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Implementation of Quality Function Deployment and analytical hierarchy process in Water Treatment Systems

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Summary:

The aim of this project is to build a structured approach to product development through the House of Quality (HOQ) with application to Water Treatment System in PETRA. The project procedure and Quality Function Deployment (QFD) implementation process was started by identifying customer's requirements, expectations and their importance about water treatment systems. Various relationships between these expectations and the corresponding technical requirements to satisfy them were determined in addition to the correlation between technical requirements themselves. To conduct a benchmark between PETRA products and other international companies' products, a planning matrix was designed. This matrix shows in what aspects the PETRA products quality is exceeded by international companies' products in addition to the proposed level of customer's satisfaction PWTS hypothesize to reach. Depending on the importance and relationships between customer's needs and technical specifications and between technical specifications themselves, the whole HOQ matrix was build. The output of this matrix is a set of scores suggesting the most important technical that should be controlled in order to satisfy the customer's requirements. After performing HOQ matrix quantitative analysis, it is clear that the quality of glue used and the cutting blades renewal are the most important technical specification that should be controlled and monitored to ensure cartoon products quality toward continuous quality improvements as a part of TQM.

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1 Introduction:

Improving the quality of an organization’s products and services is fundamental to business success. Managers on excellent companies realize that customer wants and desires changing, that customers’ expectations must be clearly understood, and that their firm must conform to customer wishes.

Quality Function Deployment (QFD) is a very is useful tool for translating customer voice into product development in quality engineering. The primary function of QFD have been expanded from product development, quality management, to wider fields such as product design and costing, especially, decision-making, included performance measurement, evaluating company’s current state. In fact, QFD is a methodology for measuring and analyzing evaluation indicators by their relationship matrix.

In this Project, we have aimed to apply QFD in PETRA which is A company for water treatment systems, QFD used as a nontraditional tool or method to recognize customers’ requirements of customer and a set of powerful product development tools that to transfer the concepts of quality control from the manufacturing process into the new product development process. The main features of QFD are a 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 (called the "House of Quality") for documenting information, perceptions and decisions.

1.1 Problem Definition:

QFD implementation can be achieved in both service and manufacturing organizations effectively to achieve its main goal in improving products quality level.

This project is mainly focus on creating a scientific comparison between PETRA and the international companies' in terms of products quality which is based on building the house of quality (HOQ) matrix to highlight the main strength and weakness points at PETRA Water Treatment Systems in addition to showing up the available aspects of improvement opportunities that should be taken into consideration by the firm’s top management and this results supported by the analytical hierarchy process results that is widely used as multi-criteria decision making tool. It uses pair-wise comparisons, takes into consideration the relative priorities of factors in a system, and enables people to select the best alternative based on their goals.

1.2 Project Objectives:

Although this project is mainly considering investigating the implementation of QFD in PETRA Water Treatment Systems, it has other important objectives that summarized as follows:

1. Developing the ability to work in one group as a teamwork.
2. Identifying the products’ quality elements from customers’ point view.
3. Obtaining a quantitative assessment about the firm ability to meet required quality elements in comparison with other companies.
4. Identifying the potential improvements opportunities and their effects in meeting customers’ expectations.

5. Performing quantitative analyses to show how customers' quality requirements can be achieved through performing suggested improvements activities.
6. Specifying data based improvement suggestions for increasing quality level from customers'' point views.
7. Discussing the role of QFD in achieving TQM targets toward business excellence.

1.3 Arrangements of chapters

Chapter 1, which has "Introduction" title, reviews a brief introduction about the role of Quality Function Deployment (QFD) and its general objectives and benefits, problem definition, and project objectives.

Chapter 2 gives detailed information about the PETRA Water Treatment Systems company, which represents the case study in which this project was implemented.

Chapter 3 represents the literature review of QFD, its definitions, concepts, benefits, applications and its link with Total Quality Control (TQM). It also shows the meaning of the House of Quality and how to build it.

Chapter 4 discusses the sequence of steps followed in order to build a practical HOQ matrix and how to analyze the relationships between customer's requirements and the technical aspects to ensure them.

Chapter 5 clarifies the working methodology followed in this project to implement QFD successfully, in addition to the analysis of results and data collected in details and step-by-step.

Chapter 6 shows the results of the project with its details and sample of calculations.

Finally, Chapter 7, which is entitled "Conclusions and recommendations", summarizes the project outputs, what concluded from this work, and suggests some recommendations for future work.

2 PETRA Water Treatment Systems

PETRA Company for water treatment systems was established after years of searching and hard efforts to solve problems of water waste. PETRA searched in different water treatment areas such as developing water treatment processes and finding the proper alternatives to use wastewater after treatment. This research achieved great results, where PETRA could reach zero losses in water using a water treatment filter working on the concept of reverse osmosis.

The results of modifying water treatment systems' research done by PETRA was presented to the Jordanian company for Innovation in Al Hassan Industrial Estate, and they sent the research to Jordan University of Science and Technology/ Deanship of Scientific Research, to examine the results provided by the company. Experiments conducted by the Deanship of Scientific Research confirmed the effectiveness of the new system and that it stop the wastage by 100%.

These results lead the Jordanian company for innovation to accept the project of manufacturing the new water treatment system, and provide PETRA with the moral and financial support, by providing the suitable location and preparing it with all required services and working on collecting financial support from several donors like Jordan Enterprise Development Corporation.

2.1 PETRA vision:

Provide a model of the Jordanian industry by following the highest standards of quality in management, production, health and the environment. Relying on a crew of qualified specialists and using renewable energy in the production processes, in a factory designed according to green building standards.

2.2 PETRA mission:

Working quickly to eliminate waste of water treatment systems operating on reverse osmosis concept, to save 18 million meters of water lost every year from old water filters' systems.

2.3 PETRA strategic Objectives:

PETRA Company's strategic objectives are:

1. Producing an environmentally friendly product. The filter made by PETRA uses the reverse osmosis with no water losses after water treatment.
2. The company relies 70% on renewable energy sources such as wind power to generate the energy for the plant.
3. Continuing research in order to find new water treatment ways, such as agriculture and raising fish.
4. A high degree of flexibility factory and a very general space.

Figure 2-1: PETRA-R7

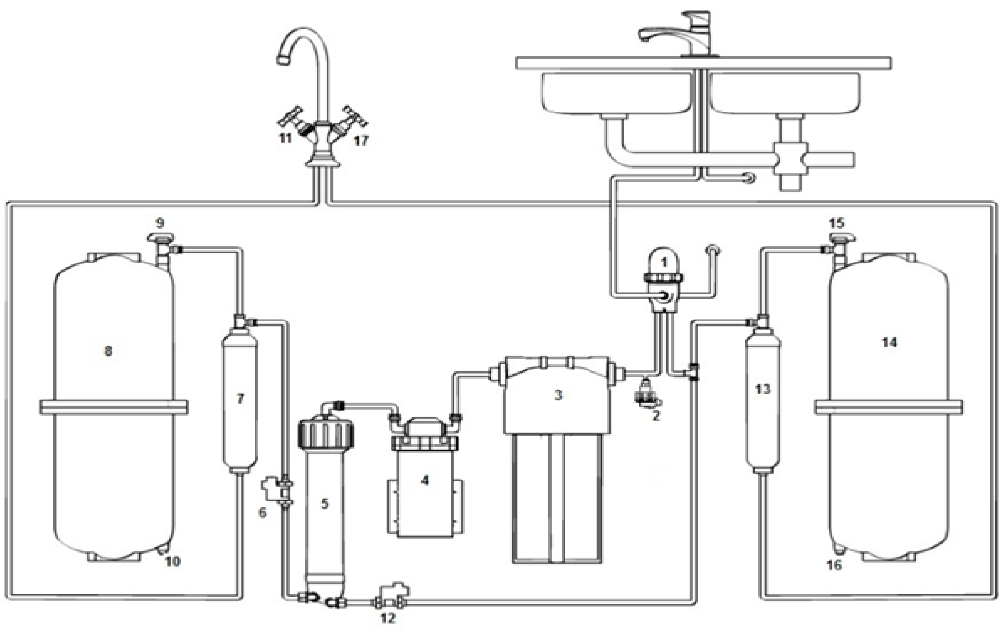


Figure 2-2: PETRA-R75 Components

1. Feeder and discharger unit:
2. Low-pressure valve.
3. Triple filtration unit:
4. Pump 300 gallon/day
5. Membrane:
6. High-pressure valve
7. Carbon filter to improve the taste
8. Fresh water tank.
9. Tank valve

10. Air supplier
11. Fresh water tap valve
12. High-pressure valve.
13. Filter for dirty water treatment
14. Salty water tank
15. Tank valve
16. Air supplier
17. Salty water tap valve

3 Theoretical Background:

3.1 Quality Function Deployment "QFD":

3.1.1 History of QFD

Professors Shigeru Mizuno and Yoji Akao developed QFD in Japan in the late 1960s. At the time, statistical quality control, which was introduced after World War II, had taken roots in the Japanese manufacturing industry, and the quality activities were being integrated with the teachings of such notable scholars as Dr. Juran, Dr. Kaoru Ishikawa, and Dr. Feigenbaum that emphasized the importance of making quality control a part of business management, which eventually became known as TQC and TQM.

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. Prior quality control methods were primarily aimed at fixing a problem during or after manufacturing.

The first large scale application was presented in 1966 by KiyotakaOshiumi of Bridgestone Tire in Japan, which used a process assurance items 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.

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.

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 on-going QFD Research Sub-Committee at the Union of Japanese Scientists and Engineers (JUSE) and their annual QFD Symposium established in 1993. They hosted the first International Symposium on QFD and are a charter member of the International Council for QFD.

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.

The Customer-Driven Approach to Quality Planning, Deployment, and QFD: Integrating Customer Requirements into Product Design, QFD caught on across a wide variety of industries in the U.S. and Western Europe. In the U.S., in particular, because of its flexibility and comprehensiveness, the methodology was eagerly embraced by the businesses that were facing the Japanese competition. There, new and innovative applications of QFD were experimented by industries and businesses that were not reached before.

Today, QFD continues to inspire strong interest around the world, generating ever-new applications, practitioners and researchers each year. Countries that have held national and international QFD Symposium to this day include the U.S., Japan, Sweden, Germany, Australia, Brazil, and Turkey.

3.1.2 QFD Definition:

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.
2) The term “QFD” is used by many people today to refer to a series of “House of Quality” 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 Drs. Akao and Mizuno originally created. (See “What is the House of Quality? Why it isn’t a QFD?” at qfdi.org for more information on this topic.) Thus, the application of the term “QFD” has changed over the course of the past 30+ years as well. Even though much was lost in translation from its Japanese name, “Quality Function Deployment” was a much more apropos name for the system of processes originally created by Akao and Mizumo than it is for the derivative tool that it has come to refer to today.

Figure 3-1: QFD Outcome

Quality Function Deployment (QFD) was developed to bring this 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 (end user) with design, development, engineering, manufacturing, and service functions. Aligning the entire company toward achieving a common goal.

As a quality system that implements elements of Systems Thinking with elements of Psychology and Epistemology (knowledge), QFD provides a system of comprehensive development process for:

1. Understanding 'true' customer needs from the customer's perspective.
2. What 'value' means to the customer, from the customer's perspective.
3. Understanding how customers or end users become interested, choose, and are satisfied.
4. Analyzing how do we know the needs of the customer.
5. Deciding what features to include.
6. Determining what level of performance to deliver.
7. Intelligently linking the needs of the customer with design, development, engineering, manufacturing, and service functions.
8. Intelligently linking Design for Six Sigma (DFSS) with the front-end Voice of Customer analysis and the entire design system.

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 transparent analytic and prioritization methods, empowering organizations to exceed normal expectations and provide a level of unanticipated excitement that generates value.

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 based on the specified part features. The crucial operating procedures in turn serve to determine the production requirements in detail. The core principle of this concept is a systematic transformation of customer requirements and expectations into measurable product and process parameters.

It 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 bottom line financial performance. The latter claim is controversial. Although many adherents 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 or nonprofits. 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 – lack rigor and theoretical support.

