Chapter-1

Introduction

Improving the quality of products and services of an organization is fundamental to business success. In an era of customer-oriented global economy, dominating the majority market with a single product line becomes very challenging and almost infeasible for most of the companies. Traditionally to satisfy market majorities, companies considered providing products with high quality, low cost, fast delivery and courteous after-sales service at most. Now mass customization embarks a new paradigm for modern manufacturing industries since it treats each customer as an individual and attempts to provide tailor-made featured products that was only offered in the pre-industrial craft era [1]. QFD is a well-known customer-driven product design methodology. QFD has become a widely used tool in the product development process. It helps to gather the wants and need of the customer and organize this data so that a product which satisfies the customer will be developed. QFD directly facilitates a customer focused product and help to get a design much closer to customer needs by making a explicit relationship between design characteristics and customer requirements. So QFD is a methodology for building voice of customer into product and service design. It is a team tool which captures customer requirements and translates those into characteristics about a product.

QFD has vast application in the field of service and manufacturing. QFD utilizes the house of quality (HOQ) as a method of understanding customer requirements and establishing the priorities of design requirements. The requirements of customers for a certain product are captured first which are known as voice of customer (VOC). Then based upon these customer requirements, technical specifications are drawn so as to full fill the needs of customer. Theses customer requirements and technical specification makes the HOQ. In HOQ prioritization of customer requirements and technical specification is done also relationship matrix of VOC and technical specification is prepared. This HOQ matrix helps in designing the product desired by the customer as it in the beginning itself incorporates the needs of customer. So the implementation of QFD helps to get a design which is more competitive in the market and suitable for customer needs.

So the main features of QFD is focus on meeting market needs by using actual customer statements (referred to as the Voice of the Customer), its effective application of multidisciplinary teamwork and the use of a comprehensive matrix (HOQ) for documenting information, perceptions and decisions.

In this project the study of implementation of QFD for a steering is considered in ABC Company. There are six chapters.

In chapter 1 introduction to QFD and project objective is discussed. Chapter 2 deals with literature review of QFD its history and development phases. Definition of QFD, various inputs and output required for QFD, its applied industries, benefits and relation with TQM is reviewed. Finally the problem is defined where QFD is applied for this project. Chapter 3 consists of QFD approach and its underlying principal. Basic HOQ is discussed and various parts of HOQ are explained. Chapter 4 consists of case study where QFD is applied in designing a steering system. Voice of customer and corresponding technical specification are placed in HOQ to get relationship between them which would ultimately help in designing the product. Chapter 5 results obtained are discussed and its importance in design is analyzed. Finally in chapter 6 conclusion of the work is discussed.

1.1 Project Objectives

QFD is a planning and problem-solving methodology that is renowned for translating customer requirements (CRs) into engineering characteristics (ECs) of a product [2]. Although this project is mainly considering investigating the implementation of QFD in design of steering system by the help of HOQ, it has other important objectives that summarized as follows.

1) Identifying the products' quality elements from customers' point view.
2) Obtaining a quantitative assessment of the firm's ability to meet required quality elements in comparison with competitors.
3) Identifying the potential improvements opportunities in meeting customers' expectations.
4) Specifying data based improvement suggestions for increasing quality level from customers point views.

Chapter-2

Literature Review

2.1 History of Quality Function Deployment (QFD)

Since its initial development in Japan in the late 1960s and early 1970s especially since it's rapidly spreading to the US in the 1980s and later to many industries in many nations, a vast literature on QFD has evolved. QFD evolved from a number of different initiatives between 1967 and 1972 but the two main drivers which led to its creation in Japan were

1. To improve the quality of design.
2. To provide manufacturing and field staff with the planned quality control chart showing the points to be controlled within the production process before the initial production run.

Therefore it is clear that it was the struggle by product designers under the total quality control movement to improve their work that started QFD in Japan [3]. QFD was developed in Japan in the late 1960s by Professors Shigeru Mizuno and Yoji Akao. The purpose of Professors Mizuno and Akao was to develop a quality assurance method that would design customer satisfaction into a product before it was manufactured [4]. Earlier quality control methods were primarily aimed at fixing a problem during or after manufacturing.

The first large scale application was presented in 1966 by Kiyotaka Oshiumi of Bridgestone Tire in Japan, which used a process assurance fishbone diagram to identify each customer requirement (effect) and to identify the design substitute quality characteristics and process factors (causes) needed to control and measure it [5]. At the same time, Katsuyoshi Ishihara introduced the Value Engineering principles used to describe how a product and its components work. He expanded this to describe business functions necessary to assure quality of the design process itself [6]. Merged with these new ideas, QFD eventually became the comprehensive quality design system for both product and business process.

Japan has continued to push the envelope of QFD applications through an ongoing research Sub-Committee at the Union of Japanese Scientists and Engineers (JUSE) and their annual QFD Symposium established in 1993 [7].

The introduction of QFD to America and Europe began in 1983 when the American Society for Quality Control published Akao's work in Quality Progress and Cambridge Research invited Akao to give a QFD seminar in Chicago [8].

2.1.1 Development of QFD in Japan

Initially Japanese industry began to formalize the QFD concepts when Mr. Oshiumi of Bridgestone Tire produced a processing assurance chart containing some of QFD's main characteristics in 1966 and K. Ishihara developed the ideas of ''functional deployment of business'' similar to those of QFD [9]. Akao was first to realise the value of this approach in 1969 and wanted to utilize it during the product design stage so that the product design characteristics could be converted into precise quality control points in the manufacturing quality control chart [6]. After several industrial trials, Akao wrote a paper on this new approach in 1972 and called it hin-shitsu-ten-kai (quality deployment). In the meantime, the Kobe Dockyard of Mitsubishi Heavy Industries began to apply the ideas of QFD in 1971 following Akao's suggestion, and Nishimura at Kobe produced a quality table that showed the correlation between the customer-required quality functions and the counterpart engineering characteristics [10]. Akao formulated all these into a procedure channeling the customer requirements from the design stages down to the production operations, which was called hin-shitsu-kino-ten-kai (quality function deployment) [11]. QFD was introduced to Toyota's Hino Motor in 1975 and Toyota Auto body in 1977 with impressive results, and was later introduced into the whole Toyota group. A Japanese book on QFD edited by Mizuno and Akao, Deployment of the Quality Function, was published in 1978 showing the fast development and wide applications of QFD in Japan [9]. Through the above-described explorations and practices QFD has been successfully used in many Japanese industries, such as agriculture systems, construction equipment, consumer electronics, home appliances, integrated circuits, software systems, steel, synthetic rubber, and textile [7][11].

2.1.2 Development of QFD in the US

After more than 10 years development of QFD in Japan, Kogure and Akao published ''Quality function deployment and CQWC in Japan'' in the October 1983 issue of Quality Progress which may mark the entrance of QFD into the US [12]. B. King and D. Clausing of Xerox and later MIT were the first two to learn of QFD and L. Sullivan of Ford Motor and the founder of American

Supplier Institute was also one of the first to grasp the importance of the QFD concept in the US. Clausing unified QFD with Taguchi method, Stuart Pugh's concept selection process and other approaches into a system for product development called Total Quality Development. Sullivan wrote an early and influential QFD paper entitled ''Quality function deployment'' in the June 1986 issue of Quality Progress. Co-authored with J. Hauser, Clausing's inspiring article "The house of quality" in the 1988 issue of Harvard Business Review was also well-known and probably increased QFD popularity in the United States more than any other single publication or event [10]. The first recorded case study in QFD in the US was in 1986 when Kelsey Hayes used QFD to develop a coolant sensor. Today QFD continues to inspire strong interest around the world, generating ever new applications, practitioners and researchers.

2.2 QFD Definitions

The name "Quality Function Deployment" gives little hint as to what the tool actually is or what purpose it serves. So why is its name so perplexing? The answer lies in two main issues.

1) "Quality Function Deployment" was originally created by two Japanese professors back in the 1960's. Thus, the process was originally given a Japanese name, which was later translated into English. The original Japanese name, "Hin-shitsu Ki-no Ten-kai", was translated quite literally into the name "Quality Function Deployment". Although the name supposedly carries with it a more intuitive meaning in Japanese, it doesn't seem to have the same readily apparent meaning in English [10].

2) The term QFD is used by many people today to refer to a series of HOQ matrices strung together to define customer requirements and translate them into specific product features to meet those needs. However, these prioritization matrices were only a small part of the system that Akao and Mizuno originally created. Thus, the application of the term QFD has changed over the course of the past years as well. Even though much was lost in translation from its Japanese name, QFD was a much more appropriate name for the system of processes originally created by Akao and Mizumo [13].

QFD was developed to bring personal interface to modern manufacturing and business. In today's industrial society where the growing distance between producers and users is a concern, QFD links the needs of the customer with design, development, engineering, manufacturing, and service functions. QFD utilizes four sets of matrices called HOQ to translate CRs into ECs, subsequently into parts characteristics, process plans, and production requirements [14].

QFD provides a system of comprehensive development process for:

- Understanding true customer needs from the customer's perspective.
- What 'value' means to the customer, from the customer's perspective.
- Understanding how customers or end users become interested, and are satisfied.
- Analyzing how do organization can know the needs of the customer.
- Deciding what features to include.
- Determining what level of performance to deliver.
- Intelligently linking the needs of the customer with design, development, engineering, manufacturing, and service functions.

It does so by seeking both spoken and unspoken needs, identifying positive quality and business opportunities, and translating these into actions and designs by using prioritization methods, empowering organizations to exceed normal expectations and provide a level of unanticipated excitement that generates value. It provides valuable guidance to manufacturer to make trade-off between customer’s wants and manufacturer’s affordability [15].

The QFD methodology can be used for both tangible products and non-tangible services, including manufactured goods, service industry, software products, IT projects, business process development, government, healthcare, environmental initiatives, and many other applications.

QFD can be described as an approach to product quality design, which attempts to translate the voice of the customer into the language of the engineer and subsequently into design characteristics. The design features are transformed into part features during a parts development process. In the work preparation phase crucial operating procedures are defined on the basis of the specified part features. The crucial operating procedures in turn serve to determine the production requirements in great detail. The core principle of this concept is a systematic transformation of customer requirements and expectations into measurable product and process parameters [16].

Its adherents of this concept claim that managers can implement QFD in any organization manufacturing, service, nonprofit or government and that it generates improved products and services, reduced costs, more satisfied customers and employees, and improved financial performance [15]. Although many openly praise QFD, others have identified significant costs and implementation obstacles. Critics have suggested, for example, that QFD entails excessive retraining costs, consumes unrealistic employee commitment levels, emphasizes process over results, and fails to address the need of small firms, service firms. Therefore, QFD’s impact on firm performance remains unclear and under-examined, and the existing empirical studies of QFD performance intended to help managers implement QFD more effectively but lack rigor and theoretical support. It is very powerful as it incorporates the voice of the customer in the design hence it is likely that the final product will be better designed to satisfy the customer's needs. Moreover, it provides an insight into the whole design and manufacturing operation (from concept to manufacture) and it can dramatically improve the efficiency as production problems are resolved early in the design phase. QFD is applied in the early stages of the design phase so that the customer wants are incorporated into the final product. Furthermore it can be used as a planning tool as it identifies the most important areas in which the effort should focus in relation to the technical capabilities [17].

In general, QFD as a quality improvement tool has many motives which defines QFD are summarized in the following points.

1) To define product characteristics that meet effective customer requirements.
2) To find all the information deemed necessary for the development of a new product or service.
3) To get a comparative analysis of product performances against those of competitors.
4) To produce coherence between manifest customer needs and measurable product characteristics without neglecting any point of view.
5) To ensure that all those in charge of each process step are constantly kept informed about the relationship between the output quality of that step and the quality of the final product.
6) To reduce the necessity of applying modifications and corrections during advanced stages of development because right from the start everyone is conscious of all the factors that can influence project evolution.
7) To minimize time allotted to customer interaction.
8) To increase the capability of a company to react. So that any errors that could stem from a faulty interpretation of priorities and objectives are kept to minimum.
9) To have self-explanatory documentation on the project as it evolves.

2.3 Input & Outputs of QFD Technique

QFD is known for its ability to ensure that products meet customer expectations during product development [18]. It is a structured and useful approach for efficiently translating customer expectations and wants into design requirements in order to facilitate much higher levels of customer satisfaction [19]. Each QFD project should have inputs and expected outputs whatever the case study is manufacturing or service.

Inputs are

- Customer requirements.
- Technical requirements.
- Customer priorities.
- Market reality/competitive analysis.
- Organization's strength and weaknesses.

Where outputs are

- Prioritized technical requirements.
- Measurable, testable goals.

2.4 Application of QFD across Industries

The application of QFD method has been conducted successfully in both improving quality of existing products and developing new products [20]. The first two reported applications of QFD were in the shipbuilding and electronics industries. QFD's early applications focused on such industries as automobiles, electronics, and software. The fast development of QFD has resulted in its applications to many manufacturing industries. QFD has also been introduced to the service sector such as government, banking and accounting, health care, education and research. Now it is hardly to find an industry to which QFD has not yet been applied.

1) Electronics and electrical utilities

Akao applies QFD to electrostatic copying machines and thus makes electronics another earliest QFD application sector. QFD has been applied to electronics-related companies as AT&T, DEC, Hewlett-Packard, IBM, Intel, Motorola, and Philips, and to electronics-related products/parts such as automated teller machines, blend door actuators chip, climatic control systems, computers, hard disk drives, integrated circuit, robotic work cell, and sensor, QFD has also been applied to electrical utilities such as battery, Florida Power and Light, gas burners, Pacific Gas and Electric, power systems, and wind turbines.

2) Software systems

Another popular application of QFD is software systems. QFD application areas include decision support systems, expert systems, human machine interface, information systems, integrated systems, management information systems, profiling systems, and Web pages.

3) Manufacturing

Manufacturing is also an earlier area of QFD applications. Along with its fast development, there have been more and more QFD applications in manufacturing. QFD has also been applied to diversified manufacturing areas, such as assembly lines/plants/stations, bearing, braking systems, capital goods, chocolate, composite material, computer-integrated manufacturing, cork removers, engine filters, equipment, food, furniture, hybrid bicycles, instrumentation, meat, medical devices, metals, metrology probes, pencils, plastic components, power protection equipment, printing, quick release top nozzles, safety shoes, tea, and tractors.

4) Services

QFD is a customer-oriented quality management and product development technique originally used for hard products, but its ideas are by no means inapplicable to soft services. Indeed, it was gradually introduced into the service sector to design and develop quality services. The wide acceptability of the QFD technique can be shown from its reported applications in various service areas such as accounting, administration, banking etc.

5) Education and research

Among the broad service areas, academic organization is a special one that has witnessed a number of QFD applications to conduct quality education and research based on QFD's customer driven planning principles. In the educational area QFD's applications include colleges/universities, distance education, educational institutes, training, vocational secondary schools and in business schools. QFD has also been applied to R&D and research program design.

