An Approach for Enhancing the Manufacturing Facility by Implementing the Four Phases of QFD with FMEA

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DECLARATION BY THE CANDIDATES

It is hereby declared that the work presented in this thesis is our own. The thesis or any part of it has not been submitted elsewhere for the award of any degree or professional qualification.

The content of this graduation exercise is the result of the work I have been carrying out since the official commencement date of the approved dissertation.

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CERTIFICATION OF RESEARCH

This Thesis entitled "An Approach for Enhancing the Manufacturing Facility by Implementing the Four Phases of QFD with FMEA" submitted by MD. Akib Ahmed (ID: 180011102) and Anzam Masud Rhodik (ID: 180011208) have been accepted as satisfactory in Partial Fulfillment of the Requirement for the Degree of Bachelor of Science in Mechanical Engineering in May 2023.

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Abstract

This thesis aims to implement the four phases of Quality Function Deployment (QFD) along with two types of Failure Mode and Effect Analysis (FMEA) in a manufacturing plant. The QFD methodology encompasses four inter-dependent phases: Product Planning, Product Design, Process Planning, and Process Control. Additionally, FMEA is employed in two forms: Design FMEA and Process FMEA. The objective is to combine these two methods effectively.

The practical implementation of QFD and FMEA is facilitated by the collaboration with Telephone Shilpa Sangstha (TSS), a manufacturing plant based in Bangladesh. TSS has generously provided qualitative data to support this study. The joint implementation focuses on the evaluation of an electrical product, specifically the 'Doel' Laptop.

Through the application of QFD and FMEA, this research aims to enhance the quality and reliability of the manufacturing process. The findings and insights derived from this study can provide valuable guidance to the manufacturing industry, particularly in the areas of product planning, design, process planning, and process control. By adopting these methodologies, manufacturing plants can improve their product development processes and minimize potential failures, thereby delivering higher-quality products to customers.

Finally, the thesis has identified a few crusty aspects of the TSS industry's (Doel Laptop) product. QFD analysis has uncovered the most prevalent customer complaints, the most important technical specification, the most important component, and the most important procedures. Combining this with DFMEA and PFMEA led to a conclusive design and process evaluation.

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We express our heartiest gratefulness to the Almighty Allaah SWT for His blessings, which made us live and possible to complete this project/thesis work successfully.

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Thank You

Table of Contents

List of Figures

List of Tables

Chapter 1
INTRODUCTION

1.1 BACKGROUND OF THE STUDY

A number of variables, including globalization, technological advancements, increased product quality, shifting consumer needs, and the need for cost optimization, can cause rivalry in the manufacturing sector to be fierce. Businesses must prioritize product innovation, operational excellence, and customer-centricity if they want to be competitive in the manufacturing industry. To remain competitive in the industrial sector, businesses must promote a culture of innovation and continual development. A considerable emphasis on product design, quality assurance, and supply chain optimization is necessary for this. A reduction in the number of design revisions, reduced startup costs, faster design cycles, fewer warranty claims, greater internal communications, and higher sales can all be attained by the company by clearly identifying the consumers' requirements from the beginning of the process. Next, it is important to consider prospective product problem assessments at later phases of the product development cycle from the standpoint of product reliability. To make sure that the finished product satisfies customer wants and expectations, the analysis helps to compare the design aspects of the product with the intended production process and experiment design.

Some of the techniques and instruments are very helpful for meeting the needs and demands of a manufacturing facility. Although all quality enhancement methods cannot be used in one study, the authors will combine two of the most essential ones. This includes QFD (Quality Function Deployment) and FMEA (Failure Modes and Effects analysis). The techniques for combining these tools are well described in this study.

1.2 IMPORTANCE OF THE STUDY

Quality Function Deployment (QFD) and Failure Mode and Effects Analysis (FMEA) are twoeffective managing quality instruments with distinct functions.

However, combining them can result in a more comprehensive analysis of a product or service, which may result in increased reliability, client happiness, and productivity. Here are some justifications for combining QFDand FMEA in a case study:

1. QFD concentrates on comprehending customer needs and translating them into design requirements, whereas FMEA identifies potential failures and their consequences. By combining these two methods, you can create a product or service that satisfies customer needs while averting potential failures that could negatively impact customer satisfaction.

2. QFD provides a structured method for prioritizing customer requirements, whereas FMEA identifies the most significant failure modes that must be addressed. Together, they can help you prioritize requirements and design features based on the level of risk associated with each requirement or feature.

3. QFD provides a framework for cross-functional collaboration and communication, whereas FMEA can help identify communication gaps or misunderstandings that could contribute to errors. By employing both methods, you can ensure that all stakeholders are on the same page regarding the product or service's requirements and potential failure modes.

4. QFD can help identify areas for improvement in the design or production process, whereas FMEA can help identify failure causes and potential process enhancements. By combining these techniques, it is possible to generate a continuous development cycle that ensures customer requirements are met and potential failure modes are addressed.

Combining QFD and FMEA is comparable to studies in the field of quality management, such as Planning for Six Sigma (DFSS), Total Quality Management (TQM), and Lean Six Sigma. By identifying and addressing the fundamental causes of problems in the design, production, and delivery of products or services, these methodologies all seek to improve quality and customer satisfaction.

DFSS is a structured approach to design that combines customer requirements, statistical analysis, and project management techniques to guarantee that items or services satisfy customer demands and are free of defects. DFSS, like QFD and FMEA, concentrates on understanding customer demands and translating them into design requirements, while utilizing statistical toolsto identify potential issues and optimize the design process.

TQM is a system of leadership that stresses constant enhancement in all aspects of an organization's operations, such as product design, production processes, and customer service. TQM is similar to QFD and FMEA in that it identifies and addresses the fundamental causes of problems in order to enhance quality and consumer satisfaction.

Lean Six Sigma is an integration of Lean manufacturing and Six Sigma methodologies with the objective of lowering waste and variability in manufacturing procedures while simultaneously enhancing quality. Lean Six Sigma, like QFD and FMEA, employs structured approaches to identify and resolve problems in order to enhance productivity, quality, and consumer satisfaction.

In conclusion, the combination of QFD and FMEA is related to similar studies in quality management, such as DFSS, TQM, and Lean Six Sigma, all of which aim to improve quality and customer satisfaction by identifying and addressing the fundamental causes of problems in product design, production, and delivery.

1.3 RESEARCH PROBLEM STATEMENT

Today, many firms in a developing nation like Bangladesh use no product development methodology for their production. Despite the fact that some firms are credited with employing a strategic approach to product development, they are not doing so in a way that will allow them to meet customer demands and reduce risk.

There are several potential problems that a company can face by not using QFD and FMEA in their product or process development. These problems can ultimately lead to increased costs, reduced customer satisfaction, and negative impacts on the company's reputation. Here are someexamples:

- Increased costs due to defects: Without the use of FMEA, potential failure modes in the product or process may not be identified and addressed, leading to increased costs associated with rework, scrap, and warranty claims. According to a study by the American Society for Quality, the average cost of poor quality in manufacturing can range from 15% to 20% of the total revenue [1].

- Safety and regulatory compliance issues: Without the use of FMEA, potential safety hazards or regulatory compliance issues may not be identified, leading to potential legal and financial consequences. For example, research done by the NIST (National Institute of Standards and Technology) found that the annual cost that is generated from non-compliance with regulations can range from 2% to 15% of a company's revenue [2].

- Lost opportunities for innovation: Without the use of QFD, the company may miss opportunities to innovate and differentiate itself from competitors. This can lead to reduced market share and revenue growth. According to a study by the Product Development and Management Association, companies that use QFD have reported a 20% increase in sales and a30% increase in profits [3].

Now from the studies above we can generalize the following problems production plants usuallyface by not using QFD and FMEA:

- Since they do not prioritize consumer demands when evaluating technical specifications, theyconsistently make mistakes and are unclear about which ones should be changed.

Manufacturing facilities are unable to make the best decisions regarding updating their productdesigns since they aren't establishing a connection between the wants of the customers and the technical requirements. Additionally, organizations lack a clear understanding of howcompetitive their industry is.

• The process of manufacturing is always connected to product design. Therefore, it is crucial to adapt the process in order to meet client expectations. Processes are consistently linked to product risk factors and various failure scenarios. These production facilities are unable to identify connections between various design matrices and techniques. They become disorganizedin their many task segments as a result.

• The production facilities are unable to pinpoint all product faults as well as all the consequences resulting from these failures. As a result, there are always some challenges that manufacturing facilities encounter when designing and producing a product.

All of the aforementioned reasons are what explain why businesses in a developing nation like Bangladesh produce goods of poor quality, cause bottlenecks, and require a lot of time and money to produce.

1.4 GOALS AND OBJECTIVES OF THE STUDY

The main aim of this work is to implement QFD and FMEA methods in a manufacturing plant to establish a proper relationship between customer requirements, product design, process design, and risk factors.

In order to achieve this aim, some objectives have been followed. These are sequentiallymentioned below:

• To demonstrate the integration of QFD and FMEA with other pertinent tools and application methodologies for quality improvement in a manufacturing facility.

• To determine the technical specifications and customers' needs in order to conduct a QFDanalysis for a product.

• To apply the four phases of QFD and find the relationships between product design and processdesign.

• To implement the SWARA method so that the weight of the WHATs in every phase ofQFD can be determined.

• To apply the FMEA method to identify the risk in the product's design and manufacturingprocess.

1.5 SCOPE AND LIMITATION OF THE STUDY

As a laptop, the quality and reliability of my components and assembly are critical to my abilityto perform well for my users. That's why the implementation of Failure Modes and Effects Analysis (FMEA) and Quality Function Deployment (QFD) is so important. Now, there is the scope of this study is to use both methods jointly in a laptop production plant, with the goal of identifying and prioritizing customer needs and requirements, while also identifying and analyzing potential failures in the production process. This study will likely involve a detailed analysis of the production process, with the hopes of improving quality and reducing potential risks. By combining these methods, the researchers hope to ensure that I, as a laptop, am made with the highest quality materials and manufacturing processes possible. This study could have important implications for my future production, as well as for the satisfaction of my users.

Ultimately, the success of this study will be measured by how well it helps to improve thequality, reliability, and overall performance of laptops like me.

There are a few different strategies and technologies that are planned for implementation. However, in order to accommodate the limits, certain strategies were not put into action. Theserestricted spheres of investigation are investigated further in this section.

• **SERVEQUAL:** which stands for "service quality gap model," is a gap approach for measuringthe quality of service that managers in a variety of fields can employ. This method can be appliedto a variety of various types of services. The primary objective of this model is to determine where there are discrepancies between the things that consumers expect and the things that are actually given at various phases of the service delivery process. When it comes to obtaining the WHATs in the first phase of QFD, this is a very effective strategy that may be applied.

But regrettably, putting this strategy into practice takes a lot of time. This calls for a significant number of surveys. Another restriction is that this form utilizes a variety of QFD approaches, but the one addressed in this study is restricted to product and process design QFD.

• **WASPAS:** The weighted aggregated sum product assessment approach, often known as WASPAS, is a fantastic combination of the weighted sum model (WSM) and the weighted product model (WPM). Because it is straightforward mathematically and provides more precise findings than WSM and WPM, it is currently widely acknowledged as an efficient instrument for decision-making. This is an efficient strategy for MCDM that takes into consideration a wide variety of factors inorder to locate the most suitable choices.