This paragraph specifically is to address the following four questions: What are the variables which affect QFD? What are the outcomes from using QFD? What relationships exist between QFD variables and outcomes? What guidelines may be offered for managers of QFD?

3.1.3 QFD Importance:

It is very powerful as it incorporates the voice of the customer in the designs - 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 our technical capabilities.

3.1.4 Objectives of QFD:

In general, QFD as a quality improvement tool has many objectives that are summarized in the following points:

1. To define product characteristics that meet effective customer requirements.
2. To assign, on specially structured forms, all the information deemed necessary for the development of a new product or service.
3. To effect a comparative analysis of our product performances against those of competitors.

4. To guarantee 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 guarantee full coherence between product planning and planning of the relative production processes (by facilitating the integration between the various product functions and by emphasizing interactions and mutual conditionings).
9. 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.
10. To have self-explanatory documentation on the project as it evolves.
11. To agree on specific reference documents, useful for the customer as well as for those involved in drawing them up, which limit to a minimum the formulation of ideas and requests that cannot be coded and, most importantly, may not find consensus

3.1.5 Inputs and Outputs of QFD:

Each QFD project should have inputs and expected outputs whatever the case study is (manufacturing or service) as inputs are as follows:

1. Customer requirements.
2. Technical requirements.
3. Customer priorities.
4. Market reality/competitive analysis.
5. Organization’s strength and weaknesses.

Where outputs are:

1. Prioritized technical requirements.
2. Measurable, testable goals.

3.1.6 Success of QFD project:

To have successes in any QFD project, many other interrelated success factors should be achieved to have an overall QFD project success. The following figure (3-2) shows these success factors and their relationships among each other's.

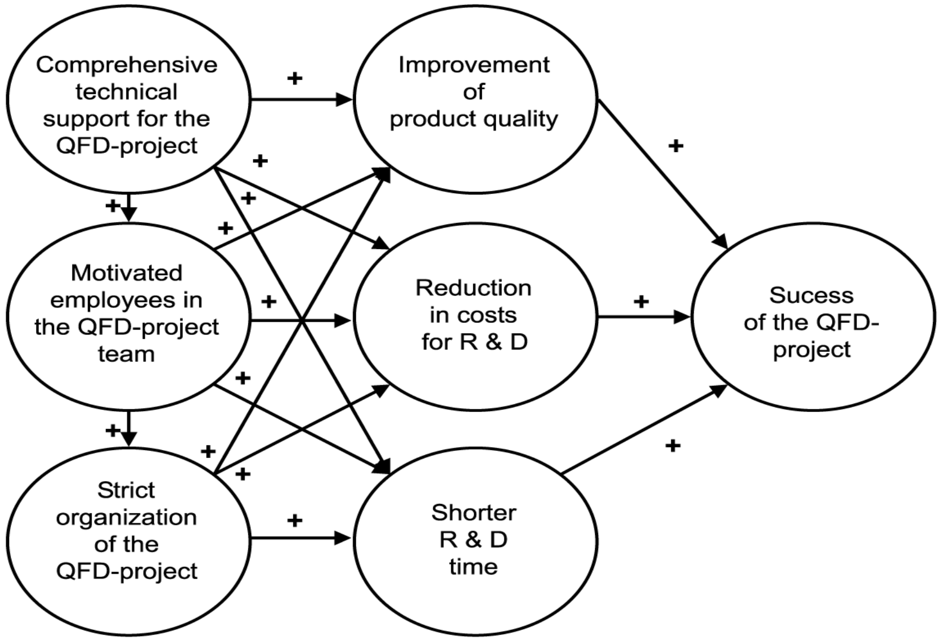


Figure 3-2: Success of QFD project

3.1.7 Improvement of product quality:

1. **Increase in customer satisfaction:** the introduction of the QFD concept has resulted in a sustained improvement in customer satisfaction.

2. **Improvement in product quality:** Numerous difficulties in the quality of goods and services have been resolved on a long-term basis.

3. **Reduction in the frequency of complaints:** The number of negative comments and complaints about the company's performance has been reduced as a result of the QFD approach.

4. **Increase in customer loyalty:** It has been possible to ascertain an increase in customer loyalty since the QFD concept was introduced.

5. **Reduction in expenditure for reworking:** Since the QFD approach was introduced; there has been a reduction in expenditure for reworking arising because of quality defects.

3.1.8 Reduction in costs for R&D:

1. **Financial requirement of other projects:** By introducing the QFD concept, more financial resources are available for other projects.
2. **Reduction in costs for research and development project:** The costs for research and development were reduced considerably by applying the QFD concept.
3. **Reduction in need for consultants:** The QFD approach contributed to a sustained reduction in the need for external or in-company consultants as part of research and development projects.
4. **Better project coordination:** The outlay for planning, coordinating, implementing and controlling research and development activities could be reduced considerably.

3.1.9 Shorter R&D time:

1. **Time saving:** A reduction in the time to market has been achieved through systematic implementation of the QFD approach.
2. **More time for other projects:** Since the company has implemented the QFD project, more time has been available for other projects than was the case before the QFD concept was introduced.
3. **Better coordination of projects:** The QFD approach makes it easier to coordinate research and development activities.
4. **More time for conceptual work:** The QFD concept makes an important contribution to ensuring that more time is available for conceptual work.

3.1.10 Comprehensive technical support for the QFD project:

1. **Measurement of what the customer wants:** What an individual wants and desires is the starting point of product design. In this respect, it is absolutely essential to make a comprehensive survey of consumer needs.
2. **Recording the activities of competitors:** The activities of competitors determine the success of a new product on the market. Consequently, systematic collection of information about competitors and their activities in respect of marketing policy is required.
3. **Identification of the actual weighting factors:** Part of the specification of the House of Quality requires the interdisciplinary team to make a large number of decisions in respect of various weighting factors. If product development is to be successful, it is absolutely essential for the determination of such coefficients to be as close to reality as possible.
4. **Mastering the complexity of House of Quality:** Even a small number of perceived product attributes and physical- chemical-technical quality characteristics result in a very complex House of Quality. Therefore, before this method is applied, it must be ensured that the members of staff involved have mastered its complexity.
5. **Knowledge of QFD techniques:** Both Akao and King give a stern warning against using the QFD method without specific experience and particular knowledge. The danger is too great that the team members may use this instrument like a cook book and come to incorrect conclusions.

3.1.11 Strict organization of the QFD project:

1. **Intensity of interaction with the management:** The progress of the project is facilitated by close contact between the members of the project team and the responsible line managers. This includes regular meetings at which the project manager passes on information on the status of the project to those who actually carry out the work within the company.
2. **Support from top management:** When a QFD project is introduced;top management must support it. Only if this is the case can one be sure that the recommended action identified because of the project will be systematically implemented.
3. **Clear structure of the project team:** QFD projects in many companies have shown that the ideal team is only made up of those employees who are absolutely essential. The success of the project is put at risk if there are tortuous and lengthy coordination processes, the lines of responsibilities are unclear and if many entirely different interests have to be taken into account.
4. **Interdisciplinary composition of teams:** When the teams are being established, it is essential that all relevant functions within the company (such as marketing, production and research and development) are represented. Thus it appears that the interests of different functions, which frequently diverge widely, can be taken into account. Innovative nature of the QFD project. Many authors argue that the prospect of a QFD project being brought to a successful conclusion is particularly high if this project refers to already established products. However, if it involves new products, new technologies and new

consumers, many problems occur which have a detrimental effect on the QFD project.

5. **Transparency in the project process:** Being open about the targets, measures and techniques facilitates project progress and increases acceptance of the project among employees and managers. The team leader should therefore at each stage of the project ensure that transparency exists concerning the stages of the work already completed and the forthcoming project phases.
6. **Keeping to the time schedule:** It would appear that keeping to the time schedule is an important prerequisite as a measure of whether the QFD project is brought to a successful conclusion and that the findings of the project are actually implemented. Differentiated network diagrams, which show even slight deviations from the time schedule, are used for this purpose.

3.1.12 Motivated employees in the QFD project team:

1. **Commitment of team members:** The success of the QFD project is greatly dependent on the commitment of the members of the project team. Parallel to this, they also act as a role model for other employees and line managers who are taking part in the project.
2. **Project experience of those involved:** Project-related experience of the employees and their knowledge of the necessary techniques assist with the smooth running of the project. Here it is also necessary to broaden the specialist knowledge of those involved through targeted training measures.
3. **Availability of project members:** It is of key importance for the implementation of the QFD project that the employees who are assigned to the

work are given relief from their normal workload. It appears that only if this procedure is adopted is it possible for those concerned to give their undivided attention to completing the tasks they are assigned as part of the project.

4. **Utilization of authority:** All authority entrusted to the team members needs to be utilized to implement the project. In this way it will be ensured that the findings obtained from the QFD project will also be applied.

3.2 QFD phases:

According to the figure below, Comprehensive QFD may involve four phases:

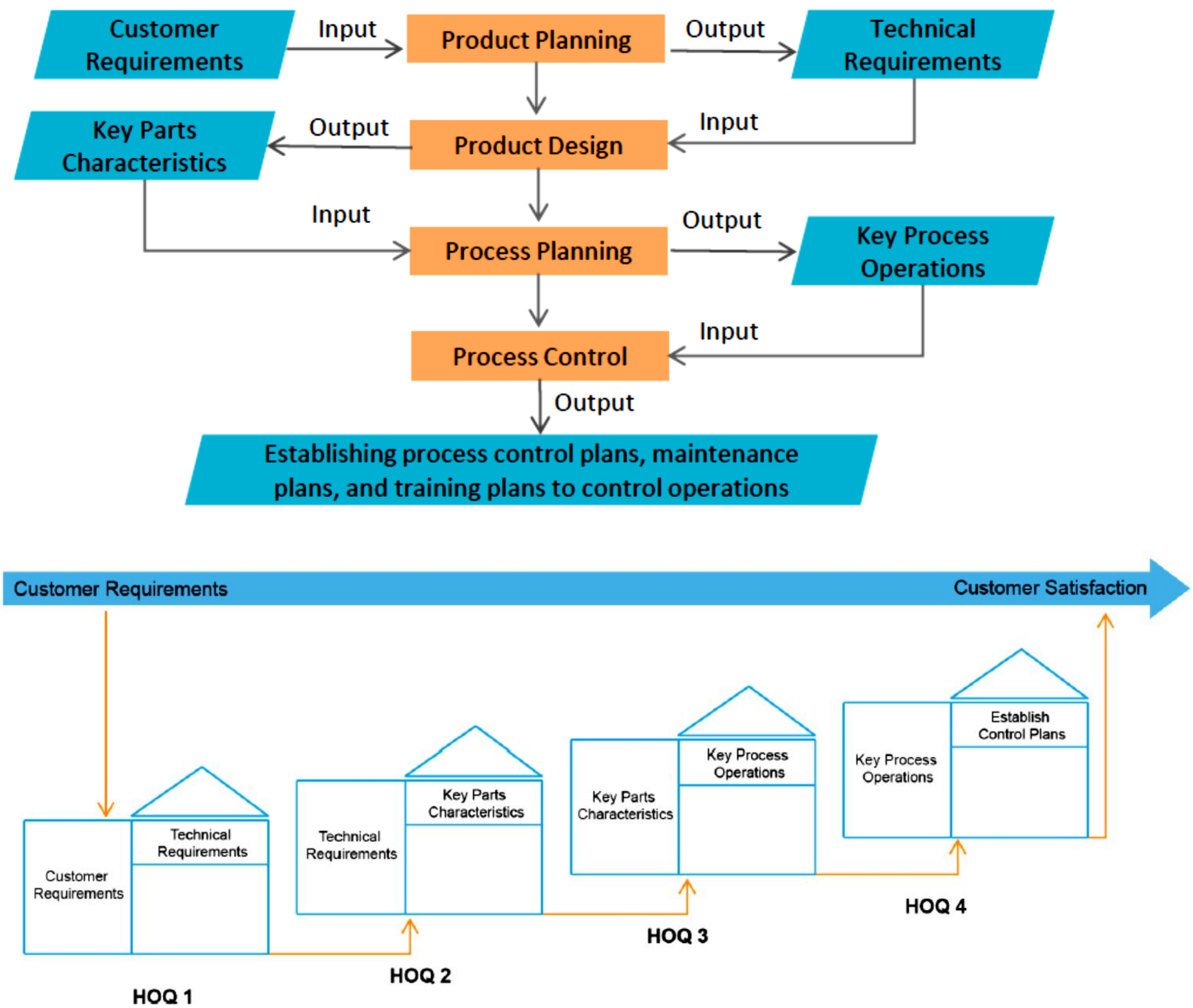


Figure3-3: Phases of QFD

1. Product Planning (House of Quality):

    1. Define and prioritize customer needs.
    2. Analyze competitive opportunities.
    3. Plan a product to respond to needs and opportunities.
    4. Establish critical characteristics target values.