6) Transportation and communication

Shipbuilding is one of the two earliest QFD application sectors. Automobile is another earlier and important industry to which many authors report their QFD applications. QFD applications can also be found in aircraft, airlines, automotive parts, car audio, commercial vehicles, container port, motors, railways, pedestrian crossings, satellite, telecommunications, transportation, transportation equipment, and voice mail systems.

2.5 Benefits of Adopting QFD Technique

QFD was originally implemented to reduce start-up costs. Organizations using QFD have reported a reduced product development time. For example, U.S. car manufacturers of the late 1980s to early 1990s need an average of five years to put a product on the market, from drawing board to showroom, whereas Honda can put a new product on the market in two and a half years and Toyota does it in three years. Both organizations credit this reduced time to the use of QFD. Product quality and customer satisfaction improves with QFD due to numerous factors depicted.

1) Fewer and Earlier Changes

QFD is a relatively simple but highly detailed system. Upon initial evaluation it may appear to be too detailed perhaps not worth the effort. The major advantage of QFD is that it promotes preventive rather than reactive development of products, causing organizations to move upstream, working at the high leverage end of the quality lever. This favorably impacts the nature of engineering changes. The change comparison illustration shows the profile of product changes for a proactive and a reactive company. Reactive companies will increase the number of changes as time progresses and product problems are surfaced through testing. After start-up, new problems are discovered, leading to further changes.

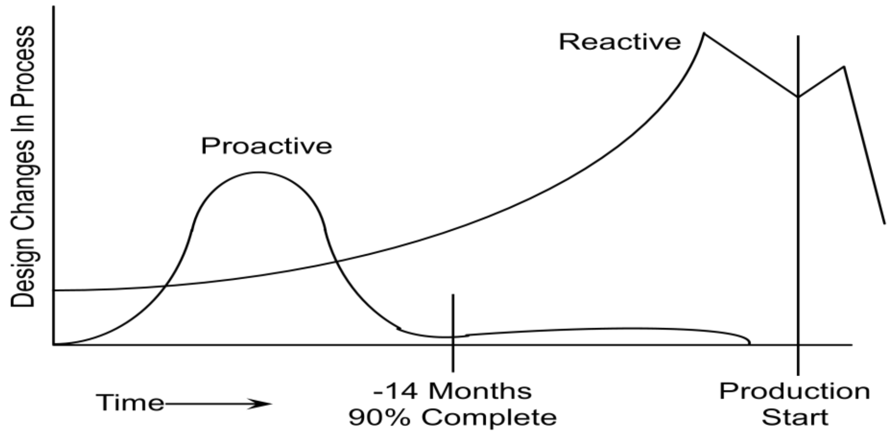

Figure 1: Change comparison after implementation of QFD (source: ABC Company)

The proactive profile shows fewer changes, but more significant is the timing of the changes. Over 90% of the changes were made more than a year before production start-up. Such changes are less expensive because they are made on paper, preventing problems instead of reacting to them.

2) Risk reduction

Development of products is inherently risky. Unknown information represents risk factors which lurk throughout the product development process waiting to cause trouble, delays and expense. When a new product development is done there are unknown factors which organization is already aware of. These may lead to research efforts to discover the answers. While there is a risk, it is managed risk because organization is aware of it. The real dangers lie in the unknown factors which are not known before they surface up. The QFD process will raise many questions, some of which will surface some of these "unknown unknowns" turning them into "known unknowns." Having surfaced these risk factors, they could then be managed. While QFD does not directly answer many questions, it is a process which raises more questions than traditional methods. It is up to our engineering methods to find the answers, and up to management judgment to decide which answers to seek.

3) Fewer start-up problems

The preventive approach fostered by QFD results in fewer downstream problems, especially at production start-up. Figure 2 illustrates the level of product problems as an old product is replaced with a new one. The figure below shows that without QFD there is a surge of product problems at start-up, as unanticipated problems are discovered.

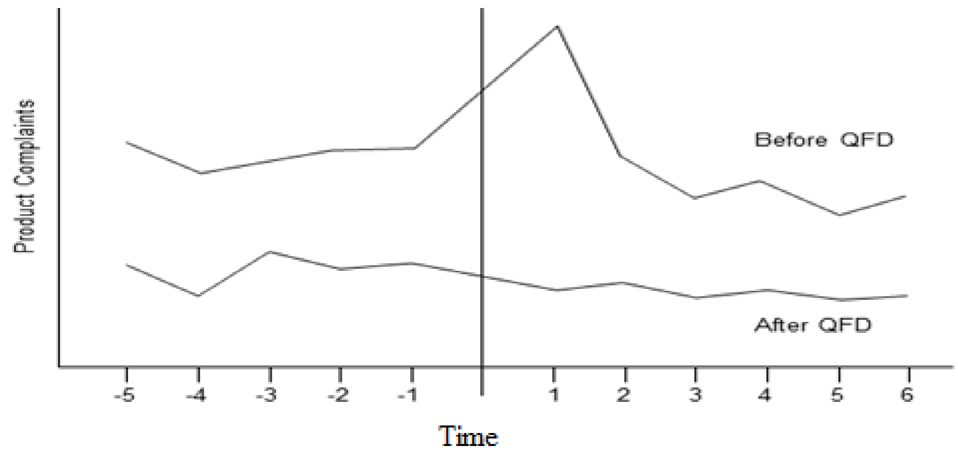

Figure 2: Production start-up problem (source: ABC Company)

After implementing QFD, it is found that the level of problems was reduced while the surge at start-up was eliminated. QFD helped eliminate the surge by causing problems to be anticipated before they happened, allowing preventative action to be taken instead of corrective action.

4) Fewer field problems

The cost savings continues well beyond start-up, and is reflected in reduced problems for customers and consequent warranty cost reduction. QFD is found to be useful in solving difficult product problems. In the 1960s and early 1970s Japanese cars had severe rust problems. The rust warranty cost for company exceeded their company profit by a factor of four. Numerous attempts were made to solve the rust problem, resulting in very small improvement. The rust problem was so complex that a highly disciplined approach was required. Through QFD the improvement effort was focused on the most important of the myriad of details, resulting in the elimination of rusting during the warranty period.

5) Satisfied customers

QFD helps in increased customer orientation because it is driven by the voice of the customer rather than the voice of the engineer or executive. By focusing on the customer numerous engineering decisions are guided to favor the customer. While various trade-offs will always be necessary for any well optimized product these trade-offs are made not for engineering convenience but for customer satisfaction.

6) Customer driven

QFD looks past the usual customer response and attempts to define the requirements in a set of basic needs which are compared to all competitive information. All competitors are evaluated equally from customer and technical perspectives. This information can then be prioritized using a Pareto diagram. Organization can then place resources where they will be the most beneficial in improving quality. Also QFD takes the experience and information that are available within an organization and puts them together as a structured format that is easy to assimilate.

7) Reduces implementation time

Fewer engineering changes are needed when using QFD. When used properly all conflicting design requirements can be identified and addressed prior to production. This results in a reduction in retooling, operator training, and changes in traditional quality control measures. By using QFD critical items are identified and can be monitored from product inception to production.

8) Promotes teamwork

QFD forces a horizontal deployment of communication channels. Inputs are required from all facets of an organization from marketing to production to sales thus ensuring that the voice of the customer is being met and that each department knows what the other is doing. Efficiency and productivity always increase with enhanced teamwork.

9) Provides documentation

A data base for future design or process improvements is created. Data that are historically scattered within operations, frequently lost and often referenced out of context, are now saved in an orderly manner to serve future needs. QFD is also very flexible when new information is introduced or things have to be changed on the QFD matrix.

10) More time for other projects

QFD helps in reduction of time required for development of the product which results in the availability of time and resources for other projects in the organization. This saving of time is very beneficial for every organization as this time can be dedicated to other important activities like marketing.

11) Reduction in cost for research and development

To implement QFD customer requirements about the product are collected prior to design stage so initial design itself is more close to the customer requirements so lesser modifications in the design are required which reduces the cost for research and development.

12) Financial availability for other projects

Implementation of QFD keeps overall cost of manufacturing of the product at low level which makes availability of finance for other projects in the organization.

13) Increase in customer loyalty

As product is designed on the basis of requirements given by the customer in form of voice of customer so the product will be more close to the needs of the customer which enhance the confidence of customer in the organization and loyalty of the customer is improved.

2.6 Factors affecting the success of QFD project

There are several factors in implementation of QFD which affect the success of QFD project. These factors should be noted in advance and requires proper monitoring. The factors are as follows.

2.6.1 Comprehensive technical support for the QFD project

Comprehensive technical support generally includes support form management. Various factors included are as follows.

1) Measurement of what the customer wants

Customer wants and desires are the basis for a QFD project. So it is essential to make a complete survey of the needs of the customer. Once the needs of the customer are clear it is easy to design the product as per the requirements of the customer.

2) Recording the activities of competitors

The activities of competitors determine the success of a new product in the market. So it necessary to record the activities of competitors as it will help the organization to find the current position of their product and modification required to excel in the market.

3) Mastering the complexity of House of Quality

Various parts of HOQ require interdisciplinary team to make a large number of decisions to construct HOQ. So for success of QFD project it is necessary to master the complexity of HOQ.

2.6.2 Strict organization of the QFD project

The project must be strictly organized for successful implementation of QFD for a good/service. Various factors involved are as follows.

1) Intensity of interaction with the management

It is necessary to regularly meet the management and brief the ongoing progress to management as it will help in proper coordination of the project and financing of project is also done by management.

2) Support from top management

When QFD technique is supposed to be implemented for a product support for top management is must as successful implementation of the QFD technique requires resources to be dedicated for the project.

3) Transparency in the project process

It is necessary to have transparency in the QFD project as it will help in organization of the project properly and more help from within the organization can be expected which will help in successful implementation of the project.

There are certain other factors which affect the success of the project like members in the QFD team must be motivated, project experience of those involved in the project, utilization of resources, authority and time. So the above stated factors are important in successful implementation of the QFD hence achievement of these factors will lead to success of the QFD project and the cost, time and resources involved are justified.

2.7 Problem Statement

QFD can be implemented in both service and manufacturing organizations effectively to achieve its main goal in improving products quality level. The focus of the project is to implement the QFD technique in ABC Company to get a design of steering system for a three wheeler by incorporating customer requirements called as voice of customer and technical specification derived from customer requirement.

Though QFD has been applied in automotive parts from earlier times but its application for steering system in India is still a field which is not explored. Steering is the important component of every vehicle as it helps to steer the vehicle in a direction as required by the driver.

2.7.1 About the Steering

The steering system is a mean to allow the driver to control the direction of the vehicle by turning the front wheels. Together with the suspension system, it plays an important role in ensuring easy and comfortable driving all the way from the low speed range to the high speed ranges. There are various types of steering system developed as per requirement in the vehicle and comfort of driver.

2.7.2 Types of Steering

Various steering systems used are as follows.

Recirculating-ball steering (RBS)

Rack and pinion steering system (RPS)

Hydraulic power steering (HPS)

Electric power steering (EPS)

1) ***Recirculating-ball steering (RBS)***

Recirculating-ball steering is used mainly in trucks and heavy vehicles. The recirculating ball steering gear contains a worn gear which can be imagined consisting of two parts. The first part is a block of metal with a threaded hole in it. This block has gear teeth cut into the outside of it which engage a gear that moves the pitman arm. The steering wheel connects to a threaded rod similar to a bolt which sticks into the hole in the block. When the steering wheel turns it turns the bolt. Instead of twisting further into the block the way a regular bolt would, this bolt is held fixed so that when it spins it moves the block which moves the gear that turns the wheels. Instead of the bolt directly engaging the threads in the block all of the threads are filled with ball bearing that re-circulates through the gear as it turns. The balls actually serve two purposes: First they reduce friction and wear in the gear; second they reduce slop in the gear. Slop would be felt while changing the direction of the steering wheel without the balls in the steering gear, the teeth would come out of contact with each other for a moment making the steering wheel feel loose.

2) Rack and pinion steering system (RPS)

Rack-and-pinion steering is actually a pretty simple mechanism. A rack-and-pinion gear set is enclosed in a metal tube, with each end of the rack protruding from the tube. A rod called a tie rod connects to each end of the rack. The pinion gear is attached to the steering shaft. When steering wheel is turned the gear spins moving the rack. The tie rod at each end of the rack connects to the steering arm on the spindle.

The rack and pinion gear set does two things

- It converts the rotational motion of the steering wheel into the linear motion needed to turn the wheels.
- It provides a gear reduction making it easier to turn the wheels.

On most cars, it takes three to four complete revolutions of the steering wheel to make the wheels turn from lock to lock (from far left to far right).

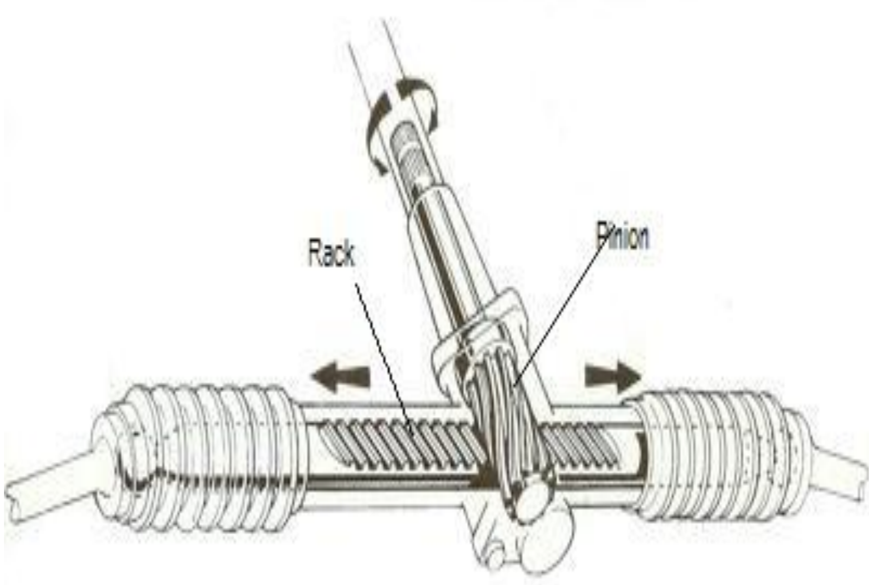

Figure 3: Rack and pinion steering [21]

3) Hydraulic power steering (HPS)

When the rack and pinion is in a power-steering system the rack has a slightly different design. Part of the rack contains a cylinder with a piston in the middle. The piston is connected to the rack. There are two fluid ports, one on either side of the piston. Supplying higher-pressure fluid to one side of the piston forces the piston to move which in turn moves the rack providing the power assist. Power rack and pinion steering assemblies are hydraulic/mechanical unit with an integral piston and rack assembly. An internal rotary valve directs power steering fluid flow and controls pressure to reduce steering effort. The rack and pinion is used to steer the car in the event of power steering failure, or if the engine that drives the pump stalls. When the steering wheel is turned, resistance is created by the weight of the car and tire to road friction, causing a torsion bar in the rotary valve to deflect. This changes the position of the valve spool and sleeve, thereby directing fluid under pressure to the proper end of the rack which helps move the rack to reduce turning effort. The fluid in the other end of the power cylinder is forced to the control valve and back to the pump reservoir. When the steering effort stops the control valve is centered by the twisting force of the torsion bar pressure is equalized on both sides of the piston, and both front wheels return to a straight ahead position.