Because of one limitation, this subject wasn't covered in the study that I'm referring to. That being said, a practical field visit is absolutely necessary in order to gather all of the availableoptions. Additional research into this subject might be the solution to this problem.

• **Failure Mode and Effects Analysis (FMEA):** Since FMEA is an assessment tool, it can only identify the risk; it cannot reduce the risk. Due to the fact that it is not a static model, the FMEA needs to be updated on a regular basis if new failure modes are found. Along with the FMEA, there must also be the integration of other approaches in order to reach the product improvement aim. To improve a product's quality, it is possible to integrate FMEA with a wide variety of tools, including QFD, Fuzzy QFD, Ishikawa Diagram, Pareto Analysis, RCA, FTA, IP, CM, and others. Only the QFD process will be connected with the FMEA for this project. Because QFD and the FMEA are both time-consuming approaches, the FMEA is not integrated with any other methodsused to improve this project.

1.6 METHODOLOGY OF THE STUDY

To effectively implement the case study and complete it on time with quality results, technique, and working stage planning is crucial. This project is divided into many phases:

1. Literature Review

Reading all published books, journals, conference proceedings, articles, and information on the internet is the initial step in conducting research on the implementation of the pertinent QFD and FMEA. History, QFD and FMEA procedures, tools and methodology, and other pertinent tools and information can all be collected throughout the study and used as the case study's guidelines.

2. Visit to a Production Plant:

In this study, the authors conducted a visit to a laptop assembly industry known as Telephone Shilpa Sangstha Ltd. (TSS). The nomenclature assigned to the subject of investigation is "Doel Laptop". The TSS is a governmental entity that is primarily recognized for its production of telephone devices. In addition to its primary product offerings, the company also engages in the production of laptops, desktops, PBX systems, digital energy meters, and other related products.This research will solely rely on the utilization of their personal computer. Examination of a particular instance or example is typically conducted for the purpose of illustrating a principle ortheory in a specific field of study.

1. Case Study

The present investigation concerns the utilization of primarily two instruments. Quality Function Deployment (QFD) and Failure Mode and Effects Analysis (FMEA) are two commonly used tools in the field of quality management. The Quality Function Deployment (QFD) methodologyinvolves the application of four distinct phases, while the Failure Mode and Effects Analysis (FMEA) methodology involves the application of two distinct types. Two commonly used methodologies in risk management are PFMEA and DFMEA. Furthermore, the present study will employ a Multi-Criteria Decision Making (MCDM) technique, specifically the Step-wise Weight Assessment Ratio Analysis (SWARA), to determine the ultimate weight of Quality Function Deployment (QFD).

2. Interview with the individual in charge

Conducting an interview with the individual in a position of an authority constituted a significant aspect of this study. The duty person has provided the qualitative data that has been collected. In this study, the individual responsible for the task was identified as Mr. Md. AK Azad, who holds the position of Junior Assistant Manager (Laptop) at Telephone Shilpa Sangstha Limited (TSS).

3. The framework of the Research

The research has been structured in a way that will guarantee its early completion and a seamlessprocess overall.

4. Data Collection

Practical data collection is the first and foremost part in order to achieve the aim properly. Three types of data are required. Those are customers' requirements, technical specifications of products, and a list of the relevant manufacturing process.

5. Data Analysis

QFD Phase One: QFD phase one consists of customers' needs as WHATs and technical specifications as HOWs. Once the WHATs are collected, the implementation of the SWARA method is good to give the final weight for QFD. QFD phase one will be applied after the collection of WHATs, HOWs, and final weight.

QFD Phase Two: The WHATs of phase one will be how in this phase and HOWs will be the further classification of the technical specification of that product. The rest of the procedure isthe same as phase one.

QFD Phase Three: To get further tasks and decisions we are required to have phase three of QFD. So, similar operations need to be done in phases one and two. This time the HOWs will be manufacturing processes that are related to product design.

QFD Phase Four: This phase will be requiring FMEA to be done. Because FMEA will give the HOWs for this particular phase of QFD. Also, every phase is required the final weight of WHATs. So, the SWARA method is mandatory to apply in every phase.

FMEA: After QFD phase four, we will determine all the process steps that need to be modified most. By using the Process FMEA method, the risks will be identified that occur during the manufacturing process. After that, the failures in the existing product's design will be identified to make a new design by applying corrective actions.

This component of the approach has a flowchart that outlines the work's procedure in detail. In addition, a Gantt chart is provided to provide a clear picture of our anticipated job progress.

1.7 CONTRIBUTION OF THE STUDY

The integration of QFD and FMEA methods helps us to achieve the following benefits:

- Enhanced dependability and quality of products and processes; Satisfaction GuaranteedService Designs;
- QFD's rough implementation at the first stage of production allows for better demand management and more efficient resource allocation.
- Efforts made to keep production costs down. Due to the elimination of unnecessary steps in the design and delivery of services, the company's bottom line benefits. The early detection of high-risk areas through quality checks means less iteration on the design.
- Focus on the next step of production to adopt FMEA and prioritize fixing any product or process flaws found.
- Increased reliability in quality assurance planning and expanded opportunity for game- changing innovation by capitalizing on institutional wisdom.
- Improved customer satisfaction

1.8 ARRANGEMENT OF THE STUDY

Five chapters make up this study report, according to the authors:

1. Introduction:

This chapter can be used to generate a broad notion. The aim of the research, or why it is required, was made plain in this chapter. This page does not provide any procedural details. But the reader will have a thorough understanding and the right amount of desire to read the next parts of this essay.

2. Literature analysis

Three different methods have been combined. MCDM, QFD, and FMEA. Knowing about all of these approaches, their uses, their histories, and their significance in this research is made easier by Chapter 2, which is the literature review. Additionally, this chapter aims to provide a brief overview of earlier research in this area, along with its limitations, conclusions, and subjects thatwere considered for this study.

3. Research Methodology and Design:

These might serve as an overview of Chapter 4. In Chapter 4, a thorough examination has been completed. But Chapter 3 went over each step in brief descriptions with illustrations. In order for the reader to find nothing confusing while moving on to the following chapter.

4. Information gathering and analysis:

This is the true thesis. Data, analysis, and presentation abound in this chapter, which concludes with a discussion. Here, each QFD process is explained in depth. Plotted graphs, pie charts, column charts, tables, and figures have simplified reading and facilitated decision-making for the industrial plant's authorities. Similarly, two different forms of FMEA are also skillfully illustrated here. Using QFD with FMEA was one of the project's goals, and in this chapter, the link betweenthese two frequently used tools is explained.

5. Conclusion:

After each of these chapters was a success, the final chapter—the conclusion—came. As thename implies, a correct conclusion is offered here.

CHAPTER 2
LITERATURE REVIEW

2.1 INTRODUCTION

This chapter provides a comprehensive literature review of QFD and FMEA, focusing on their history, development, and application. The chapter starts with an overview of QFD. It then discusses the origins and development of QFD and FMEA and their underlying principles and methodologies. The literature review covers both theoretical and practical aspects of QFD and FMEA, including case studies and examples of their implementation in different industries.

The chapter also explores the benefits and limitations of QFD and FMEA and their impact on product and process development. It examines the challenges and barriers to implementing QFD and FMEA, including the need for specialized training and expertise and the potential limitations of the methodologies in certain applications. The review concludes with a summary of the current state of research on QFD and FMEA and identifies fields for future study and development.

Overall, the literature review chapter provides a short overview of QFD and FMEA, highlighting their importance and effectiveness in improving quality and customer satisfaction in product and process development. The chapter will serve as a valuable source for researchers and practitioners who are interested in understanding and also applying QFD and FMEA in their work.

2.2 QUALITY FUNCTION DEPLOYMENT (QFD)

A methodical strategy for product design and development, QFD (Quality Function Deployment)is centered on satisfying customer needs and expectations. It is a cross-functional process that incorporates a number of organizational areas, including production, marketing, and engineering. Customer needs and expectations are prioritized while developing products using the customer- focused methodology, or QFD. QFD can result in higher-quality goods and increased customer satisfaction by coordinating consumer requirements with technical requirements and manufacturing procedures.

2.2.1 HISTORY OF QFD

The Quality Function Deployment (QFD) methodology was created by Yoji Akao, a quality engineer at Mitsubishi Electric, in Japan in the late 1960s. The technique was initially employed in the creation of new goods, and after being embraced by a large number of Japanese businesses, notably Toyota and Sony, it has subsequently gained widespread use around the globe. In response to the growing complexity of product design and the requirement to make surethat customer needs were taken into consideration during the design process, QFD was developed. The methodology was created to offer an organized way of comprehending consumer wants and converting them into particular specifications for product design. At Mitsubishi Electric, Dr. Akao and his colleagues created the first QFD matrix in 1972. The matrix, which is still extensively used today, is a tool for determining the connections between certain design aspects and customer requirements. The matrix is organized around a number of "houses," each of which stands for a distinct phase of the design process. The matrix is used to discover the most important client requirements, rank each requirement according to priority, and create a set of design guidelines that will satisfy those requirements. QFD rose to prominence in the 1980s inthe US, when it was adopted by organizations like Ford and Xerox. Many businesses in Europe and Asia adopted QFD in the 1990s, and it was utilized in a variety of sectors, including automotive, electronics, and healthcare. Today, QFD is still a well-liked technique for product design and quality improvement. Its applications have been broadened to encompass service design, software development, and strategic planning. As a potent instrument for raising customer satisfaction, cutting expenses, and stimulating innovation, QFD is now generally acknowledged. The "customer journey map" and "affinity diagrams" are two new tools and methodologies that have been incorporated into the QFD process throughout time. These resources aid in the further elaboration of design elements and customer requirements, ensuring that the finished product satisfies those requirements. QFD is an effective methodology for raising customer happiness, cutting expenses, and stimulating innovation overall. Companies all over the world utilize it as a tool for product development and design in order to enhance their goods and services.

2.2.2 FOUR PHASES OF QFD

There are four basic phases of QFD, and each has its own set of tasks and outcomes. We shall outline the four QFD phases and their main tasks in this response.

Phase 1: Product Planning

The planning of products is the first stage of QFD. The team defines the needs and requirementsof the customer during this phase and converts them into precise design features. The following tasks are included in this phase:

- Voice of the Customer (VOC) Analysis: It is a crucial phase in the QFD process. Customers are asked about their requirements and expectations, and the team records thisinformation. You can gather this data via surveys, focus groups, or other research techniques.
- Customer Requirements: The team determines and ranks the customer requirements aftercollecting the VOC. The remainder of the QFD process is built on these needs.
- Technical Requirements: The team determines the technical requirements necessary to satisfy the customer's expectations in this step. Specifications for the materials, production procedures, and other design elements are part of these technical requirements.
- Product Planning Matrix: It is commonly referred to as the "House of Quality." Theconsumer requirements and technical requirements are mapped out in this matrix.

Phase 2: Product Design

The product design phase of QFD is the second. The group creates a product design that complies with the technical requirements and client requirements at this phase. The followingtasks are included in this phase:

- Concept generation: The group comes up with and assesses design concepts in accordance with the demands of the client and the technical requirements.

- Comprehensive Design: Following the selection of the design concept, the team creates a comprehensive design that contains details regarding the materials, manufacturing procedures, and other design elements.
- Design Review: The team examines the design to make sure it complies with thetechnical requirements and client expectations.

Phase 3: Process planning

The process planning stage of QFD is the third. The team creates a manufacturing method in thisstage to produce the product with the desired quality and cost. The following tasks are included in this phase:

- Process Design: The group creates the manufacturing process, which takes into account the necessary tools, machinery, and other aspects of production.
- Process Review: To verify that the product can be produced at the desired quality andcost, the team examines the production process.