2. Product Design:

    1. Identify critical parts and assemblies.
    2. Flow down critical product characteristics.
    3. Translate into critical artlessly characteristics and target values.

3. Process Planning:

    1. Determine critical processes and process flow.
    2. Develop production equipment requirements.
    3. Establish critical process parameters.

4. Production Planning (Process Control):

    1. Determine critical part and process characteristics.
    2. Establish process control methods and parameters.
    3. Establish inspection and test methods and parameters.

Linking these phases provides a mechanism to deploy the customer voice through to control of process operations. By following these steps:

1. Learn what each element represents.

2. Form a multidisciplinary team. Obtain voice of the customer from market surveys, focus groups, observations, interviews. Identify customer requirements and ask customer to rate importance.
3. The development of the first issue of the charts is the most time consuming part. Conduct competitive analysis by customer requirement Establish a quality plan based on competitive analysis you would like to have for your future product.

Once this is completed, regular reviews and updates require minimum time. Remember that the benefits from an appropriately developed QFD chart are very big compared with the effort - put focus on the issues that are important to the customer.

3.3 QFD Applications:

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. Eventually, 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.

3.3.1 Transportation and communication:

Shipbuilding is one of the two earliest QFD application sectors, and Lyu and Gunasekaran (1993) report another such QFD application. Automobile is an 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.

3.3.2 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 such 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.

3.3.3 Software systems:

Another early popular sector of QFD applications is software systems. Especially, there are many reported QFD applications in software, such as Anonymous, Basili and Musa, Brown, Chang…Other related QFD application areas include decision support systems, expert systems, human machine interface, information systems, integrated systems, management information systems, profiling systems, and Web pages.

3.3.4 Manufacturing:

Manufacturing is also an earlier area of QFD applications, which can be found, e.g., in the earlier papers of Sullivan and Swackhamer. 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, helmet-mounted displays, hybrid bicycles, instrumentation (Rice, 1989), meat, medical devices, metals, metrology probes, pencils, plastic components, power protection equipment, printing, poultries, quick release top nozzles, safety shoes, tea, and tractors.

3.3.5 Services:

QFD is a customer-oriented quality management and product development technique originally used for hard products, but its ideas are by 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.

3.3.6 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, kindergartens, public schools, training, vocational secondary schools and, interestingly, business schools. QFD has also been applied to R&D and research program design.

3.3.7 Other industries:

QFD's principles set no prerequisites about the types of the products/services and the producing/ serving organizations. Indeed, the applications of QFD are industry free and, beyond the above six general industries, QFD has also attracted the attention from many other industries such as aerospace, agriculture, beautiful enterprises, construction, disaster prevention, environment protection, indoor air quality, management culture, military, national security, packaging, peacekeeping forces, police stations, political elections, socio-economic development, technologies, and textile.

3.4 Benefits of Using QFD:

QFD is considered as a tool that enhance the actual Quality to gain to perceived Quality level so it's used to fix, improve, redesign the product or the service in order to catch and maintain customer satisfaction toward the company, so it's very vital to utilize this the effects of QFD in the life Cycle of the product, benefits of using QFD:

1. Customer driven the focus is on customers' wants, not what the company thinks the customer wants The "Voice of the Customer" drives the development process.
2. Competitive analysis other products in the marketplace are examined, and the company product is rated against the competition.
3. Reduced development time The likelihood of design changes is reduced as the QFD process focuses on improvements to be made to satisfy key customer requirements Careful attention to customer requirements reduces

the risk that changes will be required late in the project life cycle Time is not spent developing insignificant functions and features.

4. Reduced development costs the identification of required changes occurs early in the project life cycle Minimizing changes following production reduces warranty costs and product support costs.
5. Documentation A knowledge base is built as the QFD process is implemented A historical record of the decision-making process is developed.
6. Improved communication and sharing of information within a cross-functional team charged with developing a new product. This team will typically include people from a variety of functional groups, such as marketing, sales, service, distribution, product engineering, process engineering, procurement, and production.

3.5 QFD in relation with Total Quality Management “TQM”:

In today's business environment, any organization that wishes to exceed customer expectations and stay competitive needs a long-range strategic plan. This plan must be forward-looking, visionary and achievable, while at the same time striving toward continuous improvement of the organization's key business processes. The organization must, in effect, keep "both hands on the wheel" to move forward successfully

At its core, Total Quality Management (TQM) is a management approach to long-term success through customer satisfaction. In a TQM effort, all members of an organization participate in improving processes, products, services and the culture in which they work.

The methods for implementing this approach come from the teachings of such quality leaders as Philip B. Crosby, W. Edwards Deming, Armand V. Feigenbaum, Kaoru Ishikawa and Joseph M. Juran.

The aim of QFD is to satisfy **customers**, *not* employees. The input to QFD comes from customers, not employees. Perhaps you are confusing Quality Function Deployment with Policy Deployment or TQM (Total Quality Management), Policy Deployment uses the same tool set as QFD and does incorporate input from all areas in an organization in order to plan the accomplishment of the organizational strategy. Even then, and in TQM, the essential part of strategy or improvement is often to satisfy those customers whom the organization exists to serve (thus the role for QFD in TQM). QFD aims to benefit customers directly, not employees. We apply QFD in order to benefit the customer, and to do so better than any competitor. Thus, we assure the jobs of everyone in our organization.

A key to improving quality through TQM is linking the design of products or services to the processes that produce them. Quality Function Deployment (QFD) is a means of translating customer requirements into appropriate technical requirements for each stage of product or service development and production. Bridgestone Tire and Mitsubishi Heavy Industries originated QFD in late 1960s and early 1970s when they used quality charts that consider customer requirements in the product design process.

The House of Quality: Houseof Quality or QFD is Known as an effective tools from TQM stuff tools it helps very good in achieving total quality purposes, for example the Deming chain reaction declared that explicitly.

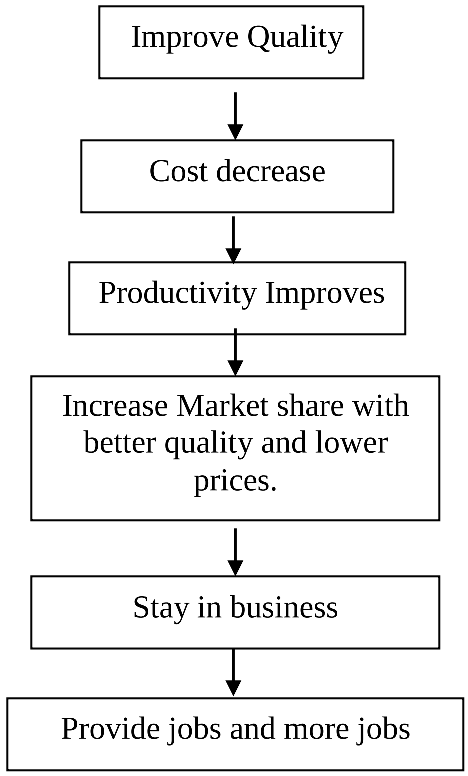


Figure 3-4: Deming Quality Chain

And also by logic there is many types of quality some of it(Quality Expected, Quality Actually, Quality perceived),by focusing on the actual and the expected quality the customer expecting specific features of quality From the producer, else it would be dissatisfied case so here if you thinking like a producer you have to increase the actual quality until it reaches the expected quality or even get over it, here begins the rule of QFD in order to integrate with total quality principle and so it’s essential to have QFD practice in the strategic planning to Quality.

3.6 Advantages and Disadvantages of QFD:

QFD is mainly a tool to help companies focus on what customers perceive as important and certify that these desired abilities exist in the final product or service. The work is usually documented in a series of matrices. Its primary benefits are reduced design costs and development time. Other benefits include improved communication and cohesion within a product development or improvement team and solidifying design decisions early in the development cycle. These are the main advantages and disadvantages of QFD:

- **Advantages:**

    1. Generates specific technical requirements.
    2. Requirements are traceable.
    3. Follows a repeatable, quantitative process.
    4. Records rational for each technical requirements.
    5. Effectively translates VOC.

- **Disadvantages:**

    1. Time-consuming process for >10requirements.
    2. Data storage, manipulation and maintenance costs.
    3. Very dependent on customer requirements.
    4. Inflexible to changing requirements, must recalculate.

3.7 HOQ Building and Analysis Steps:

The QFD program introduces a chart, commonly called the House of Quality. In very simple terms, the house of quality can be thought of as a matrix of **what** and **how**:

1. **What** do customers want and need from your product or service? (Customer requirements).
2. **How** will your company achieve the what? (Technical requirements).

The matrix shows where relationships exist between what and how, and the strength of those relationships.

Customer requirements: Customers' wants and needs, expressed in their own words. As a first step, the functional need is analyzed and translated into more specific customer requirements to better understand the perceived deficiency. In essence, the purpose of this step is to capture the "Voice of the Customer". Reference to the "customer" includes not only the end-users, but also the applicable regulations and standards, the intermediate distributors, installers, retailers, and the maintainers. As such, this is the first significant opportunity to integrate logistics requirements and issues into the mainstream design and development process.

Importance to customer: Indicates which requirements are most important to customers. On a scale from 1 - 10, customers then rate the importance of each requirement. This number will be used later in the relationship matrix.

Competitive evaluation "Benchmarking":

This provides a measure of customer satisfaction with the existing products. It is used to rate the industry competitors on each of the customer requirements or 'WHATS'. It helps the organization to get an overview of their performance when compared with industry competitors; 5-scale rating is used.

Technical requirements: The technical descriptors are attributes about the product or service that can be measured and benchmarked. Technical descriptors may exist that your organization is already using to determine product specification, however new measurements can be created to ensure that your product is meeting customer needs.

Relationship matrix: The relationship matrix is where the team determines the relationship between customer needs and the company's ability to meet those needs. The team asks the question, "What is the strength of the relationship between the technical descriptors and the customer's needs?" Relationships can either be weak, moderate, or strong or carry a numeric value of 1, 3 or 9.

Technical evaluation: To better understand the competition, engineering then conducts a comparison of competitor technical descriptors. This process involves reverse engineering competitor products to determine specific values for competitor technical descriptors.

Target values: At this stage in the process, the QFD team begins to establish target values for each technical descriptor. Target values represent "how much" for the technical descriptors, and can then act as a base line to compare against.

Importance weighting: Finally, the team calculates the absolute importance for each technical descriptor. This numerical calculation is the product of the cell value and the customer importance rating. Numbers are then added up in their respective columns to determine the importance for each technical descriptor. Now you know which technical aspects of your product matters the most to your customer!

Correlation matrix: This room in the matrix is where the term House of Quality comes from because it makes the matrix look like a house with a roof. The correlation matrix is probably the least used room in the House of Quality; however, this room is a big help to the design engineers in the next phase of a comprehensive QFD project. Team members must examine how each of the technical descriptors affects each other. The team should document strong negative relationships between technical descriptors and work to eliminate physical contradictions.

For each combination of customer and technical requirement, the level of interrelationship is recorded. Use a relative scale of high, medium, low, and none. Each ranking is assigned a numeric value such as high – 9, medium – 3, low – 1, none – 0.