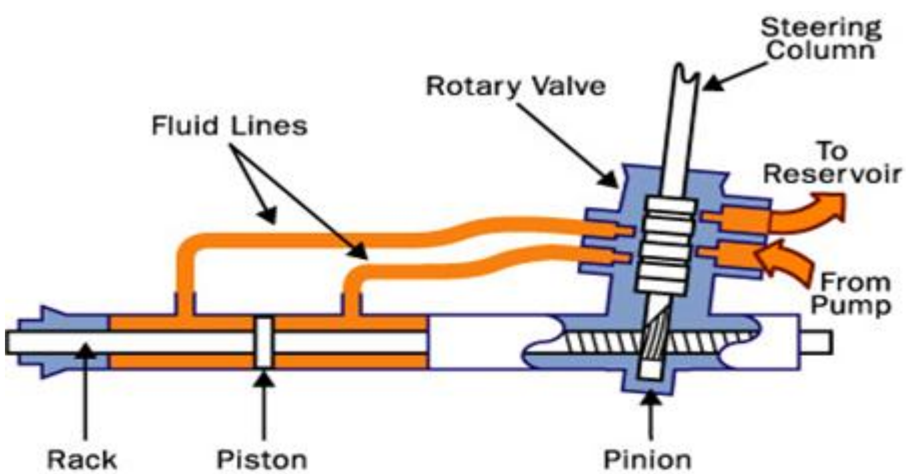

Figure 4: Hydraulic Power Steering [22]

4) Electric power steering (EPS)

EPS is generally used in lighter vehicles like cars. The steering system requires an electronically controlled motor which is operated by ECU which takes input from engine and speedometer.

When input is given to column assembly inside this there is torque sensor which observes the output resistance and gives signal to the motor through ECU. The motor assist the shaft through gear which results in to lighter steering feel. The system takes the signal from engine and speedometer in order to give the output resistance information to motor.

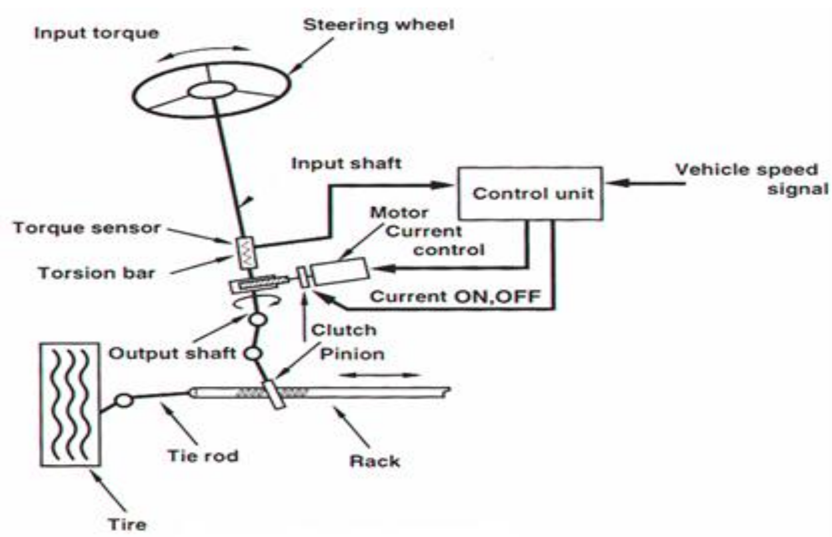

Figure 5: Electric power steering [23]

These are various steering systems used in various vehicles. In three wheelers, steering system used is rack and pinion type due to its light weight, compact assembly, easy maintenance, sharp steering response and simple design.

Chapter-3

QFD Approach

QFD is a well-known customer-driven product design methodology. Now a day the success of an organization has become more and more customer oriented. It has become very important to meet the real and latent needs or quality of the customers to be successful in the marketplace [24]. The goal of QFD is to translate often subjective quality criteria into objective ones that can be quantified and measured and which can then be used to design and manufacture the product [25]. QFD has become an important tool that may help the companies understand the customer and integrate the customer's requirements into the design and production of goods and services [26]. By employing the QFD method the human needs are systematically matched with the product characteristics that can help to improve the product quality. Companies confront several difficulties in introducing and using QFD such as: a difficulty in interpreting voice of customer [27], defining and prioritizing quality characteristics, and working with large matrices [28]. The use of QFD has gained extensive international support for helping decision-making in product planning and development [29]. QFD has a potential process-improvement mechanism [30]. It is very powerful as it incorporates the voice of the customer in the design- hence it is likely that the final product will be better designed to satisfy the customer's needs [31]. Basically, customers' desires on a specific product or service can be represented by a set of intangible customer requirements [32]. It is also an ultimate tool to increased time and resources saving throughout all stages from design to production planning [33]. In the beginning of the QFD design process, the design team needs to capture the Voice of the Customer (VOC) which are determined through personal interviews or focus groups. In QFD the voice of the customer is the critical factor in developing and producing a product that will meet or exceed customer requirements [30]. Requirements are identified on the basis of customer needs. After identification of requirements, a quantitative marketing research is conducted to evaluate the competitive position of the product in the market in terms of customer satisfaction and the importance given by customers to each requirement. The decision making process in QFD is a knowledge-intensive activity, while data available in the early stage of new product design is often limited and inaccurate [34]. Based on the competitive analysis, a target for customer satisfaction is set for each requirement. Thereafter an improvement ratio is calculated.

This improvement ratio is then multiplied by the importance that the customer gives to each requirement. The final relative weight of the requirements is then calculated. Next a set of engineering characteristics is calculated on the basis customer requirements. A crucial step during QFD concerns the linking of engineering characteristics to customer needs in the HOQ [35]. This HOQ helps to develop a design which incorporates customer needs on preferential basis.

3.1 QFD Underlying Principle

QFD is not just a quality tool but an important planning tool to introduce new products and upgrade existing products. In today's competitive marketplace it is not enough to just do the right things. In order to become and remain successful companies must focus on doing things right. To accomplish this, companies must understand the total marketplace needs for the product or service they are delivering. Companies who do not fully understand their customers' needs cannot develop a product which satisfies their needs. Failure to determine the customers' needs opens the door to competitors who develop a better understanding of their customers. Doing the right things right begins with the focus on the customer and ends with the delivery and service of a product which meets or exceeds the customers' expectations. One of the objectives of Project Sappho, a comprehensive industry research project done in Great Britain in the early 70's, was to determine why some products succeed and others fail. Poor product definition at the outset commonly leads to either failure of that product in the marketplace or extended product development time. The extended development time is usually the result of constantly redefining the product requirements as new information, which should have been determined much earlier is uncovered. Another significant finding was that an imaginative understanding of customers' needs done well and early leads to successful products and shorter development time. The basic underlying principles of QFD are as follows:

1) Customers are the number one concern and satisfied customers keep organization in business. Therefore, organization must have an excellent understanding of their needs.
2) Proactive product development is better than reactive product development. QFD can help a company move toward a more proactive approach.
3) Quality is a responsibility of everyone in the organization. QFD is a team methodology which encourages a broader employee involvement and focus.

3.2 House of Quality

The primary planning tool used in QFD is the HOQ. HOQ provides a conceptual map that enables the improvement of planning and control of the product development process [36]. The HOQ translates the voice of the customer into design requirements that meet specific target values. In other words HOQ links the voice of the customer to the voice of the technician through which process and production plans can be developed [37]. Many managers and engineers consider the HOQ to be the primary chart in quality planning. Figure 6 shows the basic structure of HOQ.

3.2.1 The parts of House of Quality

The exterior walls of the house are the customer requirements. On the left side is a listing of the voice of the customer, or what the customer expects in the product. On the right side are the prioritized customer requirements, or planning matrix [38]. Listed are items such as customer benchmarking, customer importance rating, target value, scale-up factor, and sales point.

The ceiling, or second floor, of the house contains the technical descriptors. Consistency of the product is provided through engineering characteristics, design constraints, and parameters.

The interior walls of the house are the relationships between customer requirements and technical descriptors.

The roof of the house is the interrelationship between technical descriptors. Tradeoffs between similar or conflicting technical descriptors are identified.

The foundation of the house is the prioritized technical descriptors. Items such as the technical benchmarking, degree of technical difficulty, absolute and relative weight are listed.

This is the basic structure for the HOQ; once this format is understood, any QFD matrix can be developed easily.

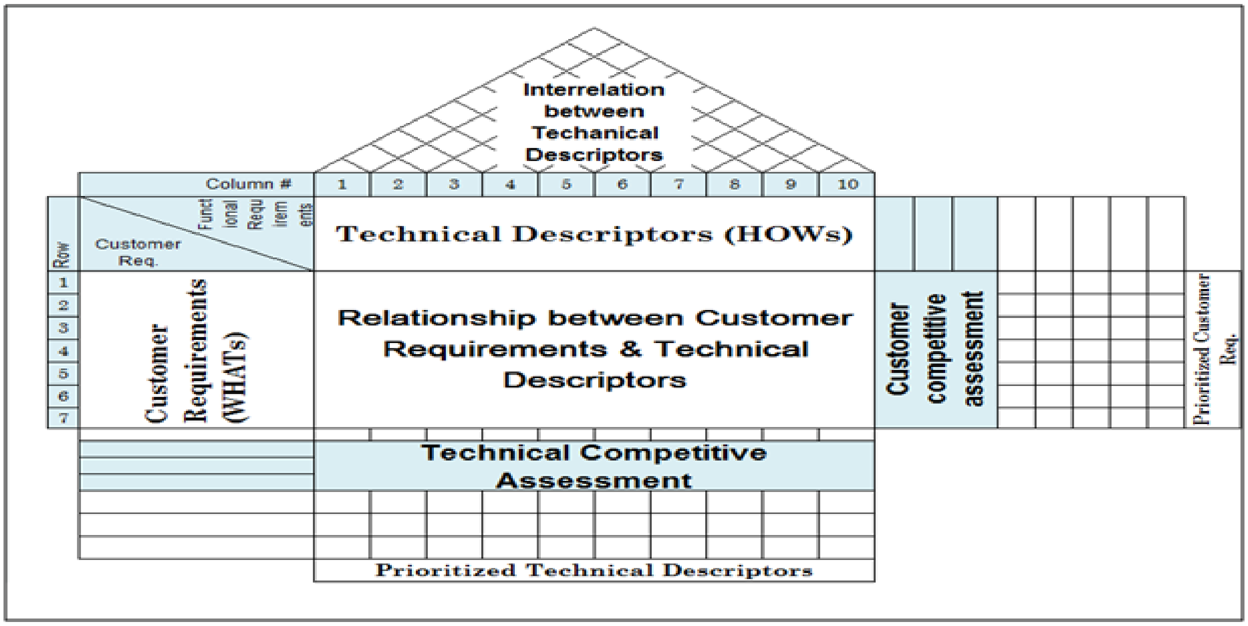

Figure 6: House of Quality

3.3 The QFD Team

When an organization decides to implement QFD the project manager and team members need to be able to commit a significant amount of time to it especially in the early stages. The priorities of the projects need to be defined and told to all departments within the organization so team members can budget their time accordingly. Also the scope of the project must also be clearly defined so questions about why the team was formed do not arise. One of the most important tools in the QFD process is communication.

There are two types of teams-one for a new product or a team for improving an existing product. Teams are composed of members from marketing, design, quality, finance and production. The existing product team usually has fewer members because the QFD process will only need to be modified. Time and inter-team communication are two very important things that each team must utilize to their fullest potential. Using time effectively is the essential resource in getting the project done on schedule.

Team meetings are very important in the QFD process. The team leader needs to ensure that the meetings are run in the most efficient manner and that the members are kept informed. The format needs to have some way of measuring how well the QFD process is working at each meeting and should be flexible, depending on certain situations. The duration of the meeting will rely on where the team members are coming from and what needs to be accomplished. There are advantages to shorter meetings and sometimes a lot more can be accomplished in a shorter meeting. Shorter meetings allow information to be collected between times that will ensure that the right information is being entered into the QFD matrix. Also they help keep the team focused on a quality improvement goal.

3.4 Planning and Organizing the Project

This section is divided into three parts:

• Project selection

• Project staffing

• Launching the project

Project Worksheets

Project selection deals with selecting and creating the description of the project, including the rationale for the project. Project staffing deals with the staffing needed for the project. After defining the project and staffing QFD project approval is considered. Launching the project deals with the initial team meeting, QFD briefing and preparation for the QFD implementation. Project worksheets are provided to guide the thought processes for the other three sections. These worksheets outline the minimum requirements to begin a QFD project.

3.5 Implementation of QFD Technique

Implementation of QFD technique starts with identifying various customers who are users of the product in order to get their feedback about the product. Various open ended question are asked about the product. Their response and feedback will form the voice of the customers. These customer requirements need to be prioritized so that the crucial customer requirements are given the due importance. This prioritization can be done by the help of Kano questionnaire consisting of various multiple choice functional and dysfunctional questions about the product. After customer requirements are collected, technical specification about the product is required to be established. These technical specifications should be derived from customer requirements so as to keep the product customer oriented rather than manufacturer oriented. For constructing the QFD house of quality it involves establishing the primary input to the HOQ which are customer requirements and technical specification [37].

A relationship matrix is established between the customer requirements and technical specification which shows the relationship between these two. An interrelationship matrix is also established between the technical specifications which forms the roof of the HOQ. These matrices are made so as to find out conflicting parameters in advance which will help in getting a more stable design even during initial stages [15].

Customer and technical competitive assessment rating requires to be done so as to make the competitive assessment of the company and to find out where company stands in respect to competitors in the market on the basis of customer requirements and technical descriptors. Importance to customer rating is required to be done on scale of 1 to 10 to find out which customer requirement is profitable when fulfilled by the organization. Various other ratings of the customer requirement can be done for target value, scale-up factor, sales point and absolute weight. Target value rating shows that how much company wants to improve for each customer requirement or no improvement needed for the customer requirement. Sales point rating for a customer requirement shows the importance of the each customer requirement in selling the product. Absolute weight rating is the combination of the ratings of importance to customer, scale-up factor, sales point [17].

Similarly for each technical descriptor rating of technical difficulty, absolute weight and relative weight requires to be done in the HOQ. Technical difficulty rating tells the company about how much is it difficult to apply a certain technical specification to achieve customer requirements. Absolute weight and relative weights rating is required to find out the importance of technical descriptor in achieving the customer requirements.

Chapter-4

Case Study

A case study of ABC Company that manufactures steering for wide range of vehicles is considered. QFD technique is applied here to the steering system which is already in the market and is used in three wheeler auto. The concern of this project is to implement QFD for getting a design of the steering which incorporates customer requirements to have more satisfied customers and more competitive product. In three wheelers rack and pinion steering system (RPS) is used.