Phase 4: Production and quality control

Production and quality control make up the fourth and final step of QFD. During this stage, the team creates the product and puts quality control procedures in place to guarantee that it complies with technical standards and client requirements. The following tasks are included in this phase:

- Production: Using the manufacturing technique created in Phase 3, the team creates theproduct.
- Quality Control: Inspections and testing are used by the team as quality control procedures to make sure the product satisfies client demands and technical standards.
- Continuous Improvement: The team seeks for chances for improvement and makesadjustments to enhance the final product and the manufacturing procedure.

The four key stages of QFD are process planning, product planning, product design, and manufacturing and quality control. The team may translate client demands and specifications into a high-quality product that fulfills customer expectations by completing a certain set of activities and deliverables during each phase.

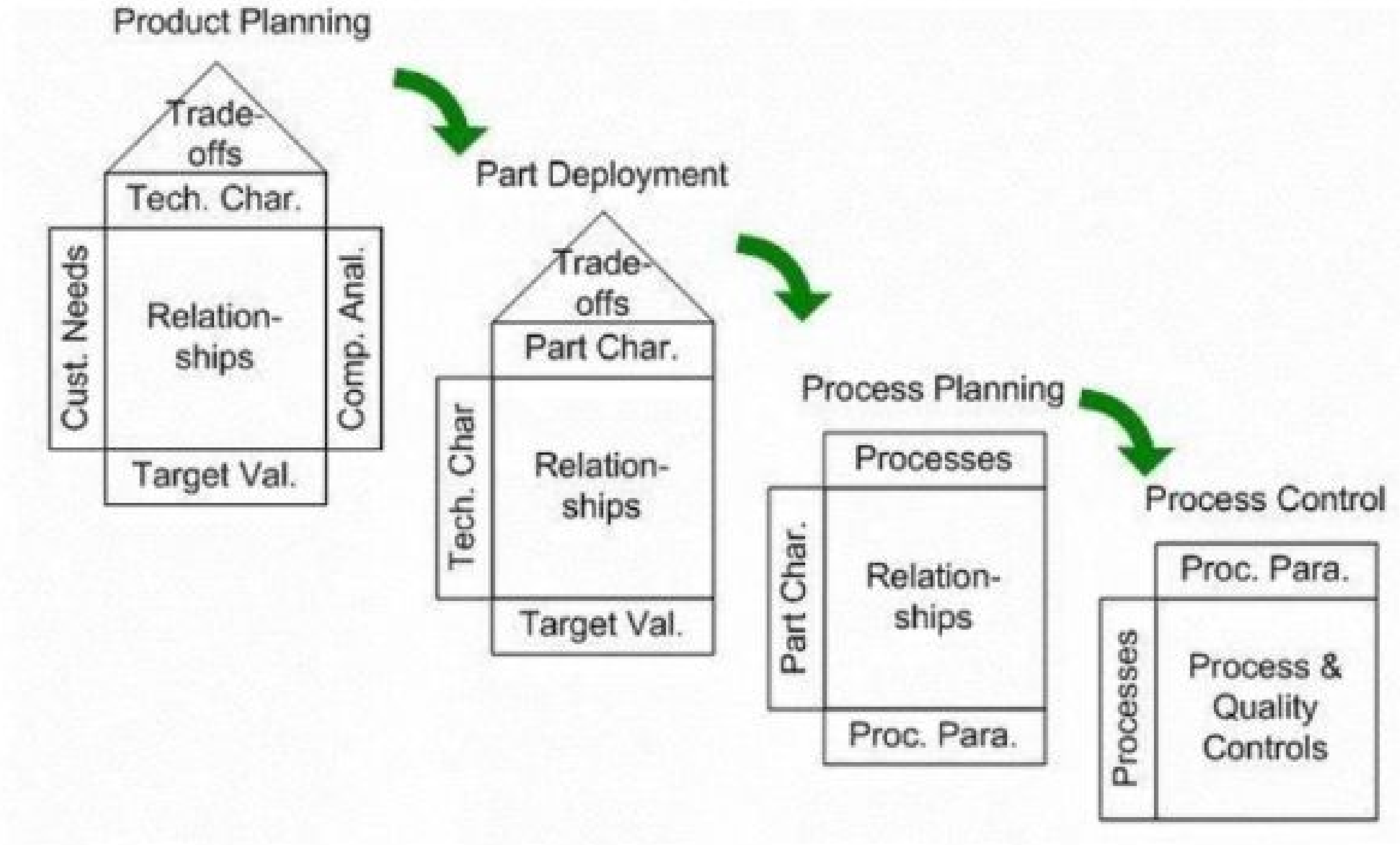


Figure 2. 1 Four phases of QFD sequential **[4]**

2.2.2.1 HOUSE OF QUALITY (HOQ)

A crucial component in the Quality Function Deployment (QFD) process is the House of Quality(HOQ). A matrix called the HOQ can be used to determine how consumer needs and technical specifications for a good or service are related to one another.

The following elements make up the House of Quality matrix:

- Customer requirements (WHATS): This is a list of what the customer wants or requiresfrom the good or service. Typically, these demands are discovered through market analysis or client feedback.

- Technical Specifications (HOWs): These are a list of the characteristics or technical criteria that a product or service must have in order to satisfy the needs of the customer.
- Relationship Matrix: This diagram illustrates the connection between technical needs and customer requirements. It is beneficial to determine which technological requirements arecrucial for satisfying the expectations of the consumer.
- Importance Rating: Each technical need is given weight or priority according to howcrucial it is to satisfy the needs of the customer.
- Technical Competitive Evaluations: the competitive assessment measures how well theproduct or service satisfies client needs.
- Planning Matrix: Based on the HOQ analysis, this describes specific steps that can beperformed to improve the good or service.

The HOQ is a visual tool that aids in prioritizing technical requirements according to how crucialthey are to satisfy the needs of the client. A team can use the HOQ to determine the most important technical requirements and prioritize their work to make sure the product or service satisfies the expectations of the client. Additionally, it serves as a foundation for ongoing improvement because the team can utilize the HOQ to track advancement and spot areas in need of improvement.

2.2.2.2 HOQ CONSTRUCTION

HOQ is constructed in six stages. The following are the six steps in creating a HOQ:

- Voice of the Customer (VOC) - Gathering information on the requirements and desires of the customer is the first step in the HOQ. Surveys, focus groups, and other types of market research can be used to accomplish this.
- Determine Technical Requirements - The technical requirements required to satisfy the customer's expectations are determined based on the VOC data. The engineering and design teams often come up with these technological needs.

- Correlate Customer and Technical needs: The third step entails comparing Customer and Technical needs. Which technical needs required to fulfill each client's needs are determined by the design and engineering teams.
- Assign importance ratings – At this stage, both technical and customer needs are given weights. This entails assigning a value to each requirement's significance in satisfying consumer wants. It is possible to rate these on a scale of 1 to 5 or 1 to 10.
- Assess Competitors - The fifth step involves assessing market competitors to ascertain their strengths and shortcomings. This aids in locating areas where the business may strengthen itself to get a competitive edge.
- Create an Action Plan - An action plan is created based on the data acquired in the earlier steps. This strategy is used by the design and engineering teams to improve current products or create new ones that better serve customers.

Companies can create and develop goods that suit client wants while also getting a competitive advantage in the market by following these six processes. The HOQ offers a structured method for improving quality and developing new products, assisting in keeping the needs of the client atthe forefront of the procedure.

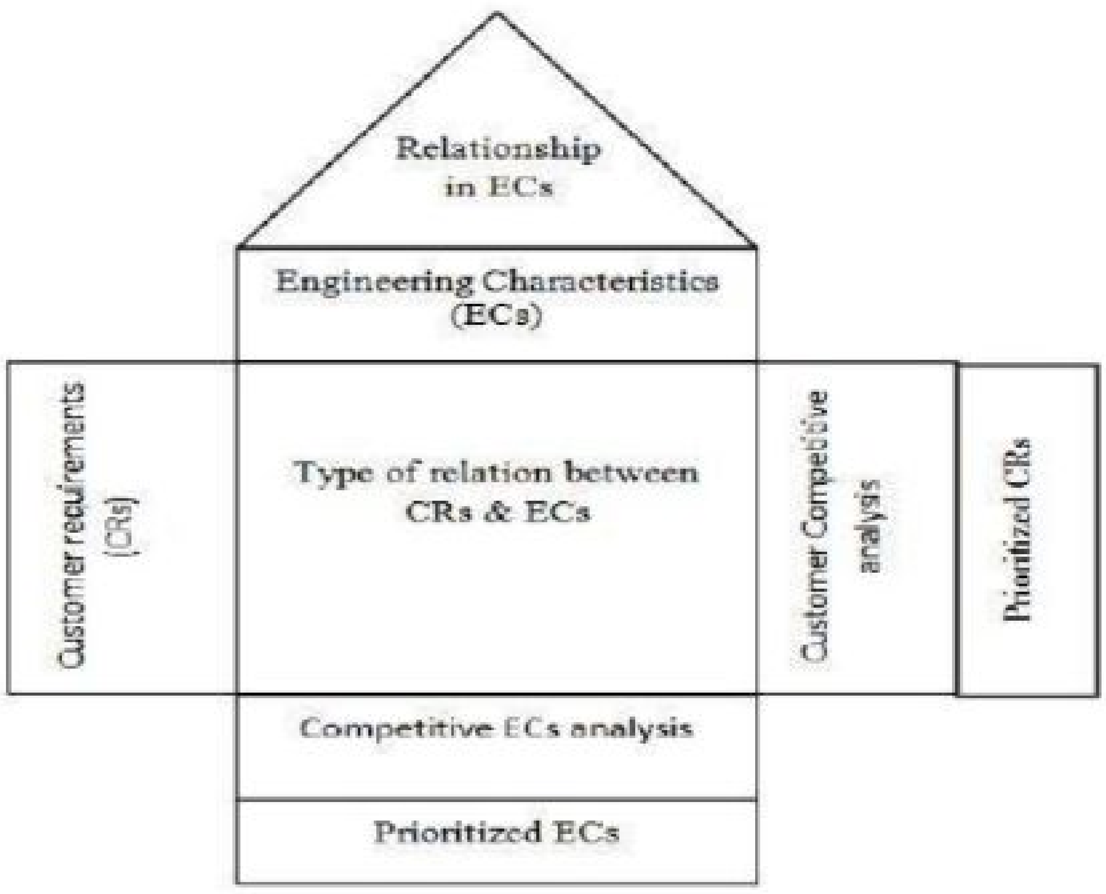


Figure 2. 2 Construction of HOQ **[8]**

2.2.3 OBJECTIVE OF QFD

The following are the main goals of applying the QFD:

- Recognize and satisfy customer needs: Understanding customer wants and converting them into technical specifications that may be used to design products is QFD's main goal.
- Determine client segments: QFD aids in determining various customer segments and thedemands of each.
- Develop products that satisfy client demands: QFD supports the creation of products thatsatisfy or beyond customer demands.
- Reduce time-to-market: By putting the demands of the consumer first from the beginning, QFD helps to shorten the time it takes to introduce new products to themarket.
- Enhance product quality: QFD contributes to product improvement and defect reductionby concentrating on client needs.
- Improved Customer satisfaction: Customer satisfaction is increased by QFD by providing them with items that either meet or surpass their expectations.
- Improve communication: Improve departmental communication by assembling cross- functional teams to work on product development. QFD facilitates departmental communication by doing this.
- Boost teamwork: QFD encourages teamwork by including participants from all departments in the product development process.
- Enhance decision-making: QFD supports decision-making by offering a structured, customer-centered approach to product development.
- Boost innovation: QFD promotes creativity and aids in the generation of fresh productconcepts by concentrating on client needs.
- Spend less: QFD saves money by preventing the need for costly redesigns later in theproduct development cycle.
- Enhance competitiveness: QFD aids in enhancing a company's

marketability by ensuring that products are delivered that either meet or surpass client expectations.

