)

The symbols are also given weights that are shown in the table below. The number on the left of each symbol is the associated weight that corresponds to that symbol.

+9	◉	Strong positive
+3	○	Positive
-3	X	Negative
-9	*	Strong Negative

A strong positive correlation means a nearly perfect positive correlation between the variables whereas; a strong negative correlation indicates a nearly perfect negative correlation.

Step 5: Competitive Assessments: Customer and Technical

In this step, the following two competitive assessments are done.

(1) Customer Competitive Assessment
(2) Technical Competitive Assessment

Customer Competitive Assessment

The customer competitive assessment shows a block of weighted columns corresponding to each customer requirement in the house of quality. The goal of this competitive assessment is to compare the company product with other competitive products.

Technical Competitive Assessment

Just as the customer competitive assessment weighs each customer requirement of the company's product to the competition; the technical competitive assessment weighs each of the technical requirements to the selected best in class company. A block of rows is added to the house of quality matrix labeled technical competitive assessment. These rows correspond to each technical descriptor where each technical descriptor is provided a weight ranging from 1 (worst) to 5(best). The weights are assigned to the product being compared and to the selected company's (company a and b) product. Each technical descriptor is given a weight for the food processor and selected competitors (company a and b). If there is a strong relationship between customer requirements and technical descriptors, then they will also show a strong relationship in their competitive assessments. If the technical assessment shows that the company's product is superior to the competition, then the customer assessment should also show a superior assessment.

Step 6: Develop Prioritized Customer Requirements

The prioritized customer requirements consist of five columns next to the customer competitive columns. These columns evaluate importance to customer, target value; scale-up factor, sales point, and absolute weight corresponding to each of the customer requirements (see Figure 6). The absolute weight is used to rank the customer requirements. The columns needed to calculate the absolute weight and rank for customer requirements are: ***Importance to Customer, target Value, scale-up factor*, *sales Point, and absolute weight.***

Step 7: Develop Prioritized Technical Descriptors

In this step, a prioritized list of technical descriptors is determined by calculating the absolute and relative weight for each technical descriptor. These weights tell the QFD team which technical descriptors are critical and which ones should be deployed in order to meet the customer requirements for the product or service.