4.1 About the company

With its beginning as a small company in 1985, now the ABC Company is a joint venture partnership and technical and financial collaboration with global leaders in their specialist areas. ABC Company is a technical and financial joint venture company of Japan. With a Market share of 50%, the company is the largest manufacturer of steering gears in India and is the leading supplier of: Hydraulic Power Steering Systems, Manual Rack and Pinion Steering Systems, Recirculate Ball Steering Systems, Collapsible, Tilt and Rigid Steering Columns and Column power steering (CEPS) for Passenger Vans and MUVs.

4.1.1 Company Policy, Performance and Working Philosophy

The company's quality policy reads: "Commitment to defect prevention and continuous improvement while meeting or exceeding customer requirements at all times." Customer Satisfaction continues to be most importance to ABC Company, as do consistent quality, constant innovation, value engineering, process improvement and customer orientation. The World Economic Forum named the company as a Global Growth Company in 1997. The company is paying a lot of attention to Total Quality Management (TQM). It is also developing its core competence and aligning objectives at all levels so as to realize synergy in operations. An initiative of improving the most important resources, the Human Resource, as well as the plant equipment has been initiated. This technique, Total Productive Maintenance (TPM), has been adopted to improve performance through the philosophy of prevention. ABC Company aims to achieve zero accidents, zero defects and zero breakdowns. ABC Company respects the dignity of human beings at all levels. In the matter of employment, it believes in the concept of equality in caste, religious, creed, race, sex and nationality. Employees' selection shall be merit based and made on basis of proven ability of the incumbents. Company endeavors to provide equal opportunity to all and one in the matter of internal promotion. Only the right person for the right job however, shall be promoted. Company is conscious of fact that the growth and progress of its employees and the company is inter-dependent, hence the concept of all round development of its team members shall be of prime importance. Company encourages meaningful participation of its team members to achieve the organizational goals and objectives. Company constantly endeavors to establish and promotes clean and safe working environment where it team members may work happily and drive joy and pleasure. Professional practices like cleanliness, punctuality, teamwork, quality control, educated workers, credible environment policy and recognition are followed.

4.1.2 Various Plants of ABC Company

ABC Company has a total of three plants, each of which manufactures different products. Plant I manufactures RPS Assemblies, rigid columns, collapsible columns and tilt steering assembly. The various in-house parts that are used in the manufacturing of these assemblies are made in Plant I. RPS Assembly consists of various components like Rack, Pinion, Case gear etc. that are produced in-house. Apart from this, various other brought out parts (BOP) are used such as Bellow, Rack cover, Rack housing etc. that come from various vendors. In addition to the various assembly line and the lines for making the in-house components, the plant also accommodates tool room machines. Plant II is slightly bigger and manufactures a larger number of items than Plant I. The most important of the products manufactured here are the RBS Assemblies for various models, Propeller Shaft Assemblies and Axle Assemblies. Plant III is also known as the Power Steering Plant. The plant is the newest of the three, and started in 1998. The plant makes Power Steering Assemblies. In addition to these three plants, there is a heat treatment plant, a paint shop (in Plant II) and an Engineering Testing Lab (in the basement of Plant II). Company has a paint shop for catering its in-house demand of painting of various components. The main components that are painted in the shop are propeller shaft, RBS Assembly, I-Shaft Assembly, lower shaft and collapsible column. Engineering testing lab is to carry out various tests on the products manufactured in the company so as to have close check on quality of the parts being manufactured in the company.

4.2 Special features of RPS System

Rack and pinion steering system has its application in large number of vehicles. In three wheelers also RPS system is used. There are certain features of PRS due to which it is used in three wheelers.

Inexpensive

Generally when rack and pinion steering is used the gearbox is fitted into the steering link structure. The Linkages are very much reduced because the RPS is complete in itself. Therefore the cost is much cheaper with respect to other types.

Light in weight

As a steering gear assembly the no. of linkages are less. From the angle of strength the material of gearbox is aluminum die cast compared to RBS, it is light in weight.

A Sharp Steering feeling

In the case of RBS type steering the torque applied to main shaft goes through the ball screw to ball nut and then to sector ear. Whereas in RPS rack and pinion are in direct contact therefore the feeling is sharper in response.

Strength is high

In the RPS type the meshing force between the teeth of the gears is lower in comparison to the RBS type therefore the impact strength is higher.

Other certain advantages of RPS are

- Construction is simple, compact. Since the gear box is small, and the rack itself acts as the steering linkage, the relay rods used in the Recirculating-ball type are not necessary.

- There is little sliding and rotational resistance and the torque transmission is better, so the steering is light.

4.3 Components of RPS system

The main components of the RPS system are steering rack bar and steering pinion. Rack bar is threaded rod placed inside rack bar housing with its end protruding out of housing. Steering pinion is also threaded which is in mash with rack bar and its non-threaded portion is connected with the steering shaft. This rack and pinion gear shaft converts the rotational motion of the steering wheel into linear motion needed to turn the wheel and it provides a gear reduction which makes it easier to turn the wheel. Dust boot is corrugated rubber component which is provided to protect inner tie rod from dust. It is fixed with the help of dust boot clips. Various components of rack and pinion steering system are shown in figure 7.

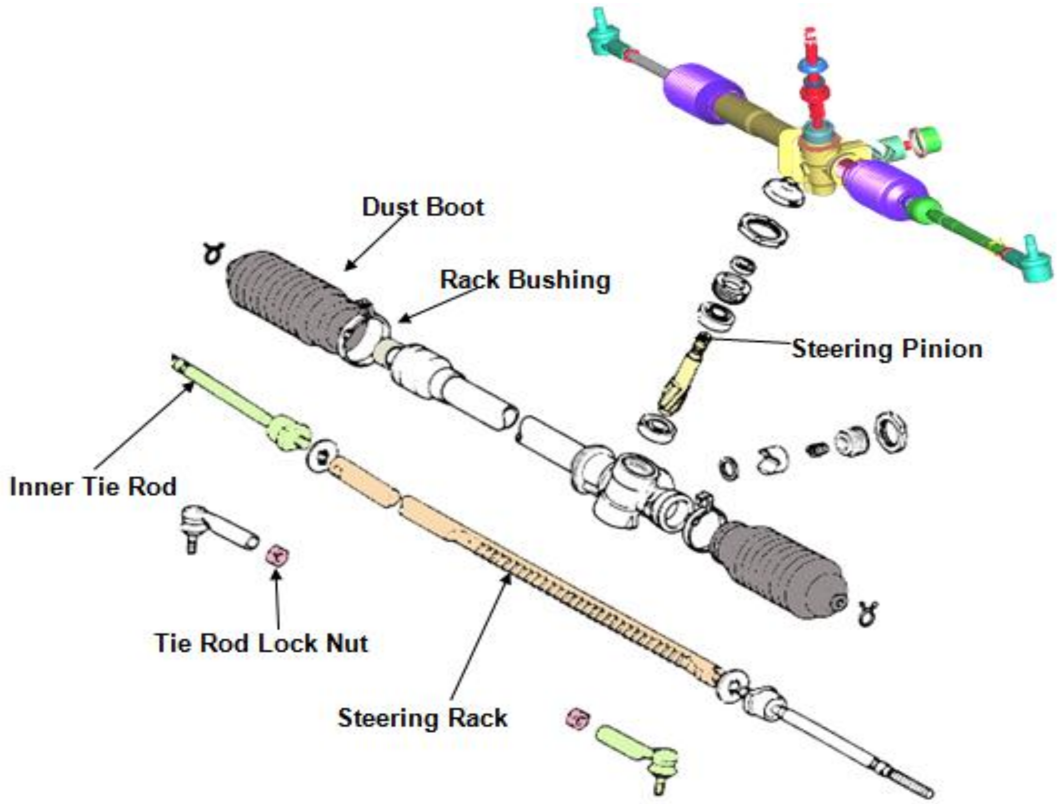

Figure 7: Components of RPS [39]

4.4 Stepwise Implementation of QFD for the Steering System

Now the system to be considered for implementation of QFD is final. Primarily customer requirements are required to begin with implementation of QFD.

4.4.1 Step 1—List Customer Requirements (WHATs)

QFD is a method for developing design quality that aims at satisfying the customer by translating their needs into functional requirements as design targets or engineering parameters for the production stage [40]. So QFD allows quality design through quality characteristics identified as customer requirements translation in the product development [41]. QFD is a well-structured, cross-functional planning technique that is used to hear the customers' voice throughout the product planning, development, engineering and manufacturing stages of any product [42][43].

i) The voice of the customer

Because QFD concentrates on customer expectations and needs, a considerable amount of effort is put to determine customer expectations. This process increases the initial planning stage of the project definition phase in the development cycle. But the result is a total reduction of the overall cycle time in bringing to the market a product that satisfies the customer.

The driving force behind QFD is that the customer dictates the attributes of a product. By focusing or listening to customers, QFD has been a useful technique that aims to satisfy customer needs at the very beginning namely the product design phase [44]. Words used by the customers to describe their expectations are often referred to as the voice of the customer. Sources for determining customer expectations are focus groups, surveys, complaints, consultants, standards and federal regulations. Frequently customer expectations are vague and general in nature. It is the job of the QFD team to break down these customer expectations into more specific customer requirements. Customer requirements must be taken literally and not incorrectly translated into what organization official's desire.

QFD begins with marketing to determine what exactly the customer desires from a product [45]. During the collection of information numerous open ended questions are asked from the customers. The organization can search (solicited) for the information, or the information can be volunteered (unsolicited) to the organization. Solicited and unsolicited information can be further categorized into measurable (quantitative) or subjective (qualitative) data. Furthermore, qualitative information can be found in a routine manner or haphazard manner. Solicited, measurable, and routine data are typically found by customer surveys, market surveys, and trade trials, working with preferred customers, analyzing products from other manufacturers, and buying back products from the field. This information tells an organization how it is performing in the current market.

Unsolicited, measurable, and routine data tend to take the form of customer complaints or lawsuits. This information is generally disliked however it provides valuable learning information.

Solicited, subjective, and routine data are usually gathered from focus groups. The object of these focus groups is to find out the likes, dislikes, trends and opinions about current and future products.

Solicited, subjective, and haphazard data are usually gathered from trade visits, customer visits and independent consultants. These types of data can be very useful however they can also be misleading depending on the quantity and frequency of information.

Unsolicited, subjective and haphazard data are typically obtained from conventions, vendors, suppliers and employees. This information is very valuable and often relates the true voice of the customer.

The goal of QFD is not only to meet as many customer expectations and needs as possible, but also to exceed customer expectations [17]. Focus of QFD implementation is to make the product either more appealing than the existing product or more appealing than the product of a competitor.

ii) Organization of information

Now that the customer expectations and needs have been identified and researched, the QFD team needs to process the information. Numerous methods include affinity diagrams, interrelationship diagrams, tree diagrams and cause-and-effect diagrams. These methods are ideal for sorting large amounts of information. The affinity diagram, which is ideally suited for most QFD applications, is discussed next.

iii) Affinity Diagram

The affinity diagram is a tool that gathers a large amount of data and subsequently organizes the data into groupings based on their natural interrelationships. An affinity diagram should be implemented when thoughts are too widely dispersed or numerous to organize new solutions are needed to circumvent the more traditional ways of problem solving or support for a solution is essential for successful implementation. This method should not be used when the problem is simple or a quick solution is needed [46]. The team needed to accomplish this goal effectively should be a multidisciplinary one that has the needed knowledge to delve into the various areas of the problem.

A team of six to eight members should be adequate to assimilate all of the thoughts. Constructing an affinity diagram requires four simple steps.

1) Phrase the objective.
2) Record all responses.
3) Group the responses.
4) Organize groups in an affinity diagram.

The first step is to phrase the objective in a short and concise statement. It is imperative that the statement be as generalized and vague as possible.

The second step is to organize a brainstorming session, in which responses to this statement are individually recorded on cards and listed on a pad.

Next all the cards should be sorted by placing the cards that seem to be related into groups. Then a card or word is chosen that best describes each related group becomes the heading for each group of responses. Finally lines are placed around each group of responses and related clusters are placed near each other with a connecting line.

4.4.1.1 Collection of voice of customers (VOC)

QFD is a cross-functional planning tool used to ensure that the customer's voice is translated into product design through a structured framework. The first step in applying the QFD method is users' requirements capture [47]. Now for designing the steering customer requirements are needed from various end users of the steering. The methodology for collecting VOC is shown in the figure 8.

i) Plan for exploration

The first step is plan for exploration. The purpose of this step is to decide how to explore broadly what Customer may need. Here it is decided whom to visit, who will collect the data and how to visit. For collecting voice of customer prof. Shiba's concept of *"Swimming in fishbowl"* is used. The steps under this are scheduling the visit, conducting the visit and debriefing. The visit is scheduled prior to the visit so as to make sure customer is available and there is no wastage of time and money. On the scheduled time visit will be conducted and various questions about the product will be asked and response will be recorded to get the views of the customer about the product.

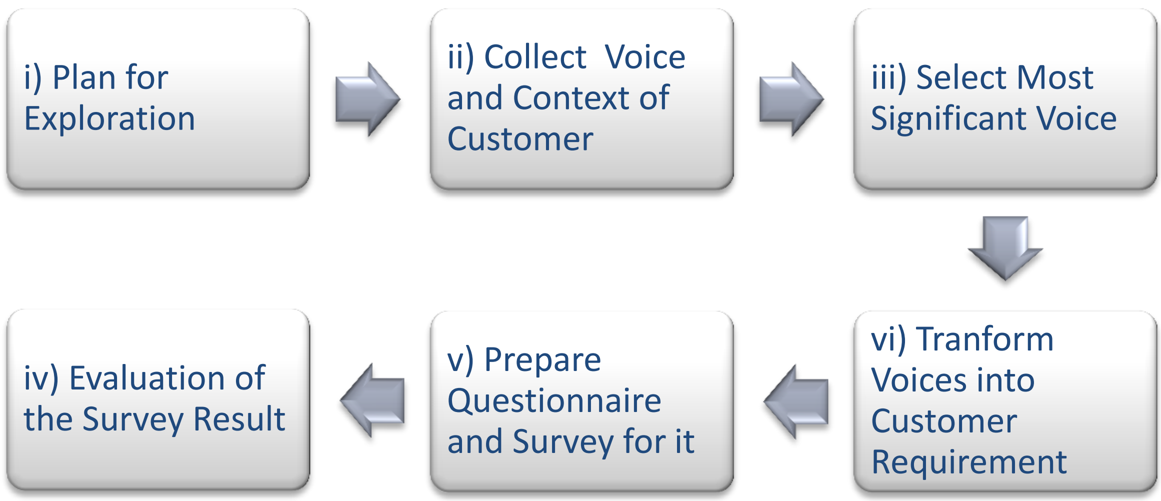

Figure 8: Methodology for collecting VOC

ii) Collection of voice and context of customers

Next step is collection of voice and context of customers. For this open ended questions are asked. Any additional information is also sought from users. Responses from the customer are properly noted down so as to have complete information of image of the customer about the steering. This step is most crucial as it will guide the complete project in a direction to achieve the most appropriate design of steering as per the needs of the customer. Various question asked to collect the voice and context of the customer are:

- From your experience what complaints, problems or weakness would you like to mention about steering system.
- What features do you think of when selecting a steering system?
- What new features might address your future needs?
- What image/scenes come to mind while using a steering system?
- Any additional comment/observations.

iii) Selection of most significant voices

Next step is selection of most significant voices. Out of various voices, the most significant voices which seem to be more realistic and helpful are selected. Various significant voices are:

1) Steering is easy to control even with a single hand.
2) It should be easy to turn at low speed.
3) Steering should come to central position very fast after making a turn.
4) The housing gets broken in a frontal accident.
5) The mounting bracket gets broken in a frontal impact.
6) The mounting bracket should be strong enough to bear impact at high speed.
7) The column is thin it looks odd.
8) The height of steering should vary according to sitting arrangement
9) Maintenance of the steering can be done by the driver.
10) The position of the steering wheel should be confortable.
11) The position of steering wheel can be adjusted.
12) Driver is able to take sharp turn.
13) Wheel pin gets easily broken.
14) Steering gets damaged due to water and rusting.
15) Leg space is to use brake, it should be on steering.
16) Gear has to be with steering wheel.
17) Steering must be smooth.
18) The steering housing gets broken due to the impact of a pit.

iv) Transfer of voices into customer requirements

Next step is to transfer voices into customer requirements. On basis of understanding of what customer requires, possibly ambiguous statement of what customer needs is converted into unambiguous statement of customer requirement. By visiting customer voices and images of the customer about the steering are collected. Then voices and image of customers are joined to get customer requirements. So the customers' requirements are driver form the customer needs and desires rather being dictated by the manufacturer.