2.2.4 BENEFITS AND DRAWBACKS OF QFD IMPLEMENTATION

Benefits of Implementing QFD are:

- Customer Focus: The application of QFD makes certain that the requirements and expectations of the customer are the main focus of the design process, which increasescustomer satisfaction.
- Efficiency Gains: QFD adoption offers a structured design process that helps shortendevelopment times and expenses.
- Improved Communication: QFD implementation fosters communication and collaboration between all organizational departments, ensuring that everyone is strivingfor the same objective.
- Better Decision Making: QFD implementation offers a framework for data-driven decision-making based on client needs and preferences, as opposed to gut feeling orconjecture.
- Competitive advantage: The application of QFD can assist in setting an organization's products apart from those of its rivals, resulting in a competitive advantage.

Drawbacks of QFD Implementation

- Time-consuming: Cross-functional teams may need to put in a lot of time and effortduring the QFD process.
- Complexity: QFD can be challenging to adopt for organizations with limited resources because it calls for specialized training and can be complicated.
- Incomplete Data: QFD calls for consumer requirements and preferences data, which isoccasionally unavailable or could be insufficient.
- Misaligned Priorities: It may be difficult to reach a QFD agreement on how to rankcustomer needs and design requirements.
- Resistance to Change: Employees who are not accustomed to a data-

driven approach or who believe that the conventional procedures are enough may oppose the introduction ofQFD.

In conclusion, implementing QFD can have a number of advantages, including better decision- making, enhanced efficiency, and a stronger emphasis on the client. However, it can also be difficult and time-consuming, call for specialized training, and encounter resistance from staff members.

2.3 SWARA METHOD

A multi-criteria decision-making approach called SWARA (Step-wise Weight Assessment Ratio Analysis) was created as an alternative to multi-criteria decision-making processes now in use, such as the Analytic Hierarchy Process (AHP), which can be labor-intensive and complicated. The foundation of SWARA is the pairwise comparisons principle, which compares decision criteria in pairs to evaluate their relative relevance. This is one of the application tools of the MCDM (Multi-Criteria Decision Making) method. The method, which is intended to be straightforward and user-friendly while still producing accurate and dependable results, employsa step-by-step procedure to establish the weights of choice criteria. Several industries, including engineering, management, and healthcare, have used SWARA. Among other applications, it has been used to make choices about resource allocation in the healthcare industry, project prioritization, supplier selection, and product design. Overall, SWARA is still a topic of ongoingresearch and development because it is a relatively new and creative method for multi-criteria decision-making.

2.3.1 HISTORY OF SWARA

SWARA stands for "Step-wise Weight Assessment Ratio Analysis," a technique developed in 2014 by Polish neurologist Dr. Przemyslaw M. Kosowski. It's a method for evaluating alternatives and deciding which to pursue first.

Engineering, business, and the social sciences are just a few of the areas where the SWARA technique has been put to use. It has received high marks for being both user-friendly and capable of accommodating a wide range of criteria and settings. It has, however, been criticized for depending too heavily on the opinions of those making the decisions.

2.3.2 SWARA PROCEDURE

The Step-wise Weight Assessment Ratio Analysis (SWARA) process consists of the followingsteps:

- Identify the problem: Clearly defining the decision-making issue and the desiredoutcomes is the first step in solving it.
- Define the criteria: Decide on the standards by which the options will be assessed.Criteria must be quantifiable, pertinent, and reflect the decision-making process.
- Pairwise comparison: To evaluate the relative importance of the criteria, compare them inpairs. This is accomplished by comparing each criterion to every other criterion and giving each comparison a score based on the significance of the comparison.
- Ratio weights: Divide the sum of the scores each criterion earned in pairwise comparisons by the total score to determine the ratio weights for each criterion.
- Normalization: Make the ratio weights equal 1 by normalizing them.
- Analyze the alternatives: Use a numerical rating system to evaluate each option in lightof the criteria.
- Weighted score: Multiply the ratings for each criterion by the associated weight before adding the results to determine the weighted score for each choice.
- Ranking: Determine the option with the highest weighted score by ranking thealternatives.

It is crucial to remember that the accuracy of the pairwise comparisons and the numerical scores given to each criterion affect the accuracy of the SWARA technique. To guarantee that the assessments are accurate and thorough, it is essential to include specialists or stakeholders in the decision-making process.

2.3.3 OBJECTIVES OF SWARA

The basic goal of SWARA (Step-wise Weight Assessment Ratio Analysis) is to offer a more straightforward method for making multi-criteria decisions. SWARA specifically seeks to:

- Provide a methodical approach for weighing and ranking options according to variouscriteria.
- Simplifying the evaluation process will decrease the complexity and time needed formulti-criteria decision-making.
- Provide decision-makers the ability to assess a variety of factors appropriately dependingon their relative relevance.
- Provide decision-makers with an approach that takes a variety of aspects intoconsideration and is accurate and trustworthy.
- Encourage stakeholder involvement in the decision-making process to guarantee that allpertinent points of view are taken into account.

2.3.4 BENEFITS OF SWARA

The benefits of the SWARA method are:

- Simplicity: SWARA is a straightforward and user-friendly strategy that doesn't requiresubstantial training or decision-making experience.
- Flexibility: SWARA can be used to solve a variety of decision-making issues, includingcomplicated ones involving a lot of criteria.
- Transparency: SWARA makes the process more open and clear by allowing decision-makers to see how the final rankings were arrived at.
- Consistency: SWARA offers a methodical and uniform approach to decision-making that makes sure all factors are taken into account properly.
- Participation of stakeholders: SWARA enables stakeholder involvement in the decision-making process, ensuring that all pertinent viewpoints are taken into account.
- Saving time: Because SWARA does not involve considerable data

collecting or analysis,it is a relatively quick way for making decisions.

- Accuracy: When pairwise comparisons and numerical ratings are performed appropriately, SWARA generates accurate and trustworthy findings.

2.4 FAILURE MODE AND EFFECT ANALYSIS (FMEA)

A methodical approach called FMEA (Failure Mode and Effects Analysis) is used to spot probable flaws or faults in a product or process before they happen. It is a proactive risk management technique that aids businesses in spotting potential flaws or breakdowns and fixingthem before they hurt or disrupt operations.

A cross-functional team from many organizational areas, including design, engineering, quality, and production, participates in the FMEA process. Together, the team analyses potential flaws or failure modes to determine how they might affect the final product or manufacturing procedure.

2.4.1 HISTORY OF FMEA

Failure Mode and Effects Analysis (FMEA) is a tool for risk management that has been used in awide variety of industries to identify and mitigate potential failures in goods, processes, and systems. FMEA was developed in the 1970s. The origins of FMEA can be traced back to the middle of the 20th century, and since that time, it has developed into an integral component of quality management and risk assessment in a variety of different industries. The first time that the Failure Mode and Effects Analysis (FMEA) technique was used was in the 1940s, when the United States military was working on developing its first ballistic missile systems. At the time, engineers were having difficulty building missile systems that were dependable and safe, as wellas ones that could survive the stresses of flight and warfare. In order to address these problems, they devised a way to identify and prevent probable failures in the systems before they occurred. This method also included mitigation strategies. This technique was improved over time and eventually came to be known as FMEA. In the 1960s, the automobile industry started using FMEA as a tool to help improve product quality and reliability. FMEA was initially adopted in the United States. The Ford Motor Company was one of the pioneers in the application of FMEAto a significant degree in the process of new product development. As a result of the publishing of the QS-9000 standard in the 1980s, FMEA was eventually made into a requirement that was legally binding for all automotive suppliers. Over the course of time, FMEA has been adopted bya variety of other industries, including the aerospace industry, the healthcare industry, and the manufacturing industry. FMEA is used to identify possible risks in clinical processes in the healthcare sector, but in the manufacturing industry, it is used to identify and mitigate potential failures in production processes. In the healthcare industry, FMEA is used to identify potential risks in clinical processes. In the late 1980s, FMEA was improved such that it could account for a wider variety of risks and not simply those that were caused by technical failures. This resulted in the development of a methodology known as Failure Mode, Effects, and Criticality Analysis (FMECA), which broadened the scope of FMEA by include an analysis of the degree to which each failure mode was catastrophic. The automobile industry started utilizing Design Failure Mode and Effects Analysis (DFMEA) and Process Failure Mode and Effects Analysis (PFMEA) in the 1990s to identify and manage risks in product design as well as production processes. The DFMEA examines the risks associated with the product's design, while the PFMEA investigates the risks associated with the manufacturing process. Today, FMEA is an essential technique in many industries for detecting and managing potential risks in goods, processes, and systems.

This is accomplished through the analysis of failure modes, effects, and modes of failure. It hasdeveloped over the course of time into a method to risk assessment that is structured and systematic, and it is generally acknowledged as an essential component of quality managementsystems.

2.4.2 TYPES OF FMEA

Design FMEA (DFMEA), Process FMEA (PFMEA), System FMEA (SyFMEA), and ServiceFMEA (SFMEA) are the four primary types of FMEA.

Design FMEA (DFMEA)

A product's design phase uses DFMEA to spot possible issues and address them before they become problems. DFMEA is used to make sure that a product is reliable, safe to use, and that it complies with design criteria and customer expectations. A cross- functional team composed of designers, engineers, quality experts, and other stakeholdersoften performs DFMEA.

DFMEA involves a number of phases, including:

i) The team examines potential failure modes, or ways in which the product mightfail to satisfy design requirements or customer demands.

ii) Establish the seriousness of each failure mode: The team assesses the potential effects of each failure mode on the user or the product and rates the seriousness of each failure mode in accordance with the failure's repercussions.

iii) Establish the propensity for each failure mode to occur: The team assesses the propensity for each failure mode to occur based on the design elements and the environment in which the product will be utilized and then rates the likelihood ofoccurrence.

iv) Assess the ability to identify each failure mode: The team assesses the capability of identifying each failure mode, either through testing or inspection, and assignsa rating based on the probability of detection.

v) Calculate the Risk Priority Number (RPN): The team multiplies the severity, likelihood, and detection ratings to arrive at the RPN for each failure mode.

vi) Create and rank action plans: The team creates action plans to mitigate the worst RPN failure modes and ranks them according to how serious and likely they are tooccur.

PFMEA (Process FMEA)

PFMEA is used in the production process to spot possible issues and address them before they become problems. PFMEA is used to make sure that the production process is dependable, effective, and able to provide items of superior quality. A cross-functional team composed of production engineers, quality experts, and other stakeholders often performs PFMEA.