Planning Matrix

1. Quantifies the customer's requirements priorities.
2. Quantifies perceptions of the performance of existing products.
3. Allows priorities to be adjusted based on the issues that concern the design team.

Measures used are gathered from customer's using a questionnaire and shown in a column alongside the customer requirement description. One of the better methods for prioritizing is the Analytical Hierarchy Process where requirements are paired and the customer picks the most important of the pair.

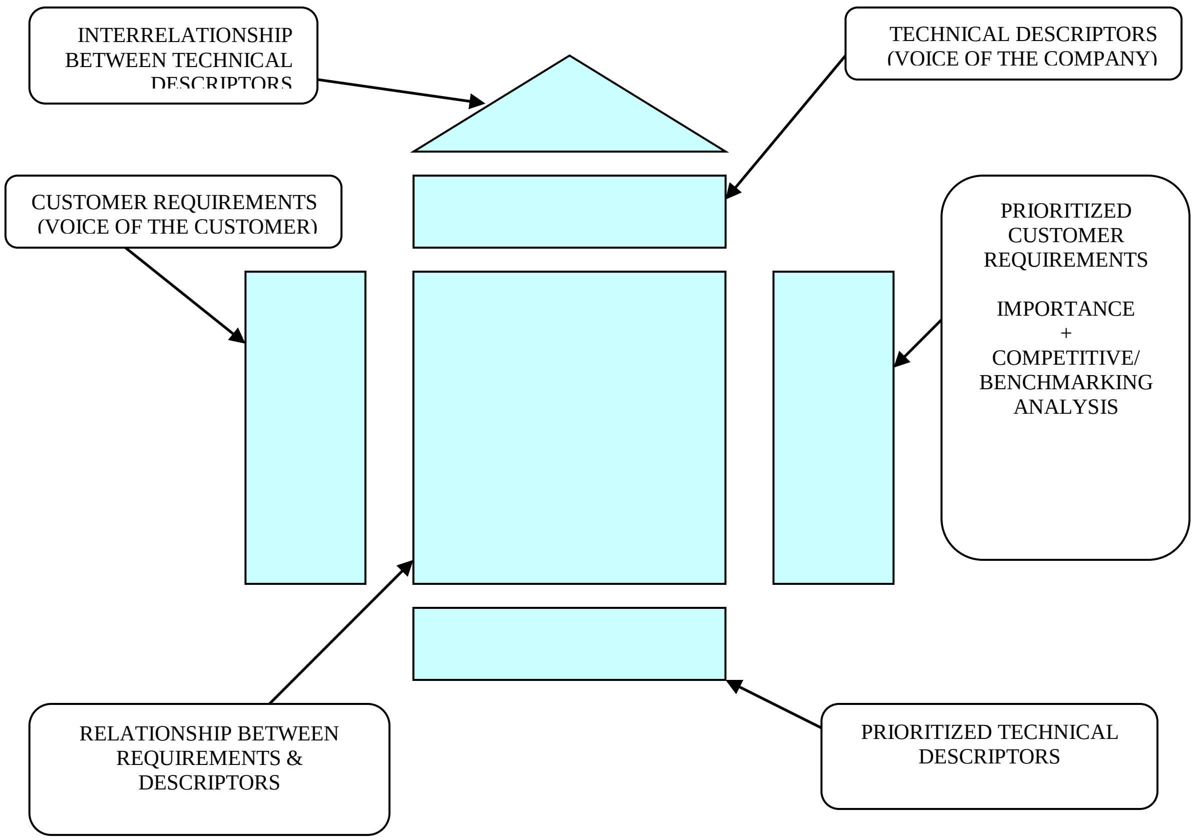


Figure 3-5: HOQ Components

To sustain continuous improvement, one of the most important tools in the Quality applications is the Quality Function Deployment (QFD). Our needs to improve the quality of the products cannot be achieved unless we follow some specific steps to build the House of Quality (HOQ), in order to determine and achieve a real progress, those steps we will explain with details.

This figure (4-2) shows the steps of QFD, step-by-step, and then its details

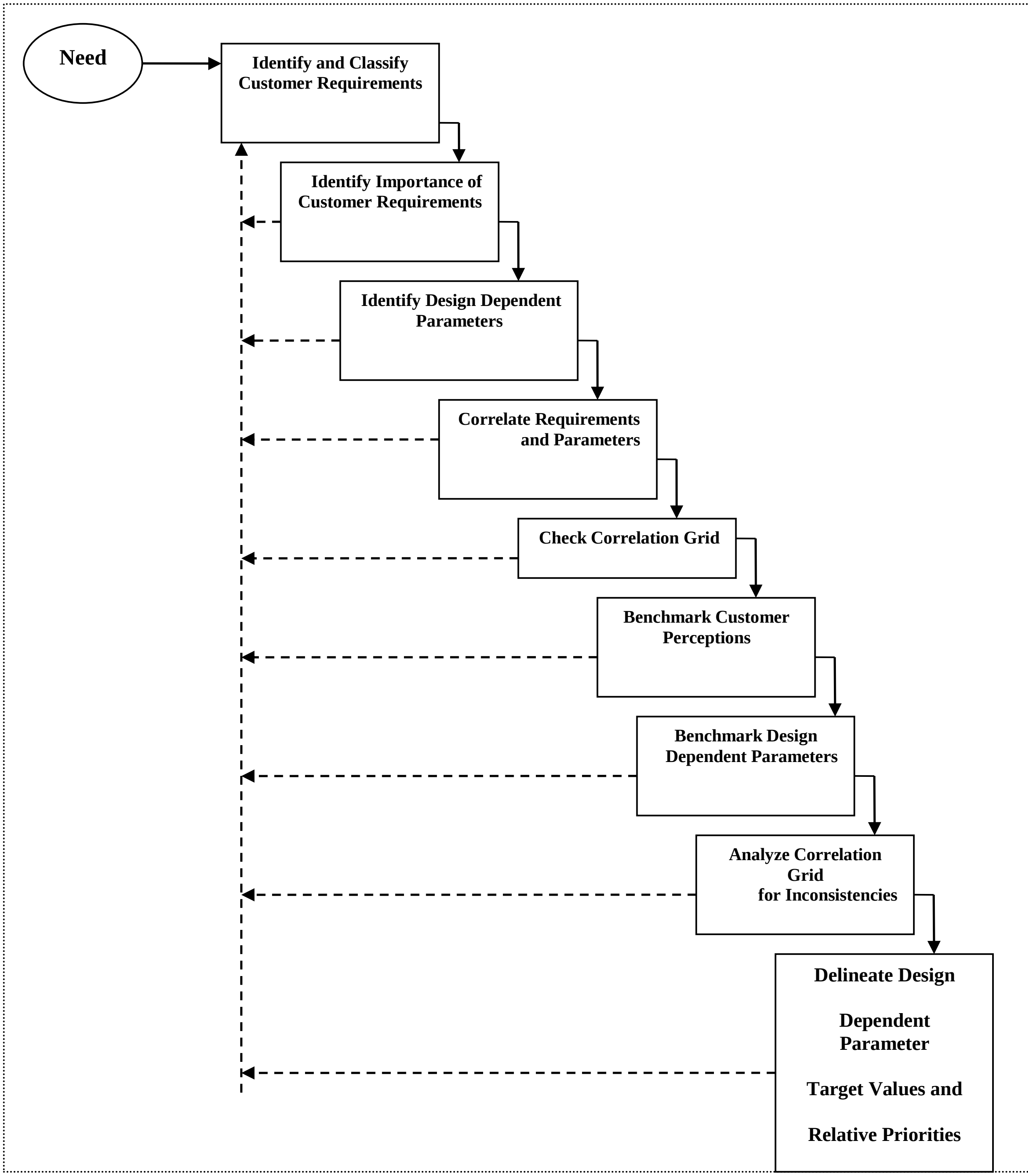


Figure 3-6:The Quality Function Deployment (QFD) process.

3.7.1 Need analysis and identification of customer requirements:

The functional need is analyzed and translated into more specific customer requirements to better understand the perceived deficiency. In essence, the purpose of this step is to capture the "Voice of the Customer". Reference to the "customer" includes not only the end-users, but also the applicable regulations and standards, the intermediate distributors, installers, retailers, and the maintainers. As such, this is the first significant opportunity to integrate logistics requirements and issues into the mainstream design and development process. Properly developed checklists and taxonomies can help ensure a comprehensive and complete identification of customer requirements. Further, consistent and concise translation of the need into customer requirements ensures uniformity of effort, and better understanding and communication between members of a design team. The customer's language is often qualitative and subjective which imparts vagueness and imprecision to this phase of system design. Often the customer requirements are generated through a brainstorming exercise by members of the design team. This approach suffers from a number of crucial drawbacks. More likely than not, this process "captures" the "Voice of the Company" or "The Voice of the Team Leader" rather than the all-important "Voice of the Customer". Such practices can lead to poor reception of the ultimate product in the market place. Once identified, similar customer requirements are classified into groups and sub-groups. This develops into a hierarchy of customer requirements, from the most abstract to the most specific. The number of classification levels depends upon system complexity or the extent of detail being represented.

3.7.2 Importance of customer requirements.

Selected requirements often affect each other adversely. For instance, a customer may desire ease while opening and closing a car door, but at the same time want power windows. Power windows increase the weight of the door and this correlates negatively with the ease of closing or opening it. To overcome such conflicts, requirements areas signed priorities. It is essential that priorities reflect preferences of the customers. There are several approaches to prioritizing customer requirements. These approaches range from direct indication by the customer to usage of the analytical hierarchy process and cost and technical factors.

3.7.3 Identification of design dependent parameters (DDPs).

Design dependent parameters or technical performance measures are engineering characteristics under a designer's control. These parameters are manipulated to directly or indirectly influence customer requirements. In this context, customer requirements are often referred to as the set of "WHATs", while design set of "WHATs", while design dependent parameters represent the set of "HOWs". The DDPs should be tangible, describe the product in measurable terms, and directly affect customer perceptions. DDPs guide the analysis and evaluation of design concepts, configurations, and artifacts during the conceptual, preliminary, and detailed system design phases. As such, it is essential that all relevant DDPs be identified. Once again, development of focused checklists and taxonomies facilitates this objective. A complete and comprehensive set of DDPs includes not only performance related parameters, but also parameters that affect system supportability and cost.

3.7.4 Correlation of customer requirements and design dependent parameters.

This step -of the QFD process involves populating the correlation matrix within the "house of quality". Each DDP is analyzed in terms of the extent of its influence on customer requirements. Varying levels of this correlation are represented in the correlation matrix. Depending upon the extent of resolution necessary, three or five levels of correlation are used. Further, correlation between DDPs and customer requirements may be represented by symbols as shown in table [1].

Correlation Label	Corresponding Icon
Strong Relationship	Θ
Moderate Relationship	O
Weak Relationship	▲

Table 3-1: Correlation Keys

3.7.5 Check correlation matrix.

It is necessary at this stage to conduct an examination of the correlation grid before proceeding further. This examination involves checking for:

• *Empty rows in the correlation matrix*. Empty rows in the correlation grid signify unaddressed customer requirements. In response, the set of design dependent parameters needs to be revisited and, if necessary, additional DDPs identified.

• *Empty columns in the correlation matrix*. Empty columns in the correlation grid imply redundant or unnecessary system-level design requirements. The design team may have included design requirements, which can't be traced back to any customer requirement and could potentially be dropped from further consideration. The above two possibilities, and other inconsistencies pertaining to customer requirements, their importance and correlation with design dependent parameters, must be identified and discussed in terms of their implication on system design and development.

3.7.6 Benchmarking customer requirements.

A key activity involves identification of available systems/products capable of responding to the functional need (to whatever extent). Customer perceptions are then benchmarked relative to how well these capabilities satisfy the initially specified set of requirements. The objective is to assess the state-of-the-art from a customer perspective. It is important that members of the design and development team not influence this activity. Benchmarking of customer perceptions is facilitated through tools such as customer surveys, customer interviews, demonstrations, media information, and feedback from the marketing, sales and service organizations. The purpose of this effort is to "highlight the absolute strengths and weaknesses of the products in the marketplace and those areas of your products that require improvement". This activity provides invaluable insight into avenues where competitive gains can be made most effectively.