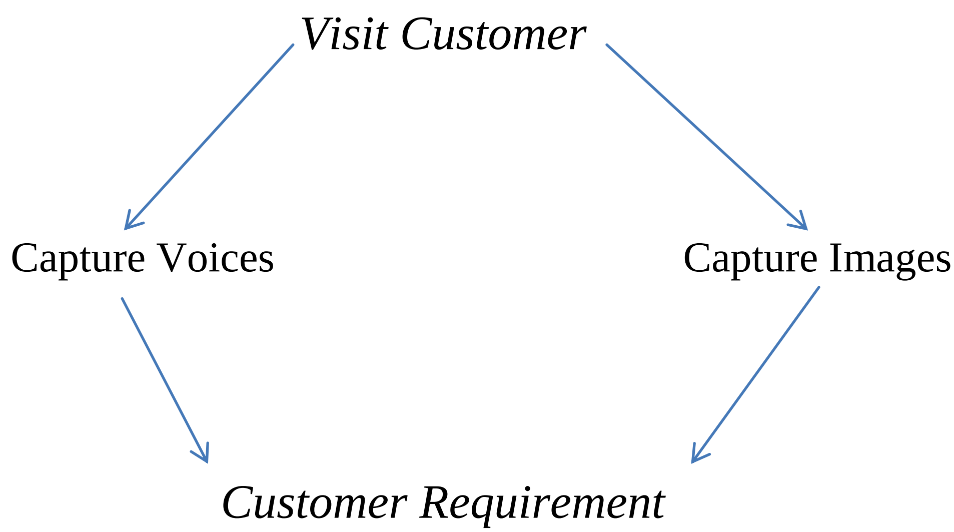

Figure 9: Conversion of VOC into customer requirement

There are seven basic rules/guidelines which are followed while changing voice of customer into requirements of the customer.

1) Avoid statement in a negative form.
2) Avoid two valued (0-1) concepts.
3) Avoid abstract words.
4) Avoid statement of Solution.
5) Avoid premature detail.
6) Avoid the auxiliary verbs should or must.
7) Avoid intangible concepts.

Following these rules and guidelines voice of customer are converted into requirements of the customer. These are necessary as these rules helps in keeping the exact sense of the voice of customer during the conversion helps to keep the product user driven rather than manufacturer driven. In order to convert the voice of the customer into customer requirement captured voice and image of the customer is written and keyword from the voice and image of the customer is collected. From the identified keyword customer requirement is constructed. Various customer requirements identified from voice of customer are listed in table 1.

Like for the voice of customer: The column is thin and it looks odd, the image in the mind of the customer is that column should look attractive. So the keyword of this voice of customer is “attractive shape of column.” Form this keyword customer requirement derived is that the shape and size of the column steering column should give secure feeling to the customer. Like this various customer requirements are obtained from voice of customer and are listed in table 1.

Various customer requirements are:

	Customer Requirements
1	Steering wheel is rotated by single hand.
2	Steering wheel is turned easily at low speed.
3	Effort required to maintain the auto in the central position is less.
4	The housing withstands shocks during the frontal accident.
5	The mounting bracket can withstand frontal accident.
6	The mounting bracket can withstand impact even at high speed.
7	Shape and size of steering column gives secure feeling to the customer.
8	The height of steering system is adjustable to suit the driver.
9	The driver is maintaining steering component himself.
10	The steering wheel is handled without stretching the arm.
11	Steering wheel is handled by little movement of elbow from body.
12	The auto does not topple while taking sharp turn at high speed.
13	Wheel pin withstand high wear and tear.
14	Steering system is water resistant.
15	The steering wheel has feature of breaking.
16	The steering provides control of gear while driving.
17	The vehicle can be steered by small turning of steering wheel.
18	The steering housing withstands impact of pit.

Table 1: Customer requirements

v) Kano Questionnaire

PROF. Noriaki Kano Developed a tool which helps to understand the relationship between the fulfillment of a requirement and the satisfaction or dissatisfaction experienced by the customer. The Kano Method builds from the premise that a combination of the level of functional fulfillment and emotional satisfaction that a customer receives from a product relates to the customer's assessment of the product's quality [48]. He proposed that the required levels functional and emotional, varied across a product's attributes and that designers should target the proper combinations of functional fulfillment and emotional satisfaction when designing product attributes. The levels of functional fulfillment and emotional satisfaction targeted in an attribute are dictated by the categorization of the attribute which Kano termed quality elements. Various attributes used in the evaluation of the questionnaire are listed below.

Attractive Quality

These attributes provide satisfaction when achieved fully, but do not cause dissatisfaction when not fulfilled. These are attributes that are not normally expected, For example, a thermometer on a package of milk showing the temperature of the milk. Since these types of attributes of quality unexpectedly delight customers, they are often unspoken.

One-dimensional Quality

These attributes result in satisfaction when fulfilled and dissatisfaction when not fulfilled. These are attributes that are spoken of and ones which companies compete for. An example of this would be a milk package that is said to have ten percent more milk for the same price will result in customer satisfaction, but if it only contains six percent then the customer will feel misled and it will lead to dissatisfaction.

Must-be Quality

These attributes are taken for granted when fulfilled but result in dissatisfaction when not fulfilled. An example of this would be package of milk that leaks. Customers are dissatisfied when the package leaks, but when it does not leak the result is not increased customer satisfaction. Since customers expect these attributes and view them as basic, it is unlikely that they are going to tell the company about them when asked about quality attributes.

Indifferent Quality

These attributes refer to aspects that are neither good nor bad, and they do not result in either customer satisfaction or customer dissatisfaction.

Reverse Quality

These attributes refer to a high degree of achievement resulting in dissatisfaction and to the fact that not all customers are alike. For example, some customers prefer high-tech products, while others prefer the basic model of a product and will be dissatisfied if a product has too many extra features.

In order to classify attributes into the Kano categories, the attributes are first classified at the individual customer level using a survey methodology and then aggregated. Respondents answer multiple choice questions about product attributes. For each attribute under consideration, respondents are first asked how they would feel the product includes the attribute (referred to as the functional question) and then how they would feel if the product did not include the attribute (referred to as the dysfunctional question). Attributes are classified based on responses to the functional and dysfunctional questions.

Based upon Kano method a questionnaire is prepared to evaluate and classify the customer requirement. The questionnaire is given in the appendix. Questionnaire consists of various multiple choice questions. Like for the customer requirement: Steering wheel is rotated by single hand, functional and dysfunctional question are asked. The functional question is "if the steering wheel is steered with one finger, how you do feel?" The dysfunctional question is "If the steering wheel is steered with both hands, how do you feel?" Multiple choices are given for each question on the basis Kano's quality attributes. For each functional and dysfunctional question response from the users are collected. For every question in the questionnaire response is taken from 67 users. Each user has his own opinion about the product and on the basis of his opinion the users selects out of the five options given for each question. The result of the questionnaire survey is shown in table 2

vi) **Evaluation of Customer response Questionnaire**

Based upon response from the questionnaire grading is done for each question. The result from the questionnaire will help in grading various customer requirements in a manner so that the customer requirement which yields more benefit to the organization will be having more rating. The result from the questionnaire will help the organization in selecting the most critical requirements and their classification. The customer requirements are classified in primary and secondary customer requirements. These customer requirements will form the basis for finding the technical descriptors. These customer requirements and technical descriptors will form HOQ which will lead to a more appropriate design as per the requirements of the customer. Evaluation of customer response questionnaire is given in the table 2.

	Customer requirement	**A**	**M**	**O**	**R**	**I**	**Total**	**Grade**
1	Steering wheel is rotated by single hand.	7	13	36	7	4	67	**O**
2	Steering wheel is turned easily at low speed.	15	12	23	10	7	67	**O**
3	Effort required to steer the auto to maintain in the central position is less.	7	21	26	0	3	67	**O**
4	The housing shocks during the frontal accident.	1	27	39	0	0	67	**O**
5	The mounting bracket can withstand frontal accident.	3	37	25	0	2	67	**M**
6	The mounting bracket can withstand impact even at high speed.	13	22	20	3	9	67	**M**
7	Shape and size of steering column gives secure feeling to the customer.	7	23	21	2	14	67	**M**
8	The height of steering system is adjustable to suit the driver.	23	4	15	12	13	67	**A**
9	The driver is maintaining steering component himself.	4	18	38	2	5	67	**O**
10	Steering wheel is handled by little movement of elbow from body.	8	14	19	24	2	67	**R**
11	The steering wheel is handled without stretching the arm.	5	15	44	1	2	67	**O**
12	The auto does not topple while taking sharp turn at high speed.	0	42	25	0	0	67	**M**
13	Wheel pin withstand high wear and tear.	4	22	41	0	0	67	**O**
14	Steering system is water resistant.	3	16	44	0	4	67	**O**
15	The steering wheel has feature of breaking.	13	3	17	18	16	67	**R**
16	The steering provides control of gear while driving.	16	3	14	28	6	67	**R**
17	The vehicle can be steered by small turning of steering wheel.	9	7	22	28	1	67	**R**
18	The steering housing withstands impact of pit.	8	13	39	4	3	67	**O**

Table 2: Evaluation of customer response

Now from the evaluation of the questionnaire sheet the customer requirements are categorized in to primary and secondary customer requirements. This list of primary customer requirements is usually vague and very general in nature. Further definition is accomplished by defining a new and more detailed list of secondary customer requirements required to support the primary customer requirements. In other words a primary customer requirement may encompass numerous secondary customer requirements. The items on the list of secondary customer requirements represent greater detail than those on the list of primary customer requirements as shown in Figure 10. For example, a primary customer requirement might be dependability and the corresponding secondary customer requirements could include reliability, longevity, and maintainability.

Two primary customer requirements here are performance and safety. Secondary customer requirements under performance are smoothness, durability, noise and light weight. Secondary customer requirements under safety are tilted column and collapsible column. Furthermore, it is not necessary to break down the customer requirements to the tertiary level. These primary and secondary customer requirements are shown in Figure 10.

	Primary	**Secondary**
Customer Requirements (WHATs)	**Performance**	Smoothness
		Durability
		Noise
		Compactness
		Maintenance
	Safety	Collapsible column

Figure 10: Refinement of customer requirements

4.4.2 Step 2—List Technical Descriptors (HOWs)

QFD is a systematic technique to translate customer needs (CN) into the technical characteristics (TC) of a product or service [49]. The goal of the HOQ is to design or change the design of a product in a way that meets or exceeds the customer expectations. Now that the customer needs and expectations have been expressed in terms of customer requirements, engineering characteristics or technical descriptors (HOWS) are required to be obtained that will affect one or more of the customer requirements. These technical descriptors make up the ceiling, or second floor, of the HOQ. Each engineering characteristic must directly affect a customer perception and be expressed in measurable terms.

Implementation of the customer requirements is difficult until they are translated into counterpart characteristics. Counterpart characteristics are an expression of the voice of the customer in technical language. The list of technical descriptors is divided into a hierarchy of primary and secondary technical descriptors as shown in Figure 11.

	Primary	**Secondary**
Technical Descriptors (HOWs)	**Manufacturing**	Torque variation
		Axial Play
		Yoke Clearance
		Steering mounting
		Returnability
		Bellow clamping
	Material selection	Housing material
		Corrosion resistant coating
		Child part material

Figure 11: Refinement of technical descriptors

The process of refinement is further complicated by the fact that through each level of refinement, some technical descriptors affect more than one customer requirement and can even adversely affect one another. For example, a customer requirement for a steering is smooth movement. This is a rather vague statement; however it is important in the selling of the steering. Counterpart characteristics for a smooth steering can be dampening, clamping, and torque variation which are the primary technical descriptors.

So in designing the steering two primary technical descriptors are material selection and manufacturing process. Secondary technical descriptors under material selection are housing material, corrosion resistant coating, bellow material and child part material. Secondary technical descriptors under manufacturing process are Torque variation, axial play, yoke clearance, steering mounting, returnability and Bellow clamping.

4.4.3 Step 3—Develop a Relationship Matrix between WHATs and HOWs

The next step in building a HOQ is to compare the customer requirements and technical descriptors and determine their respective relationships. Tracing the relationships between the customer requirements and the technical descriptors is very confusing, because each customer requirement may affect more than one technical descriptor and vice versa.

i) Relationship Matrix

The inside of the HOQ called the relationship matrix is now filled. The relationship matrix is used to represent the degree of influence between each technical descriptor and each customer requirement. Doing this early in the development process will shorten the development cycle and lessen the need for future changes.

Generally symbols are used to represent the degree of relationship between the customer requirements and technical descriptors. Symbols used here for showing the relationship are

A dark circle represents a strong relationship.
A circle represents a medium relationship.
A triangle represents a weak relationship.
The box is left blank if no relationship exists.

Each degree of relationship between a customer requirement and a technical descriptor is defined by placing the respective symbol at the intersection of the customer requirement and technical descriptor, as shown in Figure 12. This method allows very complex relationships to be depicted and interpreted with very little experience.

The symbols that are used to define the relationships are replaced with numbers, for calculation purpose later on.

●	=	9
○	=	3
▽	=	1

These weights will be used later in determining trade-off situations for conflicting characteristics and determining an absolute weight at the bottom of the matrix.