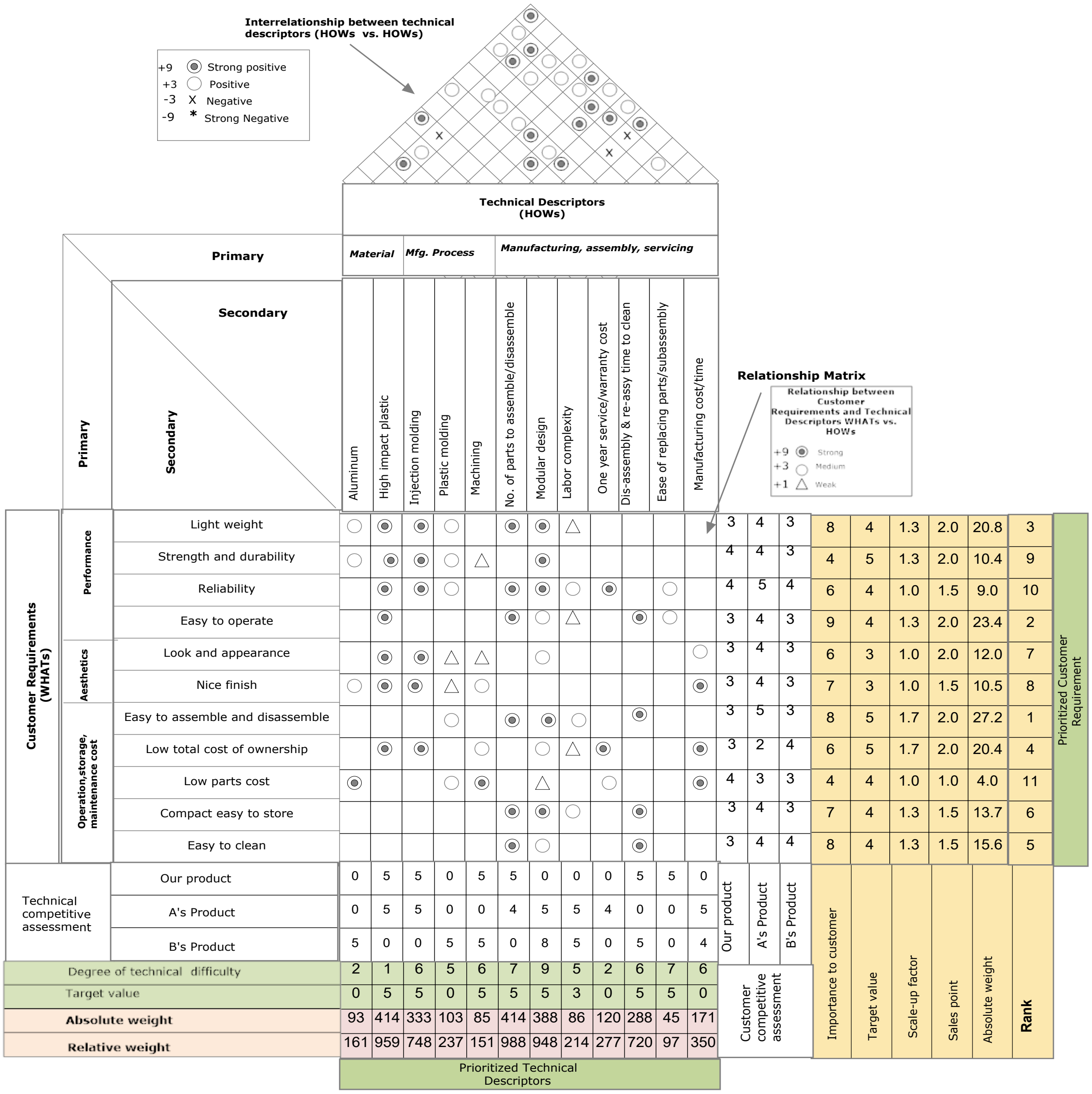

Figure 6. The Complete House of Quality Matrix with Prioritized Technical Descriptors

To determine the prioritized technical descriptors, a block of rows corresponding to each technical descriptor is added to the house of quality matrix. The added rows are the degree of technical difficulty, target value, and absolute and relative weights. The shaded region below the technical descriptors in Figure 6 shows the complete house of quality matrix with these rows. To determine the prioritized technical descriptor the following requirements are determined: ***degree of difficulty***, ***target value, absolute weight, and relative weight.***

7. Summary

To summarize the process of food processor design, Pareto diagrams of the customer requirement and absolute weight for the customer requirement and absolute and relative weights for the technical descriptors can be created. These charts are shown in Figures 7, 8, and 9.

Figure 7 shows a prioritized list of customer requirements in forma of a Pareto Chart. The chart shows the customer requirement and the corresponding absolute weight for each requirement. The figure shows the relative importance of customer requirements.

Figures 8 and 9 shows the prioritized technical requirements based on absolute weights and relative weights. These figures show the importance of technical requirements and the order in which they should be deployed to meet and exceed customer requirements.

Figure 7. Prioritized Customer Requirements

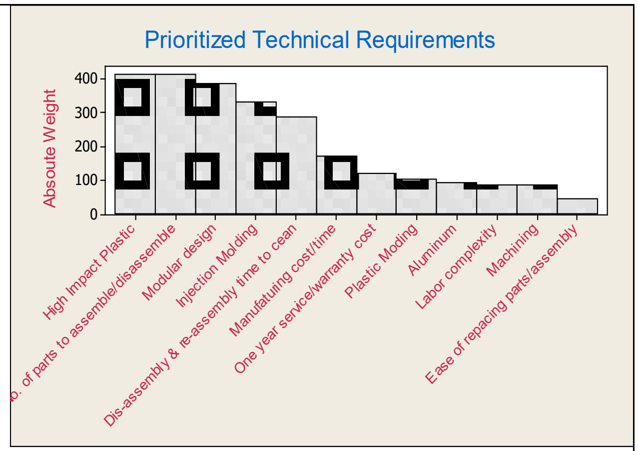

Figure 8. Prioritized Customer Requirements (Based on Absolute Weights)

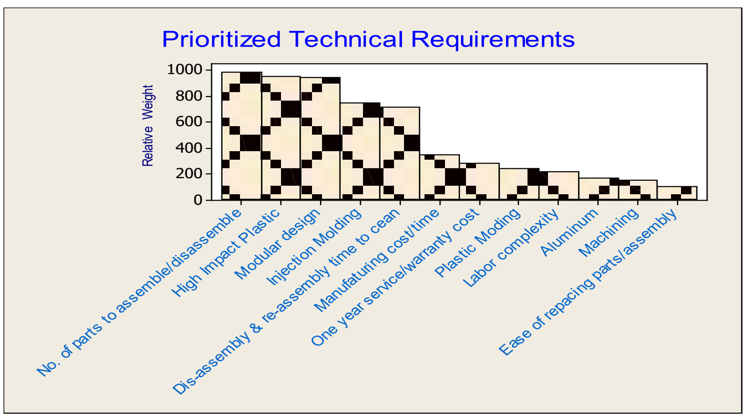

Figure 9. Prioritized Customer Requirements (Based on Relative Weights)

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Dr. Amar Sahay is a professor engaged in teaching, research, consulting, and training. He has a B.S. in production engineering (BIT, India), M.S. in industrial engineering and a Ph.D. in mechanical engineering –both from University of Utah, USA. He has taught/teaching at several Utah institutions including the University of Utah (school of engineering and management), Weber State University, SLCC, Westminster College, and others. Amar is a certified Six Sigma Master Black Belt and holds expert level certification in lean manufacturing/ lean management. He has a number of research papers in national and international conferences. Amar is the author of 10 books in the areas of Data Visualization, Business Analytics, Six Sigma Quality, Statistics & Data Analysis, Managing and Improving Quality, and Applied Regression. He is also associated with QMS Global - a company engaged in data visualization, analytics, lean six sigma, manufacturing and service systems research. Amar is a senior member of Industrial & Systems Engineers, American Society for Quality (ASQ), and Data Science (Data Science Central).