3.7.7 Technical assessment of design dependent parameters (DDPs).

This activity involves assessment of the competition from a technical perspective. Designers and engineers actively participate during this step in the QFD process. Technical assessments are expressed in-quantitative and objective terms, and often convey a need for research and technology development if the current state of the art fails to satisfy important customer requirements.

3.7.8 QFD matrix inconsistency analysis.

The source, nature, and implication of various inconsistencies in the QFD matrix must be addressed prior to the definition of design requirements. For instance, if results from the technical assessment activity seem contradictory to results pertaining to customer benchmarking, it may signal faulty measures or misinterpretation of customer perception.

3.7.9 Definition of design dependent parameter target values.

This is a critical system design activity since the DDP target values specify the feasible design space and affect subsequent design decisions. Pertinent and strategic opportunities must be identified and exploited. Experience and familiarity with similar systems is invaluable for effectiveness during this activity. Once again, for completeness, logistics-related requirements must be integrated into this step. Comprehensive definition of design requirements facilitates subsequent supportability-related analyses such as definition of the maintenance concept, level of repair analysis, failure mode, effects, and criticality analysis, maintenance task analysis, and so on.

3.7.10 Delineation of design dependent parameter relative importance.

To facilitate design analysis and evaluation activities, DDP relative priorities must be delineated. Further, in order to maintain traceability, relative priorities of design dependent parameters are computed from the importance levels assigned to customer requirements and the extent of their correlation with DDPs Along with the activities identified and discussed thus far, a "roof" is often developed over the QFD matrix. This mechanism allows delineation of positive and/or negative correlations between design dependent parameters, which in turn facilitates informed trade-offs.

4 Working Methodology

This project was accomplished completely according the following methodology:

1. Performing a scientific study to have an excellent theoretical background about QFD, its definition, elements, benefits, advantages, disadvantages, … etc.

2. Choosing PETRA, as a case study to investigate the implementation of QFD because it is a new company.

3. Identifying customers' needs and requirements through web-based questionnaire using internet as an input for building HOQ.

4. Determining Voice of Company (How) through meetings with the factory Engineers.

5. Building the HOQ, and showing all relationships between voice of customers and voice of company in addition to any comparisons between the factory and other international companies.

6. Analyzing quantitatively the whole HOQ and suggesting some improvement activities that will lead to improve quality elements.

7. Evaluating QFD implementation difficulties and build further recommendations for future work.

5 Results and Discussions:

5.1 QFD analysis:

Building the whole House of Quality Matrix requires a complete data collection methodology starting from determining customers' requirements and needs and ending by self-evaluation in comparison with international companies for further improvement activities to take place.

5.1.1 Customer's Needs (VOC) Importance:

Customer needs was examined in a market survey shown in appendix (A). The survey was established through a set of questions to two key categories: how the customers meets their needs for drinking water and what are the main requirements that the water treatment system should have.

The survey was designed and established so that customers' will evaluate or give importance or priority to their main requirements. Rating and prioritization activities were based on 1 to 10 scale.

These surveys were gathered and analyzed to generate the main customers' needs and the importance of each one, after that we looked for local competitors but we didn't find clear one; cause of that we go to make a benchmark with international companies (**Aquasana& Home Master**) to compare and evaluate our product with their product's (**Aquasana AQ-RO-3**& **Home Master Hydro Perfection**) based on each customer needs by using their product brochure as shown in Table (2) and figure (6-1) below.

Row #	Relative Weight	Weight / Importance	Quality Characteristics (a.k.a. "Functional Requirements" or "Hows") / Demanded Quality (a.k.a. "Customer Requirements" or "Whats")
1	18.8	8.9	High Quality Water
2	16.2	7.7	High Production rate
3	15.6	7.4	Low amount of wasted water
4	16.5	7.8	Long warranty period
5	15.2	7.2	Low product price
6	17.7	8.4	Life time and Maintability

Figure 5-1: Comparisons and prioritizations data

5.1.2 Voice of Company / How:

To improve PETRA level of quality, all customers' need was linked to technical specifications or design qualities supplied by PETRA engineers do to their high experience in industries.

Technical specifications that are related and have effects of products quality aspects are called voice of company. The technical specifications are summarized in table (), as we can see, the number of customers' needs is more that the number of technical specifications, which indicates that each one affects more than one quality aspect and here, comes the importance of the interrelationship between the voice of customer and the voice of company.

Table 5-1 : Voice of Company

Voice of Company/How?	
1	The amount of TDS
2	Reused Water
3	Pump specification
4	High quality components
5	Designed for assembly and disassembly

1. **Amount of TDS:**

Total dissolved solids (TDS) are the term used to describe the inorganic salts and small amounts of organic matter present in solution in water. The principal constituents are usually calcium, magnesium, sodium, and potassium cations and carbonate, hydrogen carbonate, chloride, sulphate, and nitrate anions.

The presence of dissolved solids in water may affect its taste; Panels of tasters in relation to its TDS level have rated the palatability of drinking water as follows:

1. Excellent, less than 200 ppm
2. Good, between 200 and 600 ppm
3. Fair, between 600 and 1000 ppm
4. Poor, between 1000 and 1200 ppm
5. Unacceptable, greater than 1200 ppm

In early studies, inverse relationships were reported between TDS concentrations in drinking water and the incidence of cancer, coronary heart disease arteriosclerotic heart 2 disease ,and cardiovascular disease Total mortality rates were reported to be inversely correlated with TDS levels in drinking-water.

2. Reused Water:

We conduct a search to find ways aimed to reduce the amount of wasted water by producing 1 litter of pure water using about 1 litter of normal water (supplied by gov.) but we didn't find; cause of that we thought to reuse this wasted water to solve this problem. Here in Jordan we need to such these things because as you know we are suffering from scarcity of water resources**.**

3. Pump Specification:

We select this parameter as one of the main keys, which drive production rate, because it is mainly control flow rate of feeder water and contribute restrictor to control water pressure in membrane unit so we could control production rate.

4. High quality components:

If we have High quality: Feeder and discharger unit, Low-pressure valve, Triple filtration unit, Membrane, High-pressure valve, Carbon filter to improve the taste, Tank, Air supplier, High-pressure valve and Filter for dirty water treatment. In addition, to other WTS components that's will increase their efficiency (doing things right) and there lifetime, so we could produce water with in the required specification through (Water treatment process) for long period.

Effect on:

- High Quality Water.
- Production Rate.
- Long warranty period.

- Low product price
- Lifetime.

5. Designed for assembly and disassembly:

We should take into consideration DFAD because it effect on different customers' needs in different ways such as:

- **Price**: assist the design teams in the design of product that will transition to productions at a minimum cost, focusing on the number of parts, handling and ease of assembly.
- **Maintainability**: reduce effort and time to change any component so we do not need skilled person for doing this.

Due to the high importance of technical specification in improving Water Treatment System products quality, PETRA managers built the relationship matrix between them for easier and further understanding and it can be considered as a starting point for improvements activities.

5.1.3 The Relationship Matrix:

The aim of this matrix is to convert customer requirements into design characteristics, through to a part level, and then into a manufacturing processes and controls.

The mechanism to achieve and display the results is the common matrix diagram that presents one set of ideas or data type against those of another, thereby providing a means to evaluate their relationships.

This matrix shown in Figure (6-2) below was filled with the help of PETRA engineers due to their high practical experience.

Legend		
9	⊙	Strong Relationship
3	O	Moderate Relationship
1	▲	Weak Relationship

Quality Characteristics (a.k.a. "Functional Requirements" or "Hows") / Demanded Quality (a.k.a. "Customer Requirements" or "Whats")	The amount of TDS	Reused Water	Pump specification	High quality components	Designed for assembly and disassembly
High Quality Water	⊙		O	⊙	
High Production rate	O		⊙	O	
Low amount of wasted water		⊙	▲	▲	
Long warranty period	O		▲	⊙	▲
Low product price				⊙	▲
Life time and Maintability	O		▲	⊙	⊙

Figure 5-2: The Relationship Matrix

Strong relationships were represented by circle within a point, Empty circle for medium and triangles for weak relations.

5.1.4 The Correlation Matrix:

For further analysis, the relationships between technical specifications themselves were determined through what is called correlation matrix. It is also called roof matrix because it lies over voice of company row. It was designed to determine the effect of one technical feature on the others. High correlation indicates product features that must be given consistent attention. This matrix is shown in Figure (6-3) with the same relationships symbols used in the relationship matrix between voice of customer and voice of company.

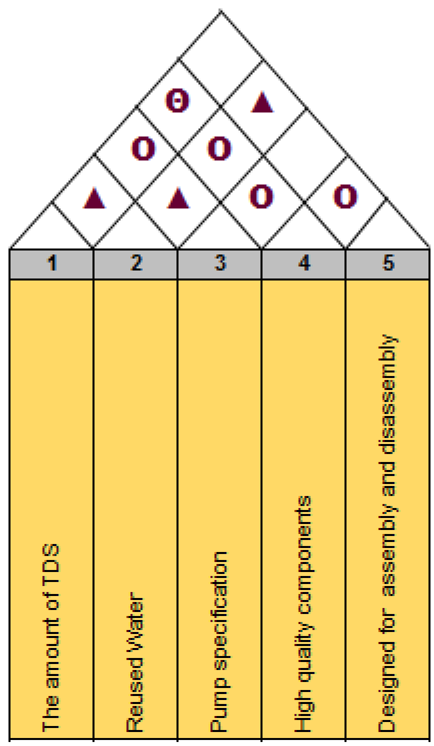


Figure 5-3: The Correlation Matrix

We explain just strong and moderate relationship between technical as shown in table below:

Table 5-2: Technical Relationships

Technical relationships		Type of Relation (Strong, Moderate)	Why?
The amount of TDS	Pump Specification	Moderate	Pump control flow rate of feeder water and contribute restrictor to control water pressure in membrane unit that's lead us to get pure water
The amount of TDS	High quality components	Strong	If we have high quality WTS components contains filters, membrane, tanks and other components which there are the main components responsible of purification of water and reducing TDS amount they will increase their efficiency (doing things right) and there lifetime, so we could produce water with in the required specification through (Water treatment process) for long period
Reused Water	High quality components	Moderate	We need components such as Feeder and discharger unit and tanks .we need a tank to store Salt water then we need feeder and discharger unit to mix this water with water supplied by governmental water so we need them with high quality to protect them from corrosion

5.1.5 The Planning Matrix:

This matrix constitute the right portion of the whole HOQ, it was designed to show the objective measures, which are a comparison customers' requirements degree of satisfaction against the proposed degree required by the PETRA.