After the relationship matrix has been completed, it is evaluated for empty rows or columns. An empty row indicates that a customer requirement is not being addressed by any of the technical descriptors. Thus the customer expectation is not being met. Additional technical descriptors must be considered in order to satisfy that particular customer requirement. An empty column indicates that a particular technical descriptor does not affect any of the customer requirements and after careful examination it may be removed from the HOQ. This helps to short out unnecessary details which do not contribute to fulfill any of the need of the customer. Early removal of these unnecessary technical descriptors will help in saving time and effort in the course of QFD implementation. If any of the rows has weak symbols then it means that no technical descriptor is properly satisfying that particular customer requirement. Technical descriptors must be reconsidered to achieve that customer requirement. Similarly if any of the columns has all weak symbols then it means that no customer requirement is properly satisfied by that technical descriptor and replace it with any other strong technical descriptor. Hence relationship matrix is a effective guide to get a design as per the requirements of the customer. Figure 12 shows the relation between customer requirements and technical descriptors forming the relationship matrix.

	Column #	1	2	3	4	5	6	7	8	9	10
Row #	Technical Specification / Customer Req. (Explicit and Implicit)	Torque variation	Corrosion resistent coating	Bellow material & clamping	Axial/Radial play	Yoke clearance	Housing material	Steering mounting	Impact strength	Returnability	Child part material
1	Smoothness	●			○	○		○		●	
2	Durability	○	●	●	○	○	●	○	●		○
3	Noise	▽			●	●		○		○	
4	Compactness			○				○			
5	Collapsible column				○						
6	Maintenance		○	○			○	▽	▽		●

Figure 12: Adding relationship matrix to HOQ

For steering the relationship matrix is constructed by assigning symbols to represent the degree of influence between each technical descriptor and each customer requirement. For instance, the relationship between the customer requirement of noise and the technical descriptor of torque variation (free torque) would be weak (+1) because free torque variation has a very little effect on steering noise as noise can be due to other reasons. Conversely, the relationship between the customer requirement of durability and the technical descriptor of impact strength of steering is strong (+9) because higher impact strength of steering system results more durability. Empty spaces indicate that no relationship exists.

4.4.4 Step 4—Develop an Interrelationship Matrix between HOWs

The roof of the HOQ is known as the correlation matrix. It is used to identify any interrelationships between each of the technical descriptors for the product design which are derived from customer requirements. The correlation matrix is a triangular table attached to the technical descriptors, as shown in Figure 13. Correlation of each technical is seen with all other technical descriptors. The correlation between technical descriptor could be strong positive, positive, strong negative or negative. In the HOQ these are shown with help of symbols. Various symbols used here for showing relation are

A double positive represents a strong positive relationship.
A single positive represents a positive relationship.
A single negative represents a negative relationship.
A double negative represents a strong negative relationship.
The symbols describe the direction of the correlation. In other words, a strong positive interrelationship would be a nearly perfectly positive correlation. A strong negative interrelationship would be a nearly perfectly negative correlation.

This diagram allows the user to identify which technical descriptors support one another and which are in conflict. Conflicting technical descriptors are extremely important because they are frequently the result of conflicting customer requirements and represent points at which tradeoffs must be made. Tradeoffs that are not identified and resolved will often lead to unfulfilled requirements, engineering changes, increased costs and poor quality. Some of the tradeoffs may require high-level managerial decisions because they cross functional area boundaries. Even though difficult, early resolution of tradeoffs is essential to shorten product development time.

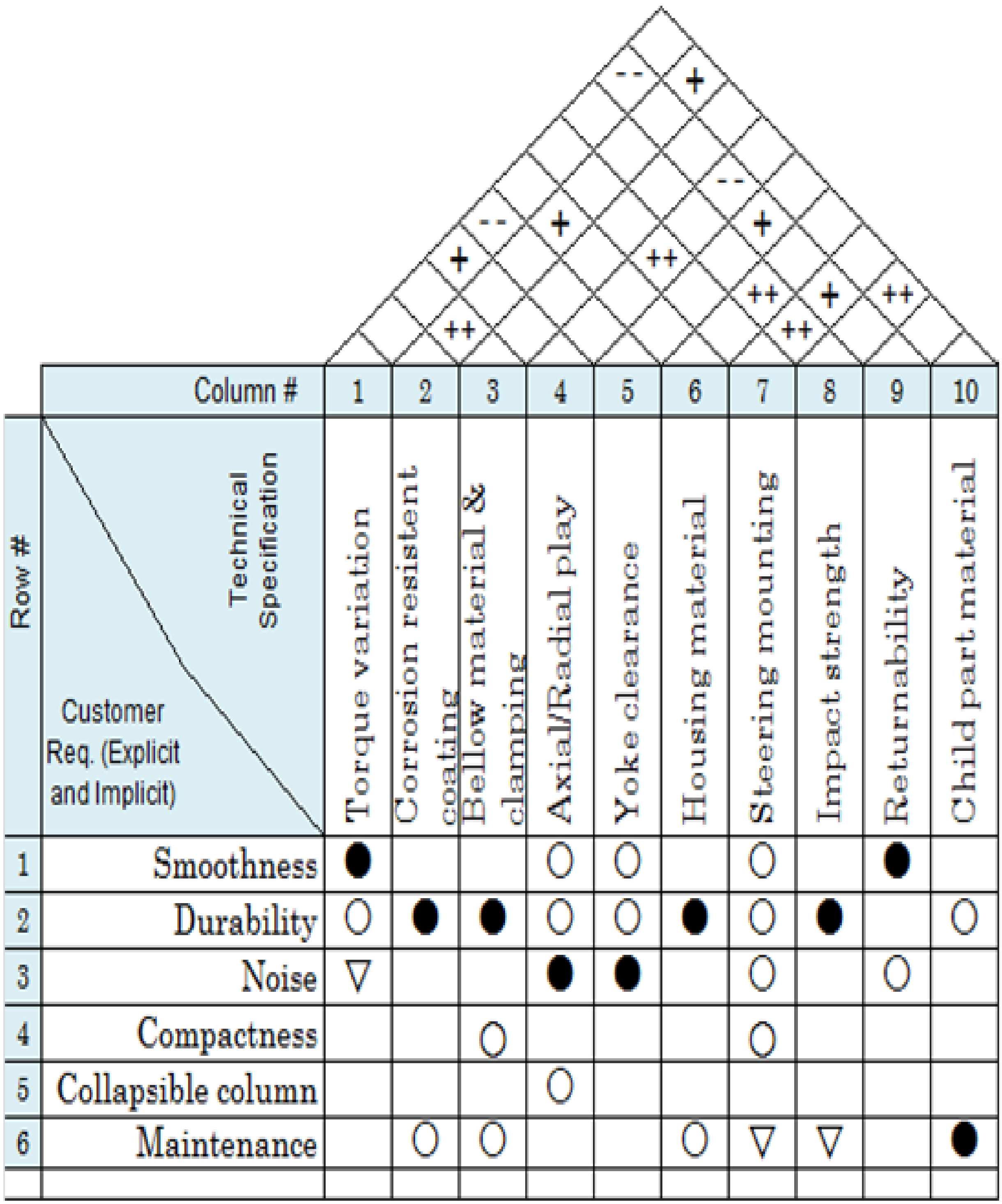

Figure 13: Adding interrelationship matrix to HOQ

For steering system design the interrelationship matrix is constructed by assigning symbols to represent the degree of correlation (positive or negative) between each of the technical descriptors.

For instance, the interrelationship between the technical descriptors of torque variation and returnabilty would be a strong negative (-9) correlation because returnability would be high when free torque is less. Conversely, the interrelationship between the technical descriptors of corrosion resistant coating and bellow material and clamping would be a strong positive (+9) correlation. Corrosion resistant coating would be more effective when bellow material and bellow clamping is good as it will support the coating. The interrelationship matrix for designing a steering system is shown in Figure 13. Empty spaces indicate that no correlation exists, either positive or negative.

4.4.5 Step 5—Competitive Assessments

The competitive assessment is the assessment of competitiveness of the product on basis of customer requirements and technical descriptors. The product is compared with product of competitors and a ranking is done. The competitive assessment tables are separated into two categories, customer assessment and technical assessment, as shown in Figures 14&15 respectively.

i) Customer Competitive Assessment

The customer competitive assessment makes up a block of columns corresponding to each customer requirement in the HOQ on the right side of the relationship matrix, as shown in Figure 14. The numbers 1 to 5 are used in the competitive evaluation column to indicate a rating of 1 for worst and 5 for best. These rankings can also be plotted across from each customer requirement, using different symbols for each product.

The customer competitive assessment is a good way to determine if the customer requirements have been met and identify areas to concentrate on in the next design. The customer competitive assessment also helps to find where an organization stands relative to its major competitors in terms of each customer requirement. Both assessments are very important, because they give an understanding on where the product stands in relationship to the market.

For designing steering system the customer competitive assessment is constructed by assigning ratings for each customer requirement from 1 (worst) to 5 (best) for the existing steering and major competitor #1's and 2's steering. Assessment for designing a steering system is shown in figure 14.

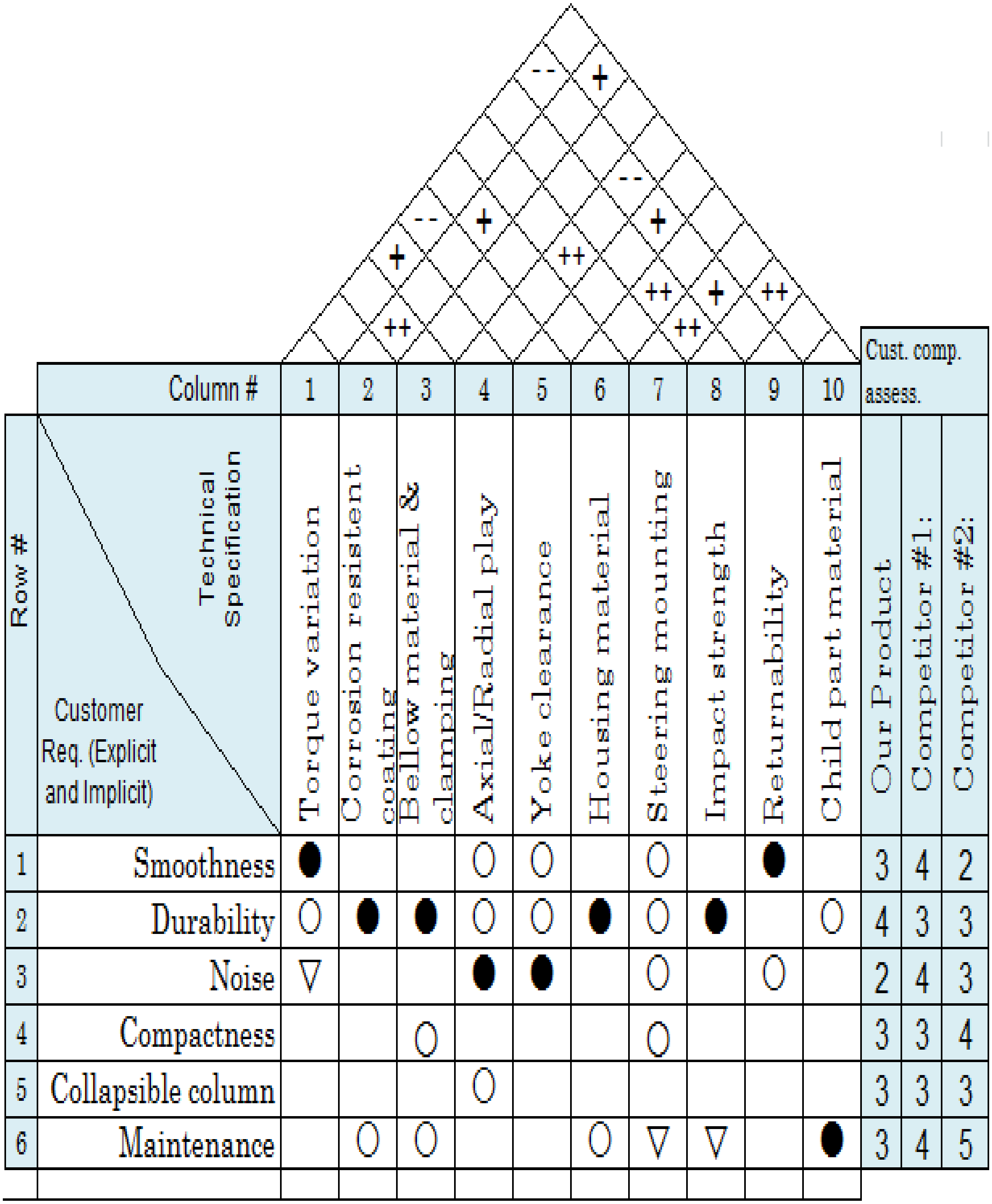

Figure 14: Adding customer competitive assessment to HOQ

ii) Technical Competitive Assessment

The technical competitive assessment makes up a block of rows corresponding to each technical descriptor in the HOQ below the relationship matrix, as shown in figure 15 below.