There are multiple steps in PFMEA, including:

i) Identify potential failure modes: The team identifies potential failure modes—or ways in which the production process could fail to create high-quality products—in the first step.

ii) Establish the seriousness of each failure mode: The team assesses the probable effects of each failure mode on the product and rates the seriousness of the failurebased on its repercussions.

iii) Assign a rating based on the probability of occurrence for each failure mode after evaluating the possibility of each failure mode occurring in light of the productionprocess and the environment in which it occurs.

iv) Assess the ability to identify each failure mode: The team assesses the capability of identifying each failure mode, either through testing or inspection, and assignsa rating based on the probability of detection.

v) Calculate the Risk Priority Number (RPN): The team multiplies the severity, likelihood, and detection ratings to arrive at the RPN for each failure mode.

vi) Create and rank action plans: The team creates action plans to mitigate the worst RPN failure modes and ranks them according to how serious and likely they are tooccur.

Service FMEA (SFMEA):

To discover and assess any flaws in the service delivery process, FMEA is a type of FMEA utilized in service sectors including healthcare and banking. The goal of SFMEA is to guarantee that the service satisfies the needs and expectations of the customer and offers a positive experience. A cross-functional team analyses the service delivery process, identifies potential failure modes, and assesses their seriousness, likelihood, anddetection as part of the SFMEA process. The group then creates and puts into effect necessary measures to reduce the risks connected to likely failure modes.

System FMEA (SyFMEA):

System FMEA is a subset of FMEA that is used to discover and assess probable failures in complex systems like computers, cars, and airplanes. SyFMEA seeks to guarantee that the system satisfies the needs and expectations of the consumer and offers a secure and dependable experience. A cross-functional team is involved in SyFMEA, which examines the system design and architecture, identifies probable failure modes, and assesses the likelihood, severity, and detection of each. The group then creates and puts into effect necessary measures to reduce the risks connected to likely failure modes.

2.4.3 FMEA PROCEDURES

The general steps involved in conducting an FMEA are as follows:

Define the scope and objectives of the FMEA: Defining the scope and objectives of the analysis is the first stage in the FMEA process. This includes identifying the process or product to be studied, the study's goal, and the participants in the study.
Create the team: For the FMEA, a cross-functional team should be put together. Experts from many fields, including as design, engineering, production, quality, and safety, should be on the team. The team members should be knowledgeable and skilled in the process or product being studied.

Identify the failure modes: The team should list every potential failure mode that could happen to the product or analysis process. A failure mode is the method by which a process or product can fall short of the desired performance standards or requirements.
Determine the potential impacts of failure: The team should determine the potential effects of failure for each failure mode they have identified. This includes the negative effects of the failure, such as displeased customers, safety risks, slowed output, and higher expenses.

Assign severity ratings: The group should give each potential failure effect a severity rating. The impact of a failure on the client or process user is referred to as severity. On ascale of 1 to 10, with 10 being the most severe, severity ratings can be given.

Finding the causes of failure: For each failure mode, the team should determine the possible causes of failure. This includes figuring out the aspects of the design, operation,or system that might contribute to the failure mode.

Assign occurrence rankings: The group should give each potential reason for failure an occurrence ranking. The probability or frequency of the cause of failure occurring is known as the occurrence. Rankings of occurrences can be determined on a scale of 1 to 10, with 10 being the most common.

Determine the current controls: The team should determine the current safeguards or precautions taken to avoid or catch the failure mode. This involves controls in the design,process, or system that are meant to stop or identify possible failure.

Assign detection rankings: The team needs to give each current control or measurement adetection ranking. The ability of the control or measure to identify a potential failure mode before it affects the customer or user is known as detection. On a scale of 1 to 10, with 10 being the most effective, detection rankings can be given.

Identify each failure mode's risk priority number (RPN): The team needs to identify each failure mode's risk priority number (RPN). The RPN yields a number that represents the overall risk connected to a failure mode and is a result of severity, occurrence, and detection rankings.

Set priorities for the activities: The team should set priorities for the actions to be taken to address the probable failure modes based on the RPN values. Redesigning the product or process, enhancing the current controls or measures, or introducing new controls or measures are some examples of possible options.

Implement the actions: After they have been prioritized, the actions need to be carried outpromptly. To guarantee that the intended results are obtained, the team should keep an eye on the effectiveness of the actions and make any required adjustments.
In conclusion, FMEA is a potent instrument for spotting and analyzing potential flaws or faults in a product or process, as well as for putting in place efficient checks or safeguards to avoid or lessen those flaws.

Table 2. 1 Severity, occurrence, and detection guidelines for FMEA

Rank	Severity (S)		Occurrence (O)		Detection (D)	
	Effect	Criteria	Effect	Criteria	Effect	Criteria
10	Hazardous	Hazardous effect	Almost certain	Failure almost certain	Almost impossible	No known techniques
9	Serious	Very high	Very high	Likely very high number of failures	Remote	Unproven technique
8	Extreme	Customer very dissatisfied	High	Likel yhigh number	Very slight	Providing durability test
7	Major	Customer dissatisfied	Moderately high	Likely moderate high number of failures	Slight	Test on products with prototypes
6	Significant	Customer experiences some discomfort	Medium	Likely medium number of failures	Low	Test on similar system
5	Moderate	Customer experiences some dissatisfa	Low	Likely occasional	Medium	Test on preproduction system

		ction		numb er of failur es		
4	Minor	Customer experienc es minor nuisance	Slight	Likel y few failur es	Moderately high	Test on early prototype
3	Slight	Customer slightly annoyed	Very slight	Likel y very few failur es	High	Modeling in early stage
2	Very Slight	Customer not annoyed	Remote	Rare numb er of failur es	Very high	Proven computer analysis
1	No	No effect	Almost never	No failur es	Almost never	Proven detection methods available

Table 2. 2 FMEA Template

Failure Mode and Effects Analysis (**FMEA)**

Item: Laptop

Functions/ Process steps	Potential FailureMode	Potential Effects of Failure	SEVERITY	RANK	Potential Causes /	Current Process	OCCURRENCE		DETECTION	RPN	Recommended Actions	Responsibility & Target	Actions Taken	SEVERITY	OCCURENCE	DETECTION	RPN

2.4.4 OBJECTIVES OF FMEA

The FMEA's objectives can be summed up as follows:

1. Finding potential failure modes or mistakes in a process or product and evaluating their seriousness, frequency, and likelihood of happening are the main goals of an FMEA.
2. The impact of the failure on the system, the severity of the failure, and the possibility that the failure will occur are taken into account by FMEA to help assess the risk associated with each conceivable failure mode.
3. Prioritizing risks according to their gravity, frequency, and possibility of happening is made easier with the aid of FMEA. This enables

businesses to concentrate their efforts on resolving the most pressing threats first.

4. FMEA aids in the development of plans to reduce or eliminate risks after they have been identified and prioritized. To avoid failure, this may entail rethinking a process or a product, altering a technique, or putting in place new controls.
5. FMEA is a continuous improvement tool, which means that it is used to spot possible issues and deal with them continuously. This aids businesses in raising the caliber of their output while lowering the possibility of failing in the long run.

2.4.5 BENEFITS OF FMEA

Some of the main advantages of FMEA include:

1. Early failure detection: FMEA enables organizations to spot potential errors or problems in a procedure or product before they happen. This enables businesses to take preventative action to avoid failures and their related costs.
2. Cost reduction: FMEA can assist organizations in cutting costs related to rework, scrap, warranty claims, and other types of waste by identifying and correcting probable problems early on.
3. Better product quality: FMEA aids businesses in identifying and addressing potential flaws that can affect the caliber of their output. As a result, the organization's reputation is enhanced and client satisfaction and loyalty are increased.
4. Enhanced safety: FMEA can assist businesses in identifying and addressing potential safety hazards related to their processes or goods. This can aid in reducing the risk of mishaps, injuries, and even fatalities.
5. Better decision-making: FMEA aids in decision-making by identifying the most important risks and directing the creation of successful risk-mitigation solutions.
6. Enhanced Team Communication: FMEA encourages cross-functional teams to cooperate in order to detect and fix potential problems, which

improves team communication and collaboration. As a result, collaboration and communication are encouraged, which can enhance teamwork and organizational culture.

Overall, FMEA is a useful technique for businesses trying to reduce risk, raise quality, andincrease customer happiness.

2.5 SIMILARITIES AND DIFFERENCES BETWEEN QFD ANDFMEA

The following are some of the main similarities and differences between QFD and FMEA:

Similarities:

- Both tools aim to raise product and customer satisfaction.
- Cross-functional teams must collaborate when using either tool to recognize and resolvepossible problems.
- Both technologies use a systematic procedure that promotes data-driven judgment.

Differences:

- FMEA is used to detect and prioritize potential failures in a process or product, while QFD is used to transform customer demands and preferences into design requirements.
- Methodology: FMEA employs a systematic approach to identify potential failure modes and their impacts, while QFD uses a matrix to connect customer requirements to design characteristics.
- Timing: While FMEA is often utilized during the production or manufacturing phase of aproduct, QFD is typically employed during the design phase.
- Result: While FMEA gives a list of potential failure modes and the risks associated withthem as well as solutions to reduce those risks, QFD provides a roadmap for product design and development.
- Focus: While FMEA focuses on lowering the risk of failure in a process or product, QFD focuses on fulfilling the needs and expectations of the customer.

2.6 SIMILAR STUDIES AND APPLICATION OF QFD AND FMEA

Understanding the topic and implementing it in a manufacturing facility requires a solid backbone. This skeleton can be created through pertinent knowledge and study. There are numerous research papers with similar findings to this one. Listed below are the publicationswith brief descriptions of their findings.

2.6.1 SECTION 1: QFD AND OTHER TOOLS

1. "Quality function deployment: a literature review" by Lai-Kow Chan, Ming-Lu Wu. This paper provides a comprehensive review of the literature on QFD and its application in variousindustries. [4]
2. "Integration of QFD and AHP in New Product Development" by Chih-Kuang Chou and Yi-Ling Chen. This paper explores the integration of QFD and the Analytic Hierarchy Process (AHP) in the new product development process. [5]
3. "Integration of QFD and TRIZ for Conceptual Design" by Jin-Woo Park, Jun-Ki Kim, and Kyung-Hoon Yang. This paper discusses the integration of QFD and TRIZ (Theory of Inventive Problem Solving) in the conceptual design phase of product development. [6]
4. "Application of QFD and Six Sigma in Service Quality Improvement: A Case Study" by M. H. Fazel Zarandi and M. Arabzad. This paper presents a case study of the combined use of QFD and Six Sigma in service quality improvement. [7]

2.6.2 SECTION 2: FMEA AND OTHER TOOLS

1. "A comprehensive review of FMEA in the automotive industry" by Mansoor Naderi and Mohammadreza Karimi. This paper provides a comprehensive review of the literature on FMEA in the automotive industry. [8]

2. "Risk Management in Aerospace Industry using FMEA and FTA" by Seyed Ali Pourhashemi, Ali Azadeh, and Hamed Fazlollahtabar. This

paper presents a case study of the use of FMEA andFault Tree Analysis (FTA) in the aerospace industry for risk management. [9]

3. "An integrated fuzzy FMEA and fuzzy TOPSIS approach for supplier selection" by Gholamreza Jahanshahloo, Fereshteh Ebrahimi, and Hamid Reza Nasiri. This paper proposes an integrated approach of FMEA and Fuzzy Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) for supplier selection. [10]

4. "FMEA and Design of Experiments to Improve the Performance of a Healthcare Service Process" by Juan Felipe Mejía, William Javier Gómez, and Edisson Alejandro Castillo. This paper presents a case study of the use of FMEA and the Design of Experiments (DOE) to improve the performance of a healthcare service process [11]