Table 5-3: Benchmarking

Product / Customer Requirements	Importance	PETRA-RO75	AquasanaAQ-RO-3	Home Master Hydro Perfection
				
High Quality Water	8.9	TDS < 100 ppm	TDS < 100 ppm	TDS < 100 ppm
High Production Rate	7.7	75 gallon= 288 L	13.32gallon= 50.4 L	75 gallon = 288 L
Low Amount of Wasted Water	7.4	1:0 (Green)	1:1.5	1:1
Long warranty period	7.8	2 years	2 years	5 years
Low Product Price	7.2	352 $	250 $	$530
Product Life Time and Maintainability	8.4	1. Sediment PP filter cartridge 1500. 2. Membrane 36,500 gallon (2 years). 3. Post carbon filter1500. 4. Magnetic post carbon filter 3000 gallon.	1. Carbon Pre-Filter 1000 gallon. 2. Membrane 4,900 gallon (1 year). 3. ClaryumPost-Filter 1000 gallon. 4. RemineralizerLIFE (1year).	1. Sediment pre-filter: 3000 gallon. 2. Membrane 55,000 gallon (3-5 years). 3. Artesian post filter 2000 gallon. 4. UV filter 3000 gallon (1year).
MADE IN		JORDAN	USA	USA

All of these data have been calculated and analyzed based on the following assumption:

1. Feed water: PSI 40 - 100 PSI = 275-689 kpa
2. Feed water Temperature: 40˚- 100˚(F) = 4.44-37.7° C
3. Max. Total Dissolved Solids (TDS): 2000 ppm
4. Max. Hardness: 10 gpg
5. PH limits: 4 - 10

Benchmarking Analysis (1=Worst, 10=Best)

Row #	Relative Weight	Weight / Importance	Quality Characteristics (a.k.a. "Functional Requirements" or "Hows") / Demanded Quality (a.k.a. "Customer Requirements" or "Whats")	The amount of TDS	Reused Water	Pump specification	High quality components	Designed for assembly and disassembly	Petra-RO75	Aquasana A Q-RO-3	Home Master Hydro Perfection	Ranking: Petra-RO75	Ranking: Aquasana A Q-RO-3	Ranking: Home Master Hydro Perfection	Target	Improvement ratio	Score	Relative Score
1	18.8	8.9	High Quality Water	Θ		O	Θ		10	10	10	89	89	89	10	1	8.9	15.8%
2	16.2	7.7	High Production rate	O		Θ	O		9	5.7	9	69.3	43.89	69.3	9	1	7.7	13.6%
3	15.6	7.4	Low amount of wasted water		Θ	▲	▲		9.7	3.4	5.2	71.78	25.16	38.48	9.7	1	7.4	13.1%
4	16.5	7.8	Long warranty period	O		▲	Θ	▲	6.4	6.2	9	49.92	48.36	70.2	9	1.41	10.97	19.4%
5	15.2	7.2	Low product price				Θ	▲	5.2	7.8	3	37.44	56.16	21.6	7.8	1.50	10.8	19.1%
6	17.7	8.4	Life time and Maintability	O		▲	Θ	Θ	6.9	4.1	8.8	57.96	34.44	73.92	8.8	1.28	10.71	19.0%
												375.4	297	362.5			56.5	100%
												1	3	2				

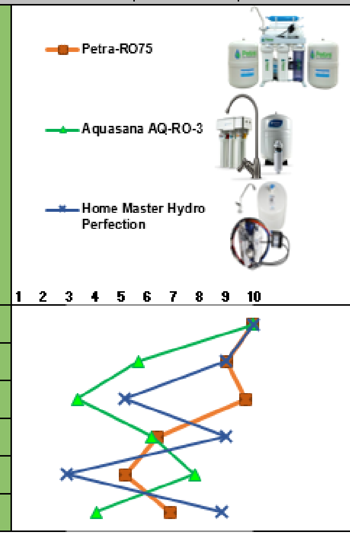


Figure 5-4: Benchmarking & Planning Matrix

The first column of this Ranking matrix represents the score of each company based on customer needs let's take the first row, which represent "High Quality Water" with importance 8.9 and Petra-RO75 take score 10 out of 10 so it's score = 8.9*10=89 points, then we take the next Customer needs "High production rate" with importance 7.7, then Petra-RO75 take 9 out of 10 so it's score = 7.7*9=69.3 points, we did this for all customers' needs so Petra-RO75 score=89+69.3+71.78+49.92+37.44+57.96= 375.4 points. Then we did this for other products, as the result of that we got that Petra-RO75 has the highest score with 375.4 points by comparing this with Aquasana A Q-RO3 (297 points) and Home Master Hydro Perfection (362.5 points), but there is no too much difference between Petra-RO75 (375.4 points) and Home Master Hydro Perfection (362.5 points); so we did AHP analysis to make sure about this difference if customers' needs weight would be changed.

Now let us back to Figure 5-4: (Benchmarking & Planning Matrix), target value that represents the proposed value of customers' ratings. It was calculated by determining the maximum rating for each customer's need between PETRA, Aquasana and Home Master product's and taking in to account its importance from customers point view. For example, Low product price, PETRA rating is 5.2 whereas it is 7.8 for Aquasana and 3 for Home Master, so that the PETRA's target value can be 7.8, which is the maximum rating between 5.2, 7.8 and 3, and the same for other requirements.

Improvement ratios were also calculated to show how much customers' requirements rating should be improved to increase customer satisfaction. It was calculated by dividing the proposed target value over the current rate, in other words (Us in the future / us today). For example, Long warranty period has an improvement ratio 1.41 calculated by (9/ 6.4) =1.41, scores were calculated by multiplying the importance of each customer need with its improvement ratio. For example, Long warranty period score equals to 10.97 calculated by (1.41*7.8) = 10.97.

To get the percentage scores, the total score for each customer requirement multiplied by 100% divided each score. For example, Long warranty period score is 10.97, so that its percentage score = (10.97/56.48)*100% = 19.4%

5.1.6 The Final Scores of technical points

Weight / Importance	Demanded Quality (a.k.a. "Customer Requirements" or "Whats") \ Quality Characteristics (a.k.a. "Functional Requirements" or "Hows")	The amount of TDS	Reused Water	Pump specification	High quality components	Designed for assembly and disassembly
8.9	High Quality Water	Θ		O	Θ	
7.7	High Production rate	O		Θ	O	
7.4	Low amount of wasted water		Θ	▲	▲	
7.8	Long warranty period	O		▲	Θ	▲
7.2	Low product price				Θ	▲
8.4	Life time and Maintability	O		▲	Θ	Θ
	Weight / Importance	320.3	140.5	252.3	677.6	191.1
	Relative Weight	19.5	8.6	15.4	41.3	11.7
		2	5	3	1	4

Figure 55: Technical Actions priorities.

As we have done with customer's requirements, it is possible to give a score for each technical actions or specifications that will directly affect the products quality level. Technical scores depends on the relationship matrix between voice of customers and voice of quality, each relationship symbol discussed previously has a value as follow:

Table 5-4: Correlation Keys

Correlation Label	Corresponding Icon	Corresponding Value
Strong Relationship	Θ	9
Moderate Relationship	O	3
Weak Relationship	▲	1

The score of each technical aspect was calculated by summing the multiplications of each relationship value by its associated customer need. For example, for the first column this represents “The amount of TDS”,

The final score =9*18.8+3*16.2+3*16.5+3*17.7 = 320.3

The percentage score was calculated by dividing scores by the total scores multiplied by 100% which represents the percentage score of each technical specifications ‘voice of customer’.

5.1.7 Final Model of HOQ

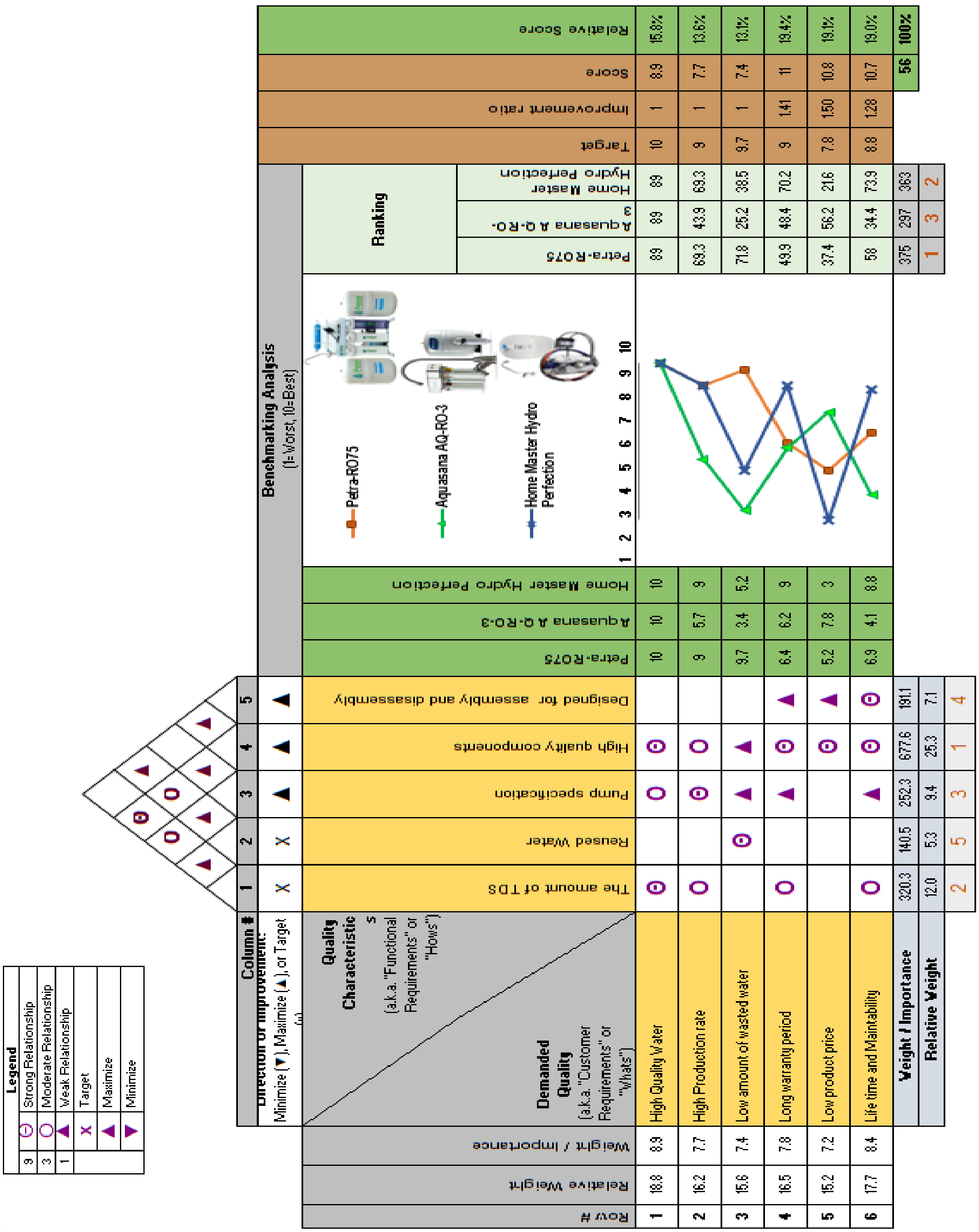


Figure 5-6: QFD Matrix

5.2 Analytical Hierarchy Process (AHP):

The analytical hierarchy process is widely used as multi-criteria decision making tool. It uses pair-wise comparisons, takes into consideration the relative priorities of factors in a system, and enables people to select the best alternative based on their goals.

5.2.1 AHP Analysis

The AHP method used in this project to select the best filter system, where the main criteria that were inserted to the software are:

1. Quality of water
2. Production rate
3. Amount of waste water
4. Warranty period
5. Life time and maintainability.
6. Price

In addition to that, the data of the survey that was distributed on a sample of people to check the most important criteria they take it in concern when buying a filter first has been scaled by ± o.3, based on this scale, for the first criteria it's weight was 8.9, where the rank up and rank down were respectively 8.9-8.61, thus the rank has been chosen to be 9, the same procedure has been applied on the other criteria and the rank was as shown in table [2].

Table 5-5: Weighted comparison matrix.