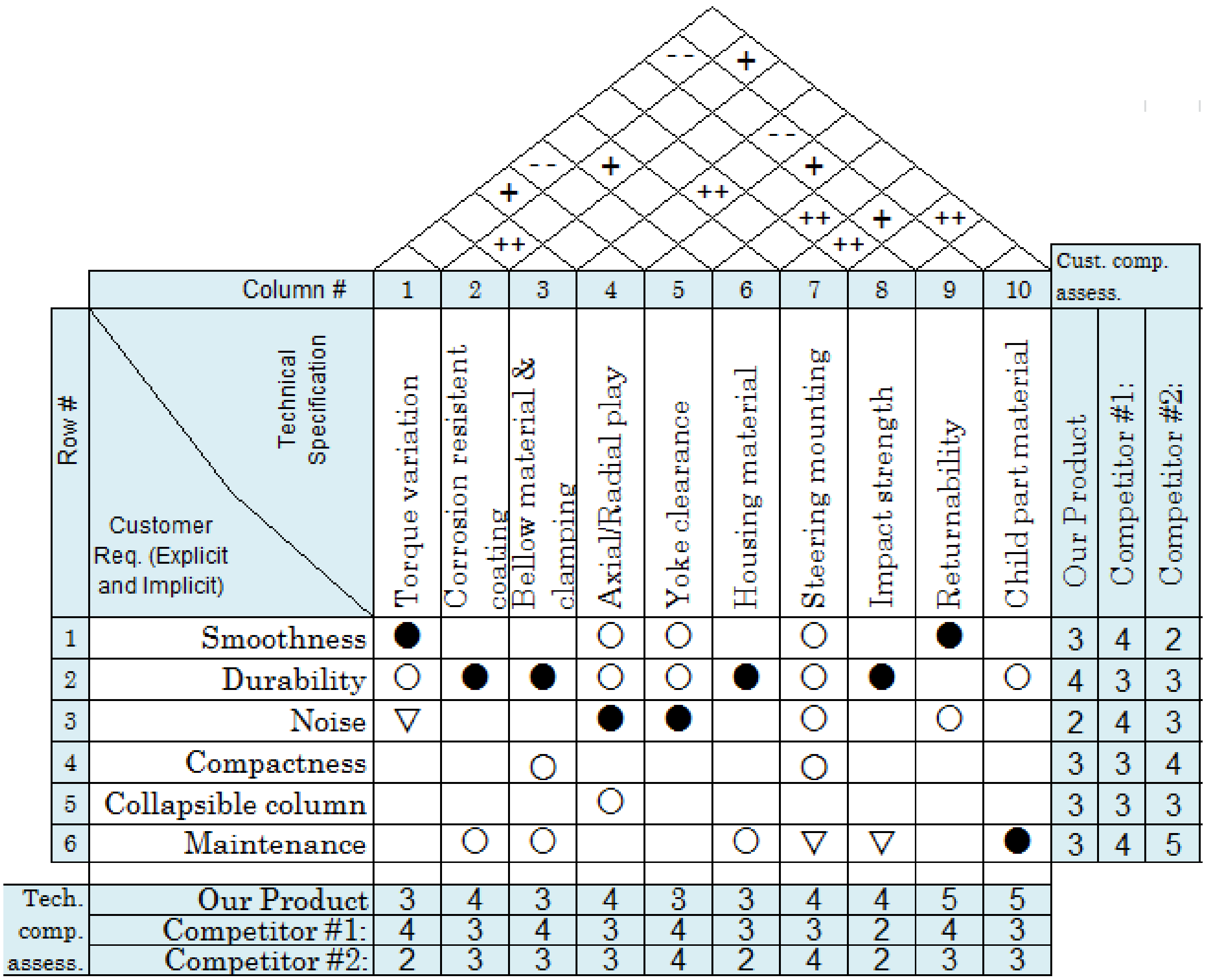

Figure 15: Adding technical competitive assessments to HOQ

Here product is evaluated for each technical descriptor. Product of organization is compared with competitors' product for each technical descriptor. This evaluation tells where the current product is lagging on the technical front with respect to its competitors. Similar to the customer competitive assessment, a ranking of 1 to 5 is done, 1 for worst and 5 for best. These rankings can then be entered below each technical descriptor using the same numbers as used in the customer competitive assessment. The technical competitive assessment is useful in removing gaps in engineering judgment. Customer requirements and technical descriptors that are strongly related should also exhibit a strong relationship in their competitive assessments. If an organization's technical assessment shows its product to be superior to the competition, then the customer assessment should show a superior assessment. If the customer disagrees, then a mistake in engineering judgment has occurred and should be corrected.

For designing the steering system the technical competitive assessment is constructed by assigning ratings for each technical descriptor from 1 (worst) to 5 (best) for our existing steering system in the market and major competitor #1's and 2's steering. The technical competitive assessment for designing a steering system is shown in figure 15.

4.4.6 Step 6—Develop Prioritized Customer Requirements

The prioritized customer requirements are a block of columns corresponding to each customer requirement in the HOQ on the right side of the customer competitive assessment as shown in Figure 16. These prioritized customer requirements contain various columns for importance to customer, target value, scale-up factor, sales point and absolute weight.

i) Importance to Customer

For each customer requirement a numbering is done on the basis of how much the customer requirement is important to the customer. Numbers 1 to 10 are listed in the importance to customer column to indicate a rating of 1 for least important and 10 for most important. In other words, more important the customer requirement is, higher is the rating. Importance ratings represent the relative importance of each customer requirement in terms of each other. The importance rating is useful for prioritizing efforts and making trade-off decisions.

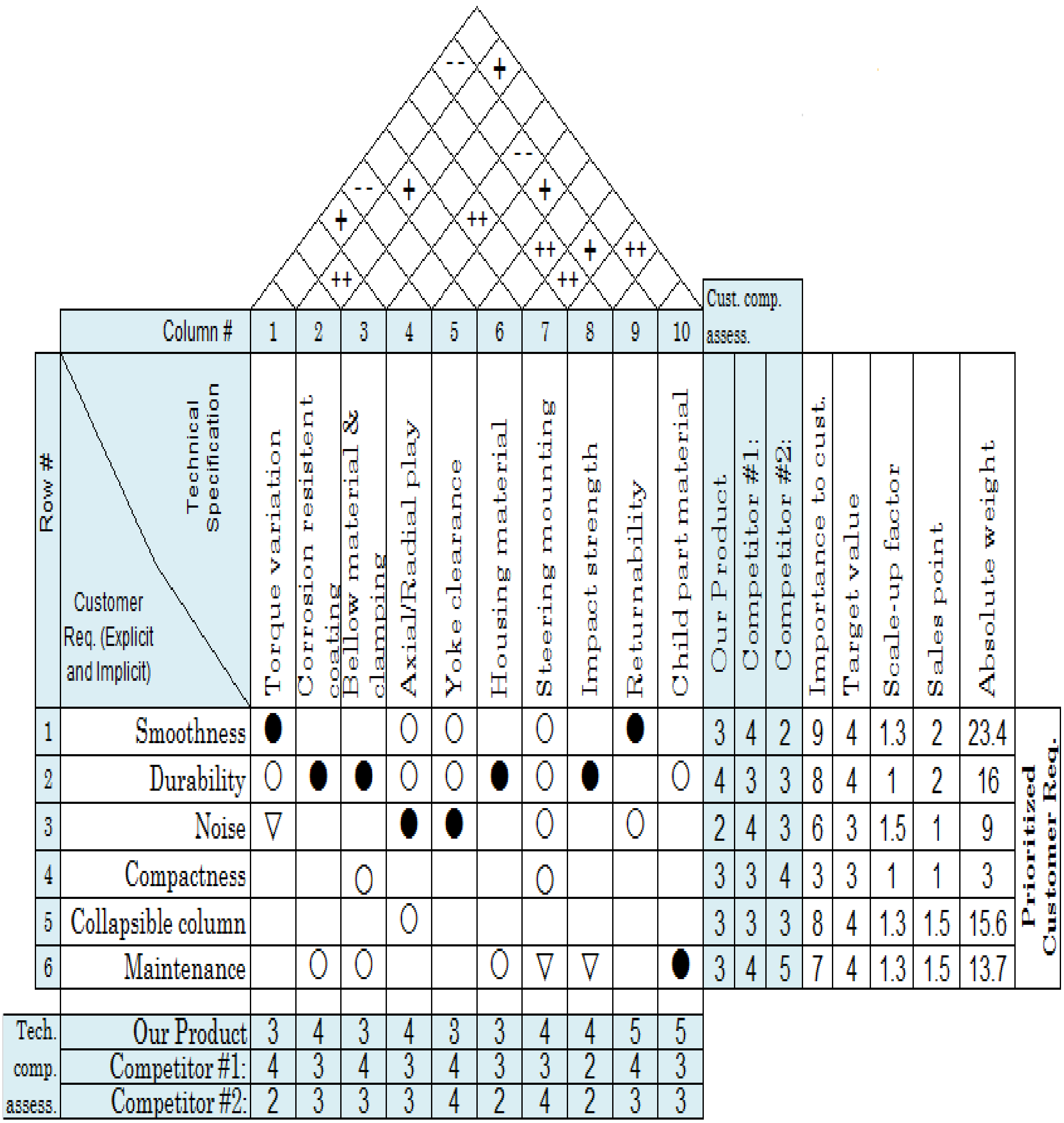

Figure 16: Adding prioritized customer requirements to HOQ

Continue the development process of design of a steering system the importance to customer is determined by rating each customer requirement from 1 (least important) to 10 (very important). For instance, smoothness is most important to the customer so it is assigned a value of 9.

Conversely, compactness is not so important to the customer so it is assigned a value of 3. The importance to customer for design of the steering system is shown in figure 16.

ii) Target Value

The target-value column is on the same scale as the customer competitive assessment (1 for worst, 5 for best). If there is any improvement required for any CR then target value for that CR is higher than the value in customer competitive assessment column like for smoothness target value is 4 as the organization want to improve on this CR as compare to its competitors. This column is where it is decided whether to keep their product unchanged, improve the product or make the product better than the competitors.

The target value is determined by evaluating the assessment of each customer requirement and placing a new assessment value which keeps the product as is, improves the product or exceeds the competition. For instance, smoothness has a product rating of 3 and improvement is required for smoothness, so the target value is assigned a value of 4. The target values for design of steering system are shown in figure 16.

iii) Scale-up Factor

The scale-up factor is the ratio of the target value to the product rating given in the customer competitive assessment. The higher the number, the more effort is needed. Here, the important consideration is the level the product is at now and what the target rating is and to decide whether effort required is economical or not. Sometimes there is not a choice because of difficulties in accomplishing the target. So the target rating is required to be reduced to more realistic values. The scale-up factor is determined by dividing the target value by the product rating given in the customer competitive assessment. For instance, smoothness has a product rating of 3 and the target value is 4, and then the scale-up factor is 1.3. The scale-up factor for of steering system is shown in figure 16.

iv) Sales Point

The sales point tells how well a customer requirement will help in sale of the product. The objective here is to promote the best customer requirement and any remaining customer requirements that will help in the sale of the product. The sales point is determined by identifying the customer requirements that will help the sale of the product. Customer requirement with higher sales point are kept at higher priority and there should be technical descriptor to cater for that particular customer requirement. For instance, smoothness could help the sale of the steering so the sales point is given a value of 2. If a customer requirement will help less in the sale of the product the sales point is given a value of 1. The sales point for designing steering system is shown in figure 16.

v) Absolute Weight

Finally, the absolute weight is calculated by multiplying the importance to customer, scale-up factor, and sales point.

Absolute Weight = (Importance to Customer)(Scale-up Factor)(Sales Point)

After summing all the absolute weights, a percent and rank for each customer requirement can be determined. The weight is used as a guide for the planning phase of the product development. The absolute weight is determined by multiplying the importance to customer, scale-up factor and sales point for each customer requirement. For smoothness the absolute weight is $9 \times 1.3 \times 2 = 23.4$. The absolute weights for other customer requirements are shown in figure 16.

4.4.7 Step 7—Develop Prioritized Technical Descriptors

The prioritized technical descriptors make up a block of rows corresponding to each technical descriptor in the HOQ below the technical competitive assessment, as shown in Figure 17. These prioritized technical descriptors contain degree of technical difficulty and absolute and relative weights. These measures provide specific objectives that guide the subsequent design and provide a means of objectively assessing progress and minimizing subjective opinions.

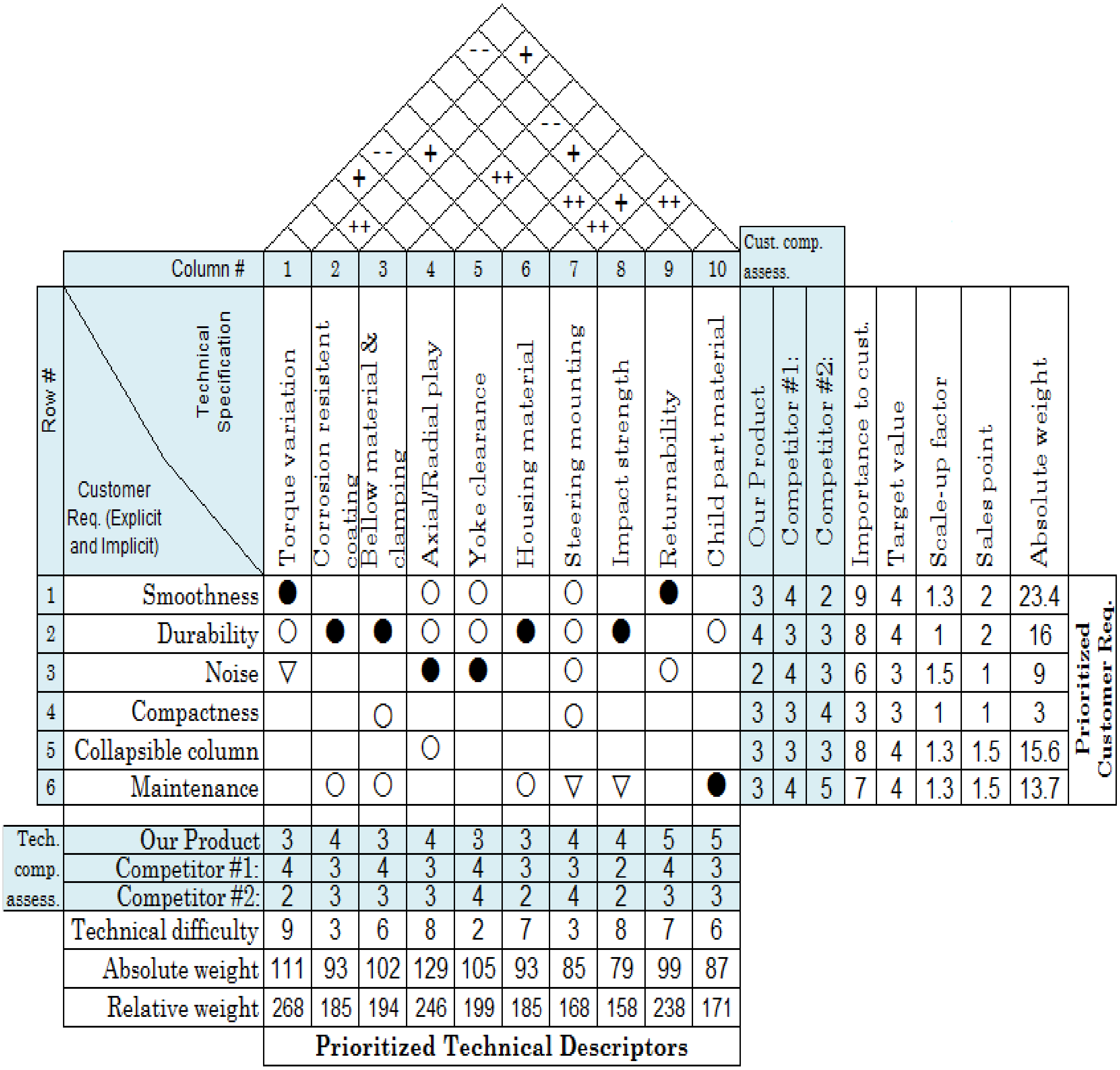

Figure 17: Adding prioritized technical descriptors to HOQ

i) Degree of Technical Difficulty

Many users of the HOQ add the degree of technical difficulty for implementing each technical descriptor, which is expressed in the first row of the prioritized technical descriptors. The degree of technical difficulty helps to evaluate the ability to implement certain quality improvements.

The degree of difficulty is determined by rating each technical descriptor from 1 (least difficult) to 10 (very difficult). For instance, the degree of difficulty for torque variation is 9 as it is very difficult to control free torque, whereas, the degree of difficulty for yoke clearance is 2 because it is a much easier to adjust the yoke clearance. The degree of technical difficulty for various other technical parameters is shown in Figure 17.

ii) Absolute Weight

The last two rows of the prioritized technical descriptors are the absolute weight and relative weight. A method for determining the weights is to assign numerical values to symbols in the relationship matrix symbols. The absolute weight for the j^{th} technical descriptor is then given by

$$a_j = \sum_{i=1}^{n} R_{ij}\, c_i$$

where a_j = row vector of absolute weights for the technical descriptors ($j = 1,..., m$)

R_{ij} = weights assigned to the relationship matrix ($i = 1 ,..., n, j = 1,..., m$)

c_i = column vector of importance to customer for the customer requirements ($i = 1,..., n$)

m = number of technical descriptors

n = number of customer requirements.