5. "Application of FMEA and TRIZ to Improve the Design of a Packaging Machine" by Haiyan Li, Yi Wu, and Shukun Chen. This paper presents a case study of the combined use of FMEA and TRIZ in the design improvement of a packaging machine. [12]

2.6.3 SECTION 3: QFD AND FMEA COMBINED

1. "Application of Quality Function Deployment and Failure Mode and Effects Analysis in the Design of a Railway Brake System" by Jie Liu, Chengjun Wu, and Zhigang Liu. (2018) This study applied QFD and FMEA to the design of a railway brake system and found that the jointuse of these methodologies can effectively identify and prioritize customer needs and potential failure modes, leading to improved product quality and customer satisfaction. [13]
2. "A Comparative Study of Quality Function Deployment (QFD) and Failure Mode and Effect Analysis (FMEA) for Improving Quality in the Automotive Industry" by Dong-Hyun Kang, Chul-Hwan Kim, and Ji-Su Kim. (2016). This study compared the effectiveness of QFD and FMEA in improving quality in the automotive industry and

found that both methodologies can be effective in identifying and addressing quality issues. However, the study also identified some limitations to the use of QFD and FMEA, such as the need for specialized training and expertise. [14]

3. "Applying QFD and FMEA in Software Development" by Jianwu Wu and Zhiguang Liu. (2015). This study applied QFD and FMEA to the development of software and found that the joint use of these methodologies can help identify potential software defects and improve the overall quality of the software product. [15]
4. "Application of QFD and FMEA for Product Development: A Case Study" by A. K. M. Najmul Islam and M. A. Hannan. This paper presents a case study of the combined use of QFD and Failure Mode and Effect Analysis (FMEA) in the product development process. [16]
5. "Integrating Quality Function Deployment (QFD) and Failure Mode and Effects Analysis(FMEA) for Designing a Service System" by Bo-Ting You and Wei-Jian Chen. (2019) [17]

CHAPTER 3

RESEARCH DESIGN AND METHODOLOGY

3.1 INTRODUCTION

In the previous chapters, an introduction to this research project and a literature review have been presented. In this chapter, we will discuss the research design and methodology used in this study, which aims to implement Quality Function Deployment and Failure Mode and Effects Analysis together to improve the quality of a product or process of laptop manufacturing.

We will begin by explaining the steps followed in the research, including how we selected the appropriate methodology for our study. We will then provide a detailed explanation of the QFD methodology flow, covering all QFD phases to provide a good understanding of the process and product components.

Next, we will introduce the FMEA methodology, covering both Process FMEA (PFMEA) and Design FMEA (DFMEA). We will explain the steps involved in each methodology and how theycan be used to identify potential failure modes and improve quality.

To ensure the effectiveness of the implementation, we will also discuss our sampling strategy andhow we selected the appropriate participants. Finally, we will address the ethical considerations relevant to this study and explain how we will ensure that our research is conducted ethically.

3.2 STEPS FOLLOWED IN THIS STUDY

To complete the implementation of four phases of QFD and FMEA, the difierent steps were being followed. Here are the steps which have been followed for this case study are below with the diagram.

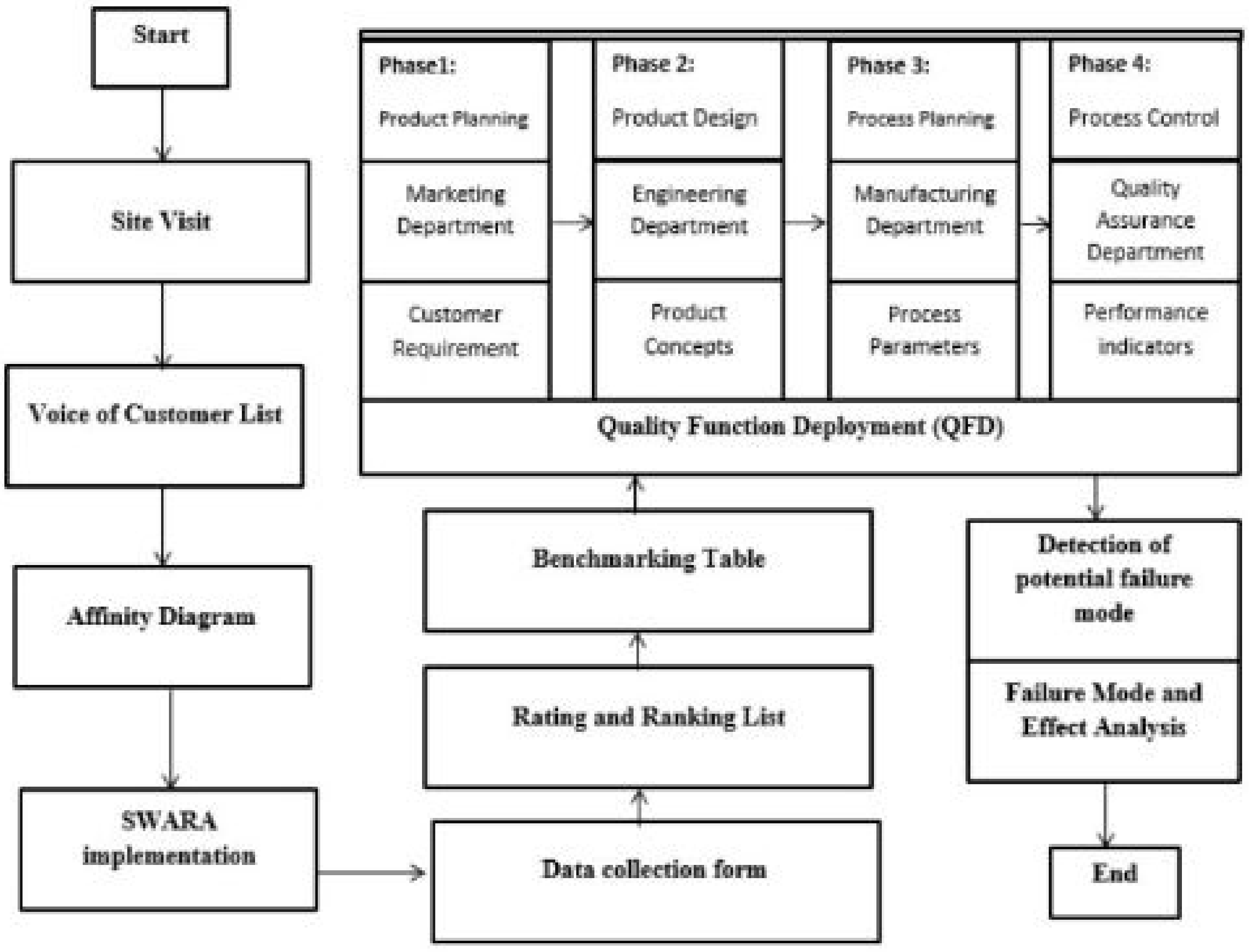


Figure 3. 1 steps flowchart that followed in the study

Site Visit: A visit was made to the site where the product or process being studied was located in order to gain an understanding of the context and observe the product or process firsthand.

Voice of Customer List: A list of customer requirements and preferences was developed through direct feedback from customers, as well as indirect sources such as social media andcustomer reviews.

Affinity Diagram: An affinity diagram was used to group related ideas and themes together inorder to identify patterns and insights related to customer requirements and potential failure modes.

SWARA implementation: The Strengths-Weaknesses-Opportunities-Threats (SWOT) analysis- based ranking approach (SWARA) was used to prioritize customer requirements based on their importance.

Data Collection Form: A data-taking form was made to collect data on the identified customerrequirements, potential failure modes, and other relevant variables.

Rating and Ranking List: A rating and ranking list were developed to prioritize the identifiedpotential failure modes based on their severity, occurrence, and detection.

Benchmarking Table: A benchmarking table was used to compare the performance of the product or process being studied with that of similar products or processes in the market.

Quality Function Deployment (QFD): QFD methodology was used to translate customers' voices into technical specifications, and prioritize the technical specifications based on their importance.

Detection of failure mode: The potential failure modes were detected using a technical approach, such as a Failure Mode and Effect Analysis, which can be product or design.

Failure Mode and Effect Analysis: FMEA methodology was required to assess the failure modes which are potential, determine their severity, occurrence, and detection, and prioritize them based on their risk level.

3.3 FLOW CHART

This study's complete methodology is illustrated in the flowchart appended below. The flowcharts suggest that all phases of QFD require three categories of information.

i) Final weight determined using the SWARA method

ii) WHATs

iii) HOWs

As depicted in the flowchart, one phase's information or data is attached to the information or data of a subsequent phase. FMEA-specific information will be provided in the letter's body. We can also observe that FMEA and QFD are strongly interconnected. Generally, FMEA is related toQFD phase four.

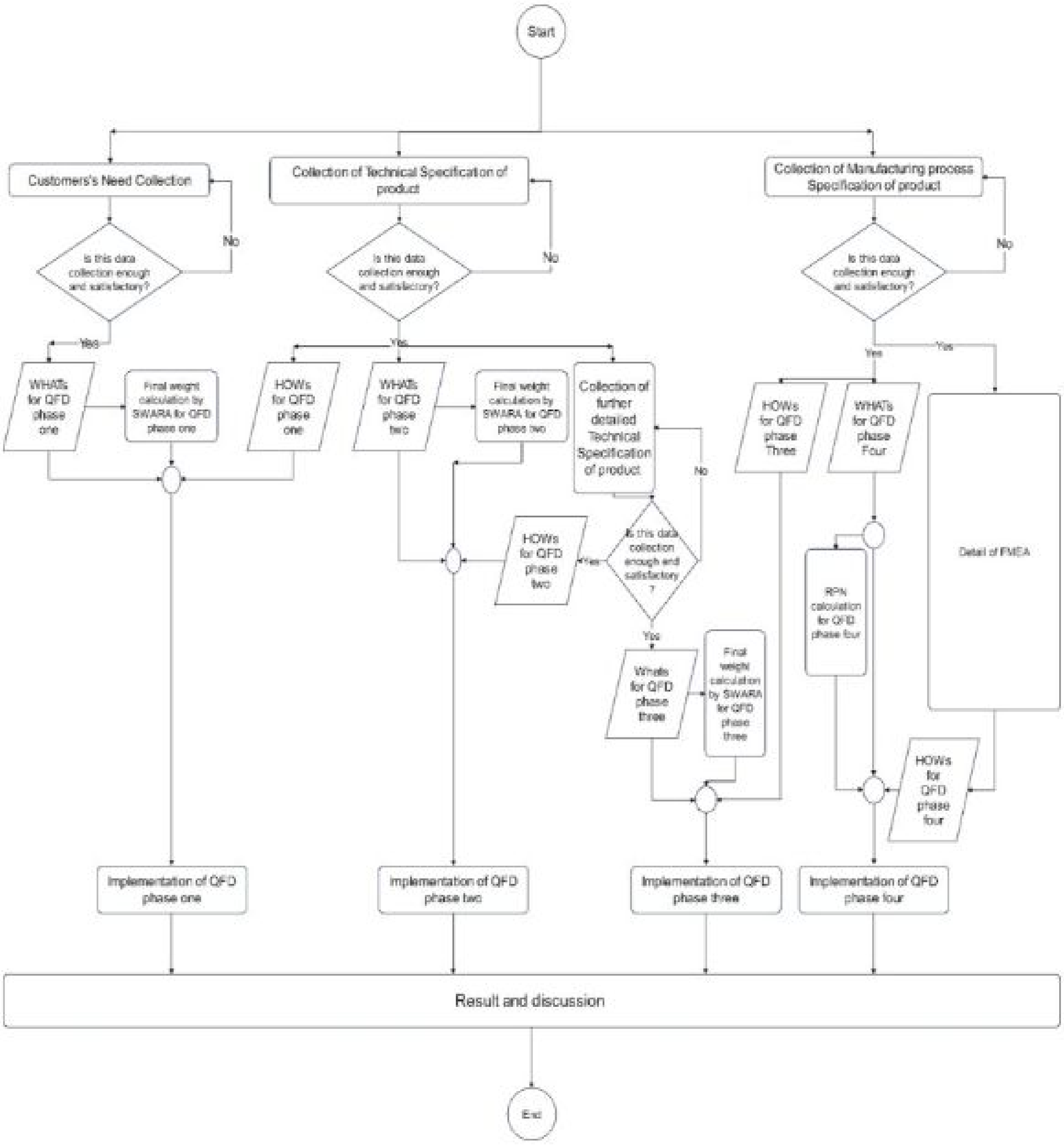


Figure 3. 2 Flow chart

3.4 QFD Methodology

Four HOQs, also known as the House of Quality, make up primarily four phases of QFD. As previously demonstrated, QFDs are interrelated. In a HOQ matrix, there are two primary components. The first category is WHATs, and the second is HOWs.