Rank up	Rank down	rank	criteria	weight	rank
8.9	8.61	9	Quality of water (c1)	8.9	9
8.6	8.3	8	Production rate (c2)	7.7	6

8.29	7.99	7	Amount of waste water (c3)	7.4	5
7.98	7.68	6	Warrantee Period (c4)	7.8	6
7.67	7.37	5	Product price (c5)	7.2	4
7.36	7.06	4	Life time (c6)	8.4	8

After that, the normalized pair-wise comparison matrix prepared by dividing each value of the weight for each criteria to the summation of the values, then the value for each criteria has been divided on the other values to compare between them, the diagonal for this matrix will always have the 1 value since it will be the result of dividing the weight of the criteria by itself, the same technique has been applied on each filter to compare between these filters based on what the filter achieve from each criteria then the results have been relocated to the Expert Choice software as shown in table [4]:

Table 5-6: Normalized pairwise comparison matrix

criteria	**c1**	**c2**	**c3**	**c4**	**c5**	**c6**
c1	1	1.5	1.8	1.5	2.25	1.125
c2	0.6667	1	1.2	1	1.5	0.75
c3	0.5556	0.8333	1	0.8333	1.25	0.625
c4	0.6667	1	1.2	1	1.5	0.75
c5	0.4444	0.6667	0.8	0.6667	1	0.5
c6	0.8889	1.3333	1.6	1.3333	2	1

Let's say the we want to compare the Quality of water with the Production rate criteria since each of them take the weight of 9 and 6 respectively the normalized value for them is 0.195 and 0.13 then the value that recorded in the table is:

$$w = \frac{normlized\ rank\ c1}{normalized\ rank\ c2} = \frac{0.195}{0.13} = 1.5$$

Based on the inserted matrix the results are tabulated as shown in table [3]:

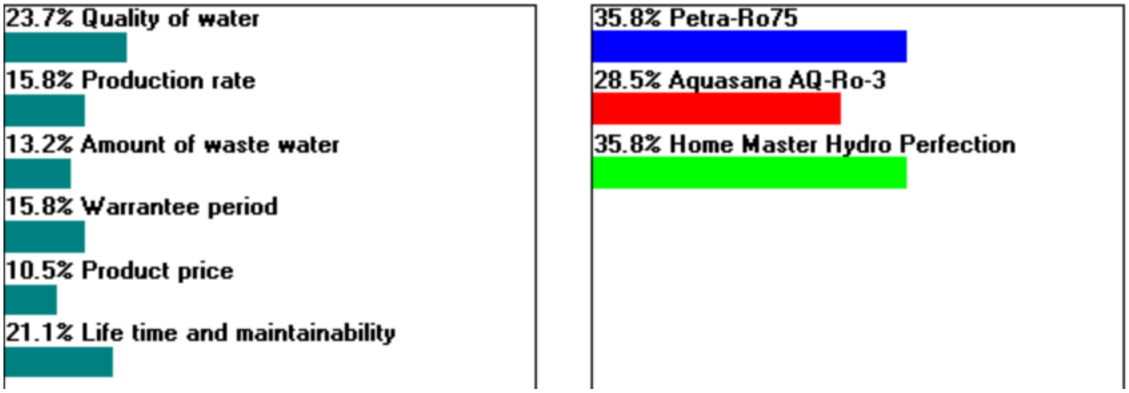
Table 5-7: Tabulated results

Filter Name	Goal	C1	C2	C3	C4	C5	C6
Petra-RO75	0.358	0.333	0.380	0.530	0.296	0.325	0.349
Aquasana-Ro3	0.285	0.333	0.241	0.186	0.287	0.488	0.207
Home Master Hydro Perfection	0.358	0.333	0.380	0.284	0.417	0.188	0.444

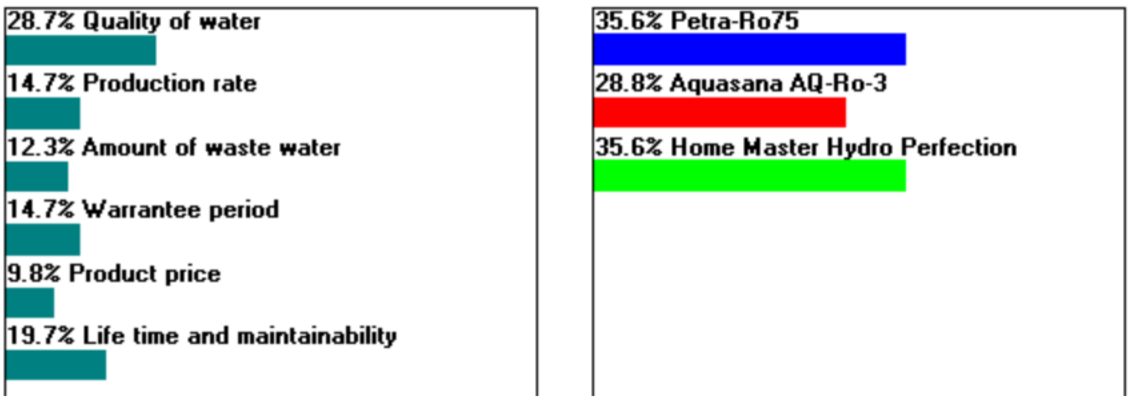
The results demonstrate that; Petra-Ro75 is the best filter regarding to the main goal which achieved by 0.358 and then Aquasana-Ro3 by 0.285 and the last Home Master Hydro Perfection by 0.358.

5.2.2 Sensitivity Analysis:

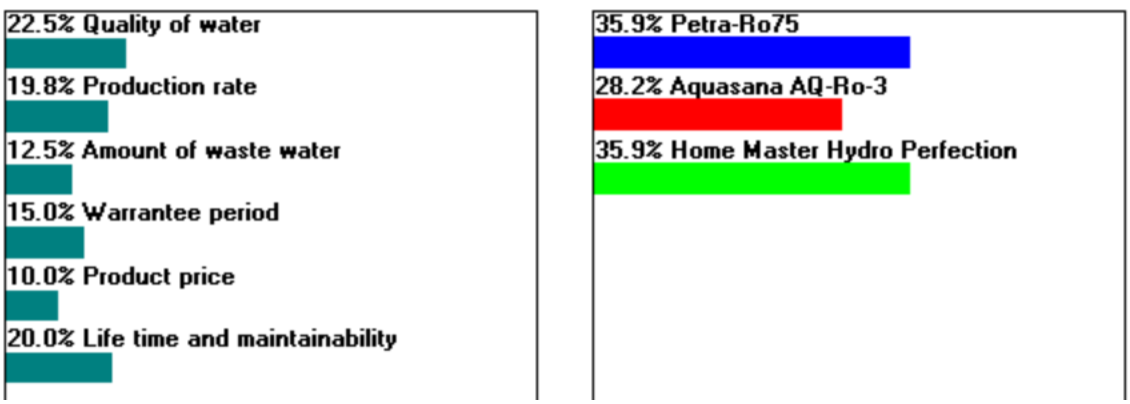
The main goal of the sensitivity analysis is to check the effect on the rank of filters based on changes in the important adopted criteria and how it will behave under these changes. Expert choices chooses to perform the sensitivity analysis, due to it well-found features that can perform such analysis, and the dynamic sensitivity graph is among these tools that can explore the results in an easy way.



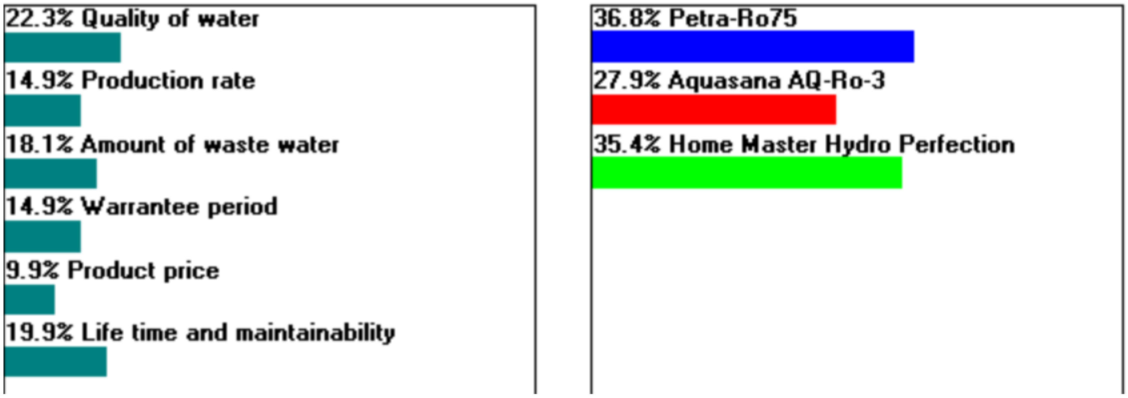
(a)Final Expert choice results.



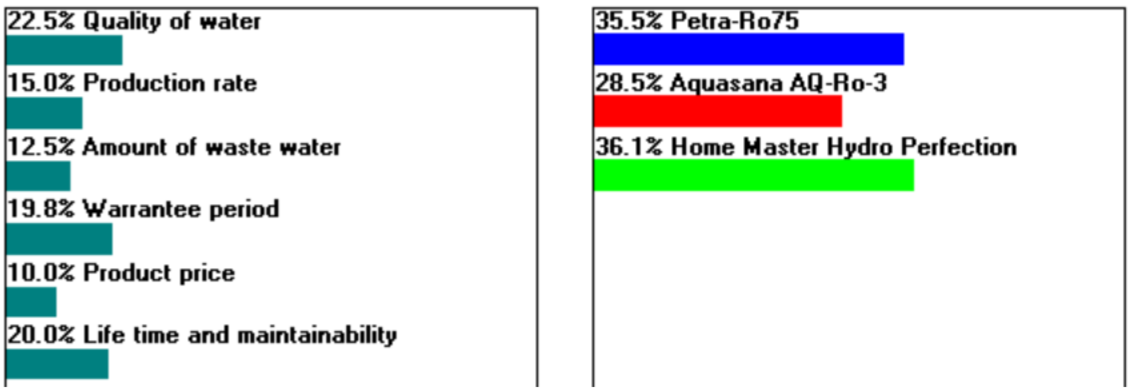
(b) First approach: Quality of water increased by 10%.



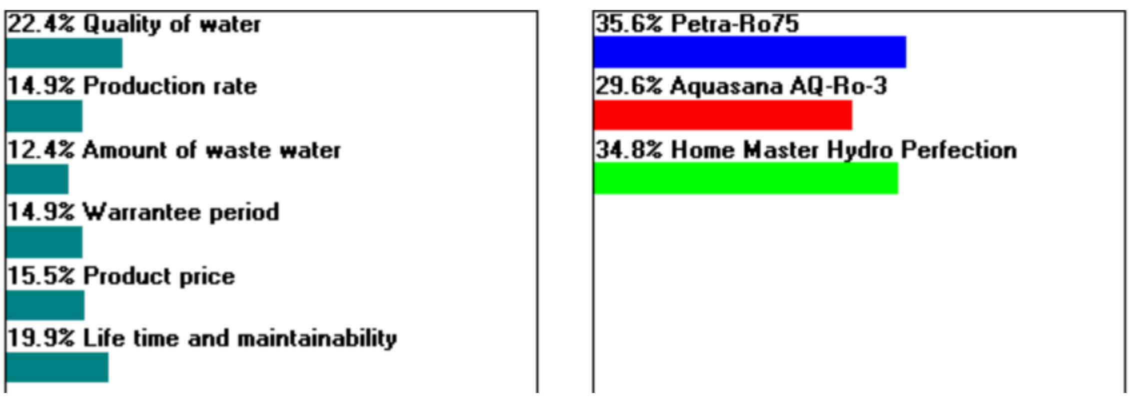
(c) Second approach: Production rate increased by 10%.



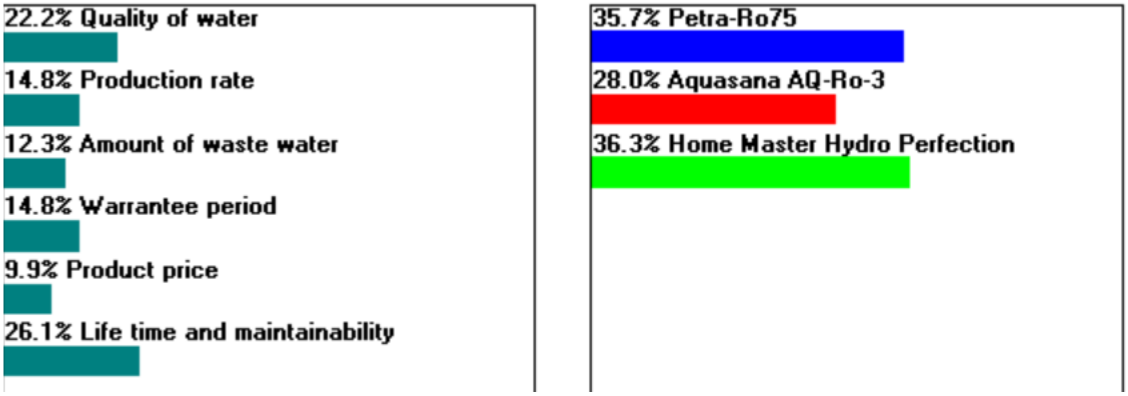
(d) Third approach: Amount of wastewater increased by 10%.