The absolute weight for each technical descriptor is determined by taking the dot product of the column in the relationship matrix and the column for importance to customer. For instance, for torque variation the absolute weight is 9×9 + 3×8 + 1×6 = 111. The absolute weight for various other technical parameters is shown in Figure 17.

iii) Relative Weight

In a similar manner, the relative weight for the j_{th} technical descriptor is then given by replacing the degree of importance for the customer requirements with the absolute weight for customer requirements. It is

$$b_j = \sum_{i=1}^{n} R_{ij}\, d_i$$

Where b_j = row vector of relative weights for the technical descriptors (j = 1,...,m)

d_i = column vector of absolute weights for the customer requirements (i = 1,..., n)

Higher absolute and relative ratings identify areas where engineering efforts need to be concentrated. The difference between these weights is that the relative weight also includes information on importance to customer, scale-up factor and sales point. These weights show the impact of the technical characteristics on the customer requirements. Along with the degree of technical difficulty, decisions can be made with regard to allocation of resources for quality improvement. The HOQ can be customized to suit the particular needs. For example, columns for the number of service complaints can be added.

The relative weight for each technical descriptor is determined by taking the summation dot product of the column in the relationship matrix and the column for absolute weight in the prioritized customer requirements. For axial/radial play the relative weight is 3×23.4 + 3×16 + 9×9 + 3×15.6 = 246. The relative weight for various parameters is shown in Figure 17.

Chapter-5

Results and Discussion

Quality function deployment specifically the house of quality is an effective management tool in which customer expectations are used to drive the design process.

QFD concentrates on customer expectations and need so a large amount of effort is needed to find customer expectation. This process increase time required in initial planning stage but overall cycle time is reduced. To collect the voice of customer “Swimming in Fishbowl” technique is used where visit to the user is scheduled and debriefing is done by visiting the customer. On visiting the customer four open ended questions are asked and customer response is collected. Customer response is rough idea about the product which cannot be directly used. Out of the response most significant voices are collected. These voices and image of customer are transformed into customer requirements.

Once the customer requirements are obtained technical specifications are required to be drawn from these customer requirements. Technical specifications are the engineering parameters which are required to full fill the customer needs so technical specifications are drawn in way that they help in achieving the customer requirements.

Once customer requirements and technical specifications for the product are final then they are placed in HOQ to get the relationship between them. Symbols are used to show the relation between them. These symbols can further be replaced with numbers for calculation purpose. This relationship matrix is of great importance from design point of view.

In the relationship matrix if there is any empty row then it shows that a specific customer requirement is not addressed by technical parameters. So some technical parameter is required to fulfill that customer need.

In the relationship matrix if there is any empty column then it shows that a particular technical specification do not relate to any customer need so it is a redundant parameters which has to be dropped from HOQ as it will consume extra time and effort without leading to any benefit.

In relationship matrix if is a row with no strong relationship then it shows that a particular customer requirement is not addressed properly and if this customer requirement bears a higher importance customer rating then it has to be addressed with a strong technical specification satisfying it.

In the relationship matrix if there are rows with repeated identical relationship then it shows the error in classification and hierarchy of customer requirements which has to addressed to avoid unnecessary effort in design and production.

In the relationship matrix if there are too many weak relationships then it shows that there is lack of clear technical specifications which can be related strongly with customer requirements. So there is a need to reconsider the technical specification.

Interrelationship matrix consists of the relation between the technical parameters and it makes the triangular roof of the matrix. Relation can be positive, strong positive, negative or strong negative. Relation between the technical descriptors is shown with the help of symbols. This matrix is of great importance for design point of view as it tells if there are any conflicting parameters that would cause trouble. These conflicting parameters are handled carefully while designing. This advance knowledge of such parameters helps to save extra effort and reduce process cycle time.

Customer competitive assessment is the comparison of the product with competitors product based on customer requirements. Rating is done on a scale of 1-5. This will help to find out where the improvement is required in the product. This helps to concentrate the effort more on the customer requirements where product is lagging with respect to the competitors. For example for smoothness product rating is 4 which is more than competitors but for noise product rating is 2 which is less than both competitors, so company has to improve on noise factor.

Customer requirements are prioritized in the column of importance to customer where customer requirements are ranked from 1to10 as per the preference by the customer. Any customer requirement which is more valuable to the customer is ranked higher and vice-versa. So this rating will tell in advance about the most desired customer requirements. So those customer requirements will be emphasized more in the design and production process. For example for smoothness importance to customer rating is 9 so smoothness is the most desirable characteristic for a steering whereas for compactness this rating is 3 which means it is less desirable characteristic so compactness should be given less importance.

Target value is the value defined for the customer requirements in comparison to current rating of the product. Where ever improvement is required target value is kept higher than current rating given by the customer about the product.

The scale-up factor is the ratio of the target value to the product rating given in the customer competitive assessment. More is the scale-up factor higher is the improvement required for the product.

Absolute weight for each customer requirement is the product of importance to customer, scale-up factor and sales point. In this way absolute weight combines importance to customer, scale-up factor and sales point for every customer requirement which helps in designing the product. For smoothness absolute weight is 23.4 and for compactness it 3. So smoothness is most important even by combining importance to customer, scale-up factor and sales point ratings.

Technical competitive assessment is the comparison of the product with the competitors based on the technical specification of the product. This will help to find where the current product is lagging behind as compared to the competitors based on technical specification. Technical competitive assessment rating is given in figure 17. For example for yoke clearance technical competitive assessment rating for the product is 3 which less as compare to competitors so the company need to work on yoke clearance parameter.

Degree of technical difficulty is an important parameter as it tells how much it is difficult to incorporate any technical parameter in designing. Higher value of technical descriptor shows that it is difficult to incorporate or modify that technical parameter. Degree of technical difficult rating is given in figure 17. For example technical difficulty rating is for yoke clearance is 2 which mean it is easy to implement or modify yoke clearance parameter. So degree of technical difficulty will help to make a trade-off between implementing the technical parameter and cost associated with its implementation.

The absolute weight for each technical descriptor is determined by summation of the product of the column in the relationship matrix and the column for importance to customer. Higher value of the absolute weight for a technical descriptor means that it will cater more customer requirements so it has to be necessarily incorporated in design of product. Also those descriptors are considered for which degree of technical difficulty is low as it is easy to implement those descriptors. Absolute weight for each customer is given in figure 17. Absolute weight for technical specification axial/radial play is 111 which is highest whereas for child part material it is 87 which is lowest.

The relative weight for each technical descriptor is determined by summation of the product of the column in the relationship matrix and the column for absolute weight for customer requirement. The difference between absolute weight and relative is that absolute weight incorporates only importance to customer rating for customer requirements whereas relative weight incorporates importance to customer, scale-up factor and sales point. So relative weight incorporates more details about customer requirements. Higher value of relative weight for a technical descriptor makes it more critical and it should be included in designing. Relative weight for each technical descriptor is given in figure 17. Relative weight for torque variation is 268 which is highest whereas for impact strength relative weight is 158 which is lowest.

So QFD forces the entire organization to constantly be aware of the customer requirements. Every QFD chart is a result of the original customer requirements which are not lost through misinterpretation or lack of communication. Marketing of the product yields more benefits because specific sales points that have been identified by the customer are given due importance in designing and manufacturing of the product. Most importantly, implementing QFD results in a satisfied customer.

Chapter-6

Conclusion

In this competitive world quality is a major concern for an organization to survive. QFD is a technique which helps in manufacturing a quality product guided by the requirements of customer. The product obtained by the help of QFD technique leads to greater customer satisfaction, more competitive product at lesser cost and lesser overall product cycle time. This study presents the implementation of QFD in getting a design of three wheeler steering which is obtained by considering the needs of customer prior to the design stage. Voice of the customer were collected and prioritized so as to get customer requirements which yield maximum benefit. On the basis of these customer requirements technical parameters were obtained. These customer requirements and technical descriptors were placed in the HOQ. Competitive analysis of the existing product was done based on customer requirements and technical descriptors and relationship was obtained in the HOQ producing the relationship matrix. Absolute weight and relative weight for each technical descriptor were calculated which helped in deciding and prioritizing the technical parameters for the design of the product. This prior implementation of QFD leads to lesser changes in the design and a more stable design is obtained. The customer driven design and manufacturing of the product helps in getting more satisfied and loyal customer and this will help the company to improve their position in the market.

After collecting the voice of customers response from 67 customers was taken for the Kano questionnaire. Response from more customers could be collected to get more correct categorization of customer requirements. More customer requirements could be incorporated in to get more precise product as per customer needs but this would increase the cost of production. Number of customer complaints could row could be added below the technical specification so as to get the idea of number of customer complaints for each technical specification; this would help in finding the weakness of the product on basis technical specifications. Interrelationship matrix could be established for customer requirements in order to find out various conflicting customer requirements before the initiation of actual design phase which would reduce the time required to design the product.

In this study QFD technique is applied to get a design as per requirements of the customer. So here QFD is applied for the design phase which is a practice followed mostly followed in American companies. In future QFD can be implemented for process planning and production planning phase. Implementation of QFD to process planning phase will help in determining critical processes and process flow. It will also help in determining production equipment requirement and critical process parameter. Implementation of QFD in production planning phase will help in determining critical part and process characteristics also it will establish process method and parameters.

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APPENDIX

Questionnaire

Name : ____________ (Owner/Driver) Driving Experience : _____Year(s)
Auto Model : __________________ What did you drive before this : ___________________

<table>
<tr><td>1a</td><td>If steering wheel is steered with one finger, how do you feel?</td><td rowspan="2">I like it this way
It must be this way
I am neutral
I can live with it this way
I dislike it</td></tr>
<tr><td>1b</td><td>If steering wheel is steered with both hands, how do you feel?</td></tr>
<tr><td>2a</td><td>If steering wheel rotated easily at low speed, how do you feel?</td><td rowspan="2">I like it this way
It must be this way
I am neutral
I can live with it this way
I dislike it</td></tr>
<tr><td>2b</td><td>If steering wheel rotated easily at high speed, how do you feel?</td></tr>
<tr><td>3a</td><td>If vehicle stays at the center of the road, how do you feel?</td><td rowspan="2">I like it this way
It must be this way
I am neutral
I can live with it this way
I dislike it</td></tr>
<tr><td>3b</td><td>If you need to put effort to keep vehicle at the center of the road, how do you feel?</td></tr>
<tr><td>4a</td><td>If housing withstands frontal impact, how do you feel?</td><td rowspan="2">I like it this way
It must be this way
I am neutral
I can live with it this way
I dislike it</td></tr>
<tr><td>4b</td><td>If housing breaks in frontal impact, how do you feel?</td></tr>
<tr><td>5a</td><td>If mounting bracket withstands frontal impact, how do you feel?</td><td rowspan="2">I like it this way
It must be this way
I am neutral
I can live with it this way
I dislike it</td></tr>
<tr><td>5b</td><td>If mounting bracket gets damaged during frontal impact, how do you feel?</td></tr>
<tr><td>6a</td><td>If mounting bracket withstands impact of pits while driving at high speed, how do you feel?</td><td rowspan="2">I like it this way
It must be this way
I am neutral
I can live with it this way
I dislike it</td></tr>
<tr><td>6b</td><td>If mounting bracket does not withstand impact of pits while driving at high speed, how do you feel?</td></tr>
<tr><td>7a</td><td>If steering column is made thick, how do you feel?</td><td>I like it this way
It must be this way</td></tr>
</table>

<table>
<tr><td>7b</td><td>If steering column is made thin, how do you feel?</td><td>I am neutral
I can live with it this way
I dislike it</td></tr>
<tr><td>8a</td><td>If height of the steering is adjustable, how do you feel?</td><td rowspan="2">I like it this way
It must be this way
I am neutral
I can live with it this way
I dislike it</td></tr>
<tr><td>8b</td><td>If height of the steering is not adjustable, how do you feel?</td></tr>
<tr><td>9a</td><td>If steering system is maintenance free, how do you feel?</td><td rowspan="2">I like it this way
It must be this way
I am neutral
I can live with it this way
I dislike it</td></tr>
<tr><td>9b</td><td>If need to go to mechanic for the maintenance, how do you feel?</td></tr>
<tr><td>10a</td><td>If steering wheel is close to your body, how do you feel?</td><td rowspan="2">I like it this way
It must be this way
I am neutral
I can live with it this way
I dislike it</td></tr>
<tr><td>10b</td><td>If you hold steering wheel after stretching both hands, how do you feel?</td></tr>
<tr><td>11a</td><td>If you drive vehicle while sitting on the seat, how do you feel?</td><td rowspan="2">I like it this way
It must be this way
I am neutral
I can live with it this way
I dislike it</td></tr>
<tr><td>11b</td><td>If you bent on the steering wheel to drive the vehicle, how do you feel?</td></tr>
<tr><td>12a</td><td>If vehicle does not topple on the full rotation at high speed, how do you feel?</td><td rowspan="2">I like it this way
It must be this way
I am neutral
I can live with it this way
I dislike it</td></tr>
<tr><td>12b</td><td>If vehicle topples on the full rotation at high speed, how do you feel?</td></tr>
<tr><td>13a</td><td>If maintenance of the wheel pin is not required for longer time, how do you feel?</td><td rowspan="2">I like it this way
It must be this way
I am neutral
I can live with it this way
I dislike it</td></tr>
<tr><td>13b</td><td>If wheel pin requires frequent maintenance, how do you feel?</td></tr>
<tr><td>14a</td><td>If the steering system functions well while running in water, how do you feel?</td><td rowspan="2">I like it this way
It must be this way
I am neutral
I can live with it this way
I dislike it</td></tr>
<tr><td>14b</td><td>If steering system requires maintenance after running in water, how do you feel?</td></tr>
<tr><td>15a</td><td>If the steering wheel is having facility of brakes, how do you feel?</td><td>I like it this way
It must be this way</td></tr>
</table>

15b	If brake paddle is provide at the floor, how do you feel?	I am neutral I can live with it this way I dislike it
16a	If gear is mounted on the steering, how do you feel?	I like it this way It must be this way I am neutral I can live with it this way I dislike it
16b	If you can change gear with the gear lever, how do you feel?	
17a	If the vehicle turns full with one rotation of the steering wheel, how do you feel?	I like it this way It must be this way I am neutral I can live with it this way I dislike it
17b	If the vehicle turns full with two rotations of the steering, how do you feel?	
18a	If steering housing withstands impact of road pits at high speed, how do you feel?	I like it this way It must be this way I am neutral I can live with it this way I dislike it
18b	If steering housing does not withstand impact of road pits at high speed, how do you feel?	