WHATs signify the input of a HOQ matrix, whereas HOWs represent the output. A HOQ matrixwill always have the WHATs on the left side and the HOWs on the top. In the next iteration of QFD, the output (WHATs) will become input (HOWs). Thus are the four phases of QFDs interconnected. Figure 3.3 gives a clear explanation.

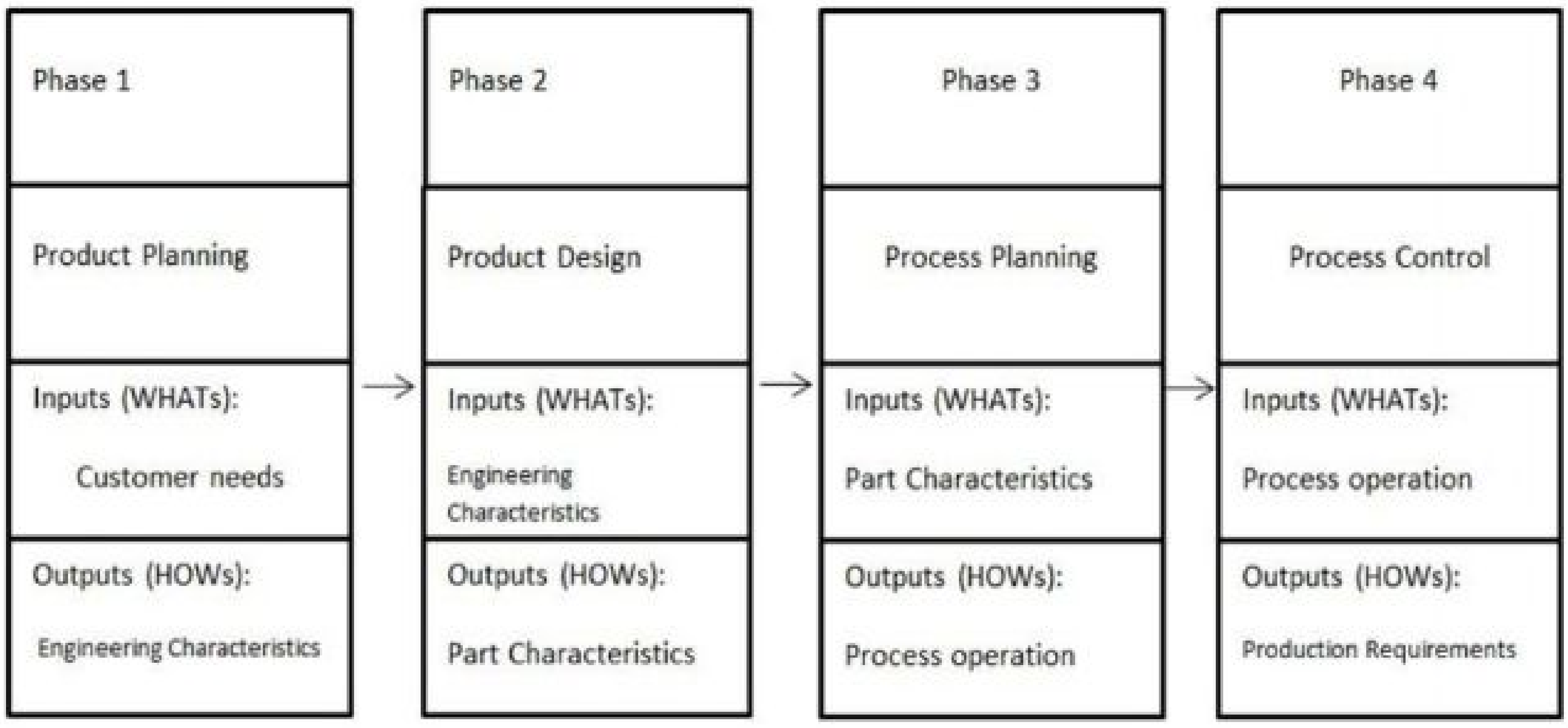


Figure 3. 3 QFD methodology flow

For the relation matrix, the following table has followed.

Table 3.1 Relation Matrix

Relationship	Score
No	0
Weak	1
Moderate	3
Strong	9

Table 3.2 Number used in the relationship matrixThe formula used for QFD calculation is given

	D1	D 2	… ..	DL
G1	x11	x 1 2	… ..	x1L
G2	x21	x 2 2	… ..	x2L
…..	…..	… ..	… ..	…..
GN	xM1	x M 2	… …	xNL

Here, GN represents engineering characteristics (HOWs)

DL represents competitors' company

XNL represents the technical parameters or performance score of Company L's product.

3.4.1 PRODUCT PLANNING

In this stage, the requirements and expectations of the consumer are identified, and the product is planned accordingly. The Voice of the Customer (VOC) is collected to comprehend the customer's demands, and those requirements are prioritized. The product specifications are then defined in accordance with the requirements and expectations of the consumer. Here the house of quality (HOQ) can be divided into 6 rooms which gives an idea about different things.

ROOM 1: Customer Needs. [WHATs]

ROOM 2: Competitive Properties.

ROOM 3: Technical Design Features. [HOW]

ROOM 4: What and How Relationships.

ROOM 5: Design Relationships.

ROOM 6: Target Values.

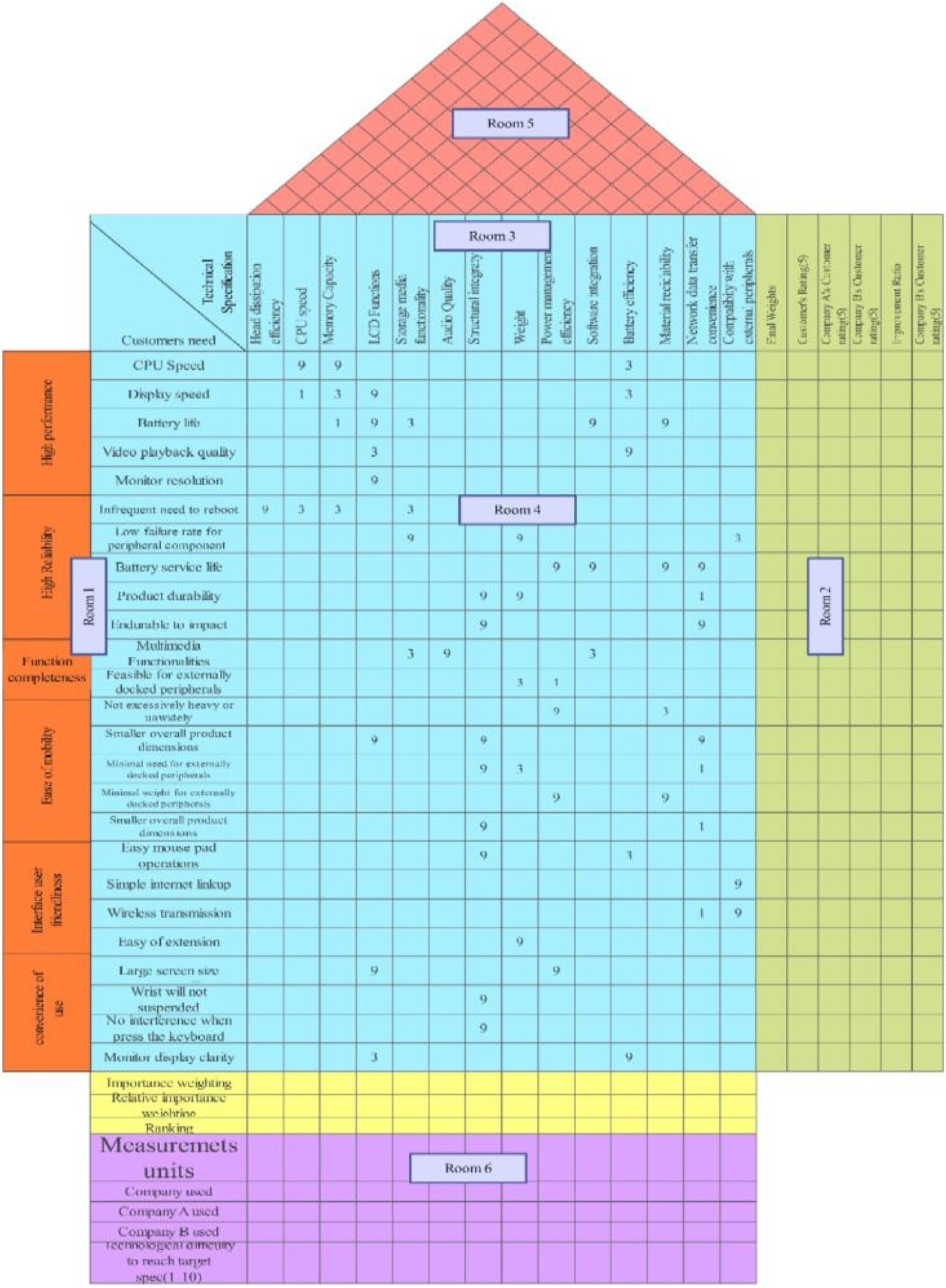


Figure 3. 4 QFD phase one's template

3.4.2 PRODUCT DESIGN

In this stage, the product is designed based on the consumer requirements and specifications established in the preceding phase. The design is evaluated to ensure it fulfills the customer's requirements and is producible.

This phase is called the product design phase. This can only be performed after completing Phase One QFD. Here, the HOWs of phase one will become the WHATs. During this phase, the team can define the design requirements by figuring out which parts and assembly components are most important. Then, the House of Quality matrix is used to rank the list of offering characteristics that were made during the product planning phase.

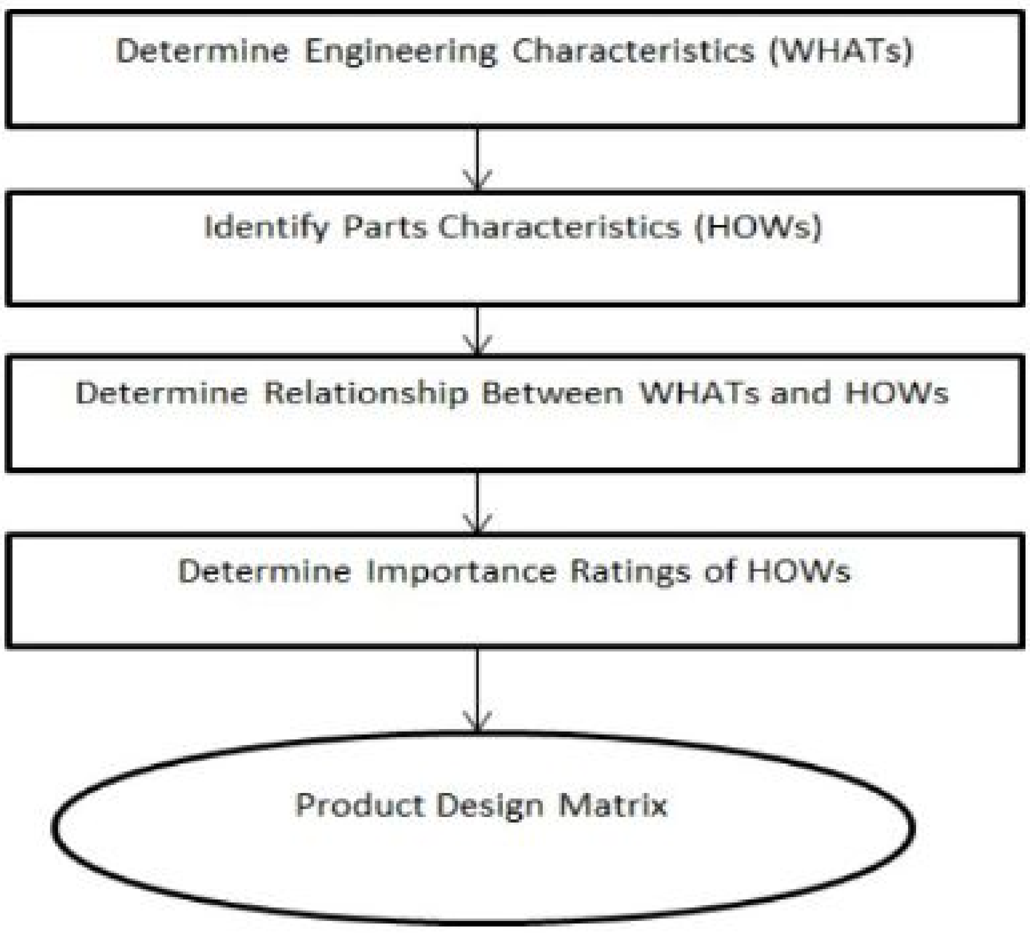


Figure 3. 5 Flow chart for product design matrix

Here, there can be 4 rooms

ROOM 1: Technical Design Features **[WHATs]** **ROOM 2**: Critical Parts and Characteristics **[HOWs]ROOM 3:** WHATS and HOWS Matrix

ROOM 4: Ranking and Technological Description

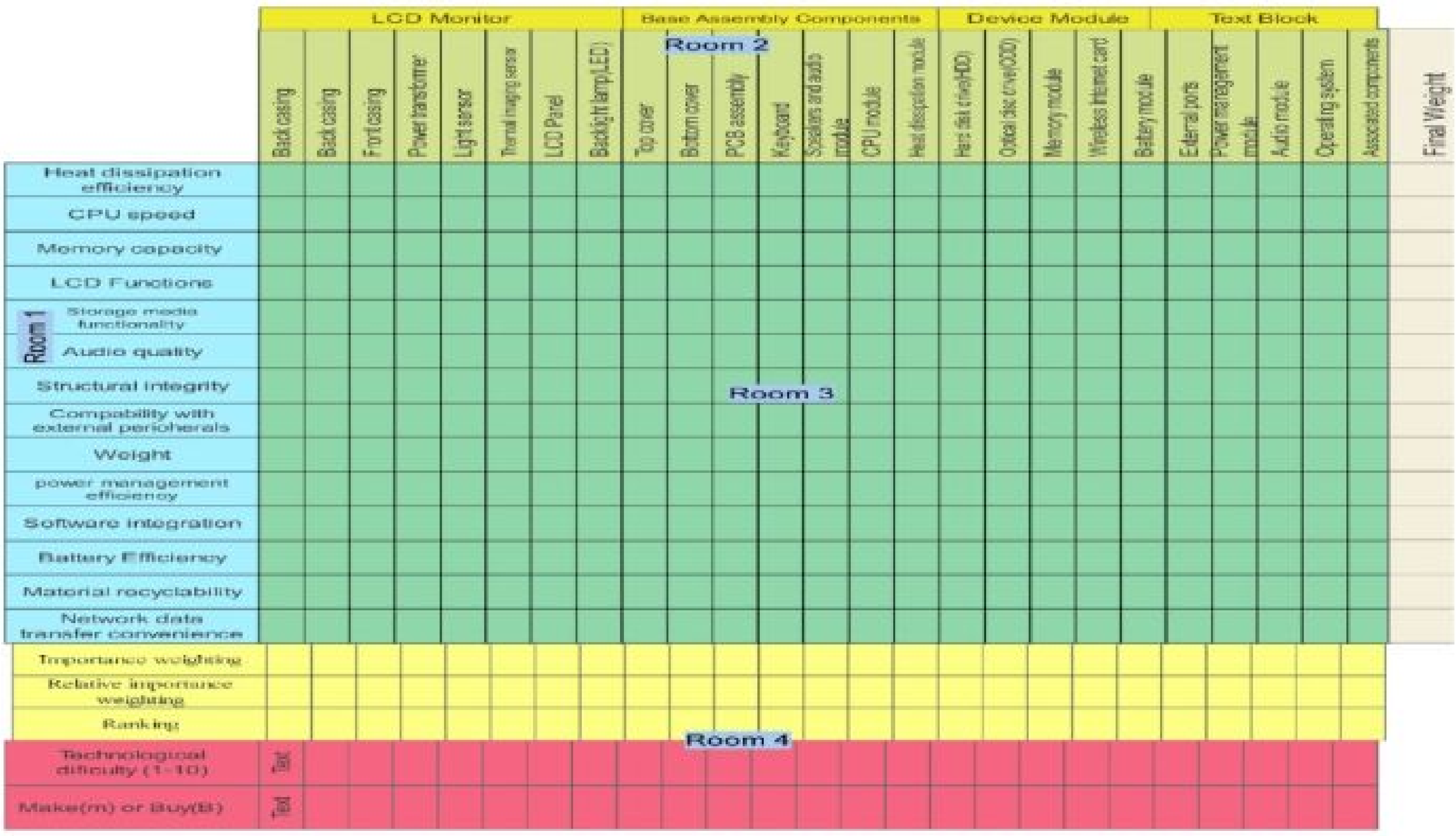


Figure 3. 6 QFD phase two's template

3.4.3 PROCESS PLANNING

During this phase, the manufacturing process is planned to ensure that the product is manufactured consistently and efficiently. The process is designed to satisfy the product's specifications and to reduce defects and waste to a minimum.

This can only be performed after completing Phase 2 QFD. Here, the HOWs of phase two will become the WHATs. The third phase entails determining the design, manufacturing, and assembly processes that best address the product development requirements. Teams tasked with this aspect must be able to define the necessary standard operating procedures, elements, andcriteria.

ROOM 1: Critical Parts and Characteristics **[WHATs] ROOM 2**: Critical Process Parameters **[HOWs] ROOM 3:** WHATS and HOWS Matrix

ROOM 4: Ranking and Technological Description

Figure 3. 7 QFD phase three's template

A process planning matrix can be found by following certain steps that have been shown below.

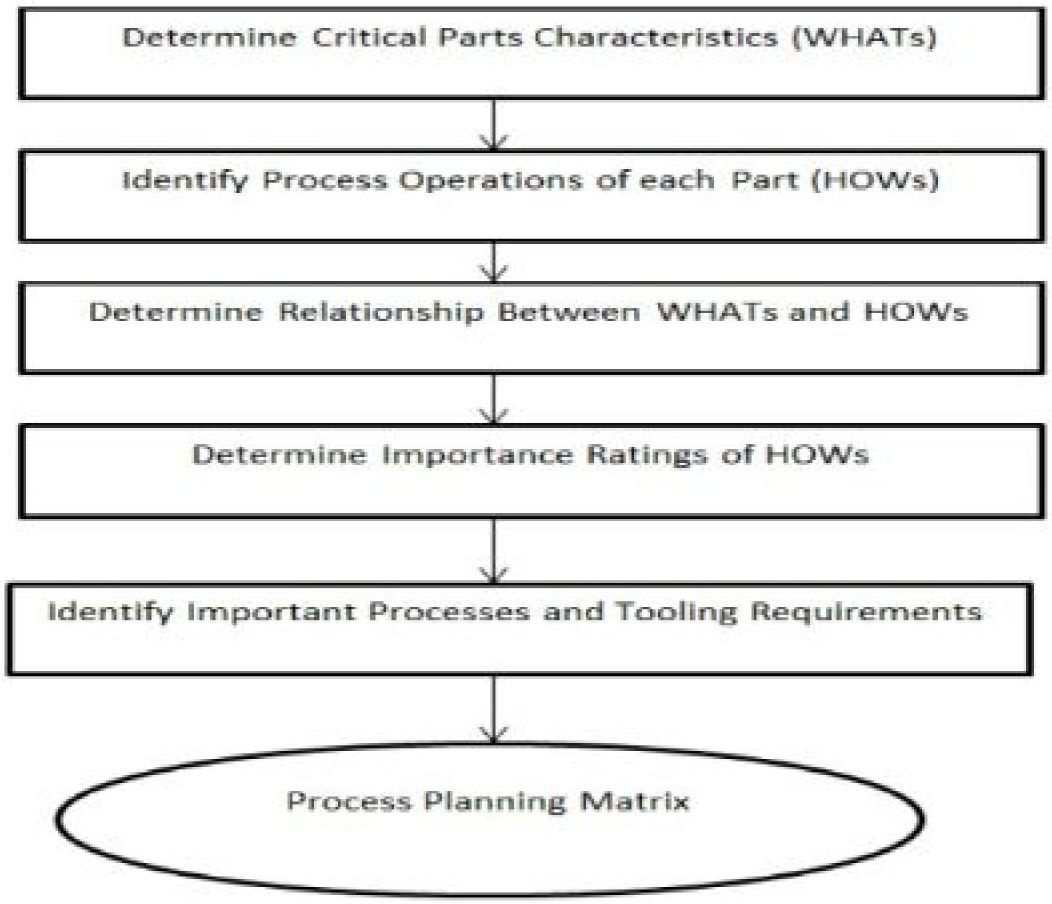


Figure 3. 8 Flow chart for process planning matrix

3.4.4 PROCESS CONTROL

During this phase four, the manufacturing process is tracked and controlled in order to guarantee that the product is consistently produced and meets customer expectations. Statistical Process Control (SPC) techniques are utilized to identify and rectify any manufacturing process-related issues.

This phase is called the production planning phase. This can only be performed after completing Phase Three QFD. Here, the HOWs of phase three will become the WHATs. In the final phase, process control methods as well as production and inspection procedures are established. These are necessary to ensure that the features are fulfilled and are continuously evaluated and enhanced. Here, I put five rooms in the HOQ for QFD.

ROOM 1: Critical Process Parameters

[HOWs] ROOM 2: Critical Production Characteristics

[WHATs]ROOM 3: WHATS and HOWS Matrix with Final Score

ROOM 4: Factors to Control

ROOM 5: Technological Difficulty