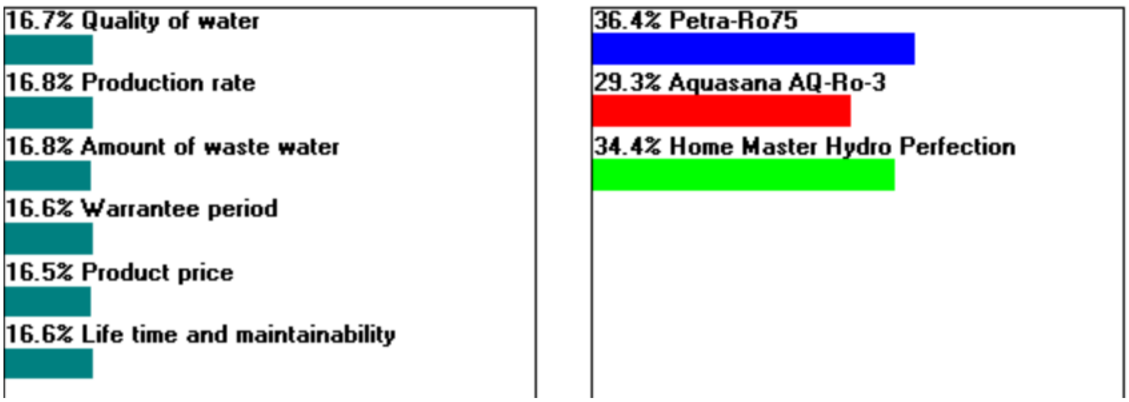
(e) Fourth approach: Warrantee period increased by 10%.



(f) Fifth approach: Life time and maintainability increased by 10%.



(g) Sixth approach: Product price increased by 10%.



(h) seventh approach: All criteria have the same weight.

Figure 6-5: Dynamic sensitivity graph for the AHP model: These graphs represent the seven simulated scenarios (a-h)

At the beginning, the weights by the expert Choice assigned to be the base to compare the other approach with Fig. [a] Which indicate that Petra-Ro75 and Home Master are the most preferable. then, we obtain that the system very sensitive to 10% increasing the weight since the results changed completely thus each one of them is improved by increasing the weight of only one criterion by 5% over the weight in the base approach, this increase is automatically compensated by an equal deduction from the weights of other criteria. The results clearly indicate that, Petra-Ro75 still the most preferable these scenarios are shown in Fig. [e-g, f]. However, the scenario shown in Figures [e, g] shows that Home Master Hydro Perfection is most preferable by simple variance.

In the last scenario, all criteria are given almost equal weights with respect to the overall goal and Petra-RO75 stay as the best choice with 36.4% score as shown in Fig. [h]. The results indicate to the strength of the decision made, as the ranking of the alternatives is not highly sensitive to the changes in the criteria weights the same judgment basis of AHP and the judgment of the quality function deployment.

5.2.3 Conclusion of AHP:

We used the expert choice to make a decision about the best water treatment system based on specific criterion assigned from the customers. Therefore, the expert choice uses the analytical hierarchy process to make this decision which shows that Petra-Ro75 achieve the main goal by a percentage 35.8%, which can be considered good evaluation for the filter. Once this result can be used as a validation for the quality function deployment result and by this agreement, we can consider this decision for the filters the right one. In addition, keep the continuous improvement procedure to keep this rank.

6 Conclusion:

Row #	Relative Weight	Weight / Importance	Quality Characteristics (a.k.a. "Functional Requirements" or "Hows") / Demanded Quality (a.k.a. "Customer Requirements" or "Whats")	The amount of TDS	Reused Water	Pump specification	High quality components	Designed for assembly and disassembly	Target	Improvement ratio	Score	Relative Score
			Column #	1	2	3	4	5				
			Direction of Improvement: Minimize (▼), Maximize (▲), or Target (x)	x	x	▲	▲	▲				
1	18.8	8.9	High Quality Water	Θ		O	Θ		10	1	8.9	15.8%
2	16.2	7.7	High Production rate	O		Θ	O		9	1	7.7	13.6%
3	15.6	7.4	Low amount of wasted water		Θ	▲	▲		9.7	1	7.4	13.1%
4	16.5	7.8	Long warranty period	O		▲	Θ	▲	9	1.41	11	19.4%
5	15.2	7.2	Low product price				Θ	▲	7.8	1.50	10.8	19.1%
6	17.7	8.4	Life time and Maintainability	O		▲	Θ	Θ	8.8	1.28	10.7	19.0%
			Weight / Importance	320.3	140.5	252.3	677.6	191.1			56	100%
			Relative Weight	12.0%	5.3%	9.4%	25.3%	7.1%				
				2	5	3	1	4				

Figure 6-1: Technical score

- As shown on the figure (7-1) (Yellow cells) we can concludes that we have the following opportunities for improvement:
  1. Long warranty period.
  2. Low product price.
  3. Lifetime and Maintainability.

7 Recommendation:

As we conclude in the previous section, we have three opportunities for improvement so we have to or we should put them into an action plan and we recommend the following things:

7.1.1 Technical recommendation:

1. **Pump Specification**

We could use non-electric pump, which uses only the hydraulic movement of the brine water (water going down the drain like a water wheel) to pull additional purified water (i.e. “permeate”) into storage tank.

Features and Benefits for use permeate pump

1. Improves water quality through improved membrane ne efficiency.
2. Reduces wastewater by up to 80%, extends component life.

2. **Improve Quality of Components:**

If we want to have High quality components for water treatment system to increase their efficiency and lifetime we should do the following:

1. Get good raw materials from certified suppliers; so there is no need to do pre-inspections, which led us to reduce cost and at the same time getting high quality row materials.
2. Schedule preventive maintenance and calibrations for equipment's should be done; to reduce number of defects and source of variations (come from equipment's.

3. Develop training plan for employees to be educated in how work should be done and to build Continuous Improvement concept on their minds to improve and maintain the stability of the processes.
4. Deploy lean six sigma principles (DMAIC-Cycle).

3. Designed for assembly and disassembly:

We should take into account DFSD because it is effect on different customers' needs (Price Maintainability) and it could be done by applying the following principles:

1. Minimize part count.
2. Design parts with self-locating features.
3. Design parts with self-fastening features.
4. Minimize reorientation of parts during assembly.
5. Design parts for retrieval, handling, and insertion.
6. Emphasize 'Top-Down' assemblies.
7. Standardize parts (minimum use of fasteners).
8. Encourage modular design.
9. Design for a base part to locate other components.
10. Design for component symmetry for insertion.

7.1.2 Managerial Recommendation:

QFD Method is an effective tool to gain with every need to improve, it is widely spread in the west industries and it is an important key in quality success by achieving competitive advantage, though it has not well known in our industries at all, we recommend:

1. Implementing a strategic vision to aware and declare the rule of Continuous Improvements in the success of industries as a growing one in Middle East.
2. Developing Marketing Strategy.
3. Developing KPI's and set specific target for each indicter and measure it frequently to control and monitor business processes.

8 APPENDICES

8.1 General Questioner

جهاز معالجة المياه المنزلي (فلتر الماء)

*Required

السؤال الاول: كيف تؤمن احتياجاتك اليومية لمياه الشرب؟ *

- المياه الواردة من سلطة المياه
- شراء قوارير المياه
- جهاز معالجة المياه المنزلي / نوع: بترا للريادة المنزلية الخضراء
- جهاز معالجة المياه المنزلي / نوع آخر
- Other:

السؤال الثاني: هنالك في الاسفل عدد من المواصفات والمتطلبات الرئيسيه الواجب توافرها في جهاز معالجة المياه المنزلي، يرجى منكم التكرم بتحديد مستوى اهمية كلاً منها بالنسبة اليكم، واضافة اي متطلب ترغبون به لم يتم ذكره

1) جوده المياه المنتجه *

	1	2	3	4	5	6	7	8	9	10	
قليل الأهمية	○	○	○	○	○	○	○	○	○	○	شديد الاهمية

2) انتاجية جهاز المعالجة للماء النقي (عدد لترات الماء المنتجة في اليوم) *

	1	2	3	4	5	6	7	8	9	10	
قليل الأهمية	○	○	○	○	○	○	○	○	○	○	شديد الاهمية

3) ان تكون كمية الماء المهدوره قليلة *

	1	2	3	4	5	6	7	8	9	10	
قليل الأهمية	○	○	○	○	○	○	○	○	○	○	شديد الاهمية

4) مده الضمان (الكفاله) *

	1	2	3	4	5	6	7	8	9	10	
قليل الأهمية	○	○	○	○	○	○	○	○	○	○	شديد الاهمية

5) سعر الجهاز *

	1	2	3	4	5	6	7	8	9	10	
قليل الأهمية	○	○	○	○	○	○	○	○	○	○	شديد الاهمية

6) سهولة الصيانه والعمر الافتراضي للجهاز *

	1	2	3	4	5	6	7	8	9	10	
قليل الأهمية	○	○	○	○	○	○	○	○	○	○	شديد الاهمية

7) شكل الجهاز (الناحية الجمالية) *

	1	2	3	4	5	6	7	8	9	10	
قليل الأهمية	○	○	○	○	○	○	○	○	○	○	شديد الاهمية

8) أخرى (يرجى ذكر الصفة/ المتطلب الذي ترغب بأخذه بعين الاعتبار)

Your answer

BACK SUBMIT

8.2 Survey

Product / Customer Requirements	Importance	PETRA-RO75	Aquasana AQ-RO-3	Home Master Hydro Perfection
				
High Quality Water	8.9	**TDS < 100 ppm**	**TDS < 100 ppm**	**TDS < 100 ppm**
		1 2 3 4 5 6 7 8 9 10	1 2 3 4 5 6 7 8 9 10	1 2 3 4 5 6 7 8 9 10
High Production Rate (Per Day)	7.7	**75 gallon = 288 L**	**13.32gallon= 50.4 L**	**75 gallon = 288 L**
		1 2 3 4 5 6 7 8 9 10	1 2 3 4 5 6 7 8 9 10	1 2 3 4 5 6 7 8 9 10
Low Amount of Wasted Water	7.4	**1:0**	**1:1.5**	**1:1**
		1 2 3 4 5 6 7 8 9 10	1 2 3 4 5 6 7 8 9 10	1 2 3 4 5 6 7 8 9 10
Long warranty period	7.8	**2 years**	**2 years**	**5 years**
		1 2 3 4 5 6 7 8 9 10	1 2 3 4 5 6 7 8 9 10	1 2 3 4 5 6 7 8 9 10
Low Product Price	7.2	**352 $**	**250 $**	**$530**
		1 2 3 4 5 6 7 8 9 10	1 2 3 4 5 6 7 8 9 10	1 2 3 4 5 6 7 8 9 10
Product Life Time and Maintainability	8.4	**1. Sediment PP filter cartridge 1500 gallon. 2. Membrane 36,500 gallon (2 years). 3. Post carbon filter 1500. 4. Magnetic post carbon filter 3000 gallon.**	**1. Carbon Pre-Filter 1000 gallon. 2. Membrane 4,900 gallon (1 year). 3. Claryum Post-Filter 1000 gallon. 4. Remineralizer LIFE (1year).**	**1. Sediment pre-filter: 3000 gallon. 2. Membrane 55,000 gallon (3-5 years). 3. Artesian post filter 2000 gallon. 4. UV filter 3000 gallon (1year).**
		1 2 3 4 5 6 7 8 9 10	1 2 3 4 5 6 7 8 9 10	1 2 3 4 5 6 7 8 9 10

All of these data have been calculated and analyzed based on the following assumption:

1. Feed water: PSI 40 - 100 PSI = 275-689 kPa.
2. Feed water Temperature: 40˚- 100˚(F) = 4.44-37.7° C.
3. Max. Total Dissolved Solids (TDS): 2000 ppm.
4. PH limits 4 – 10.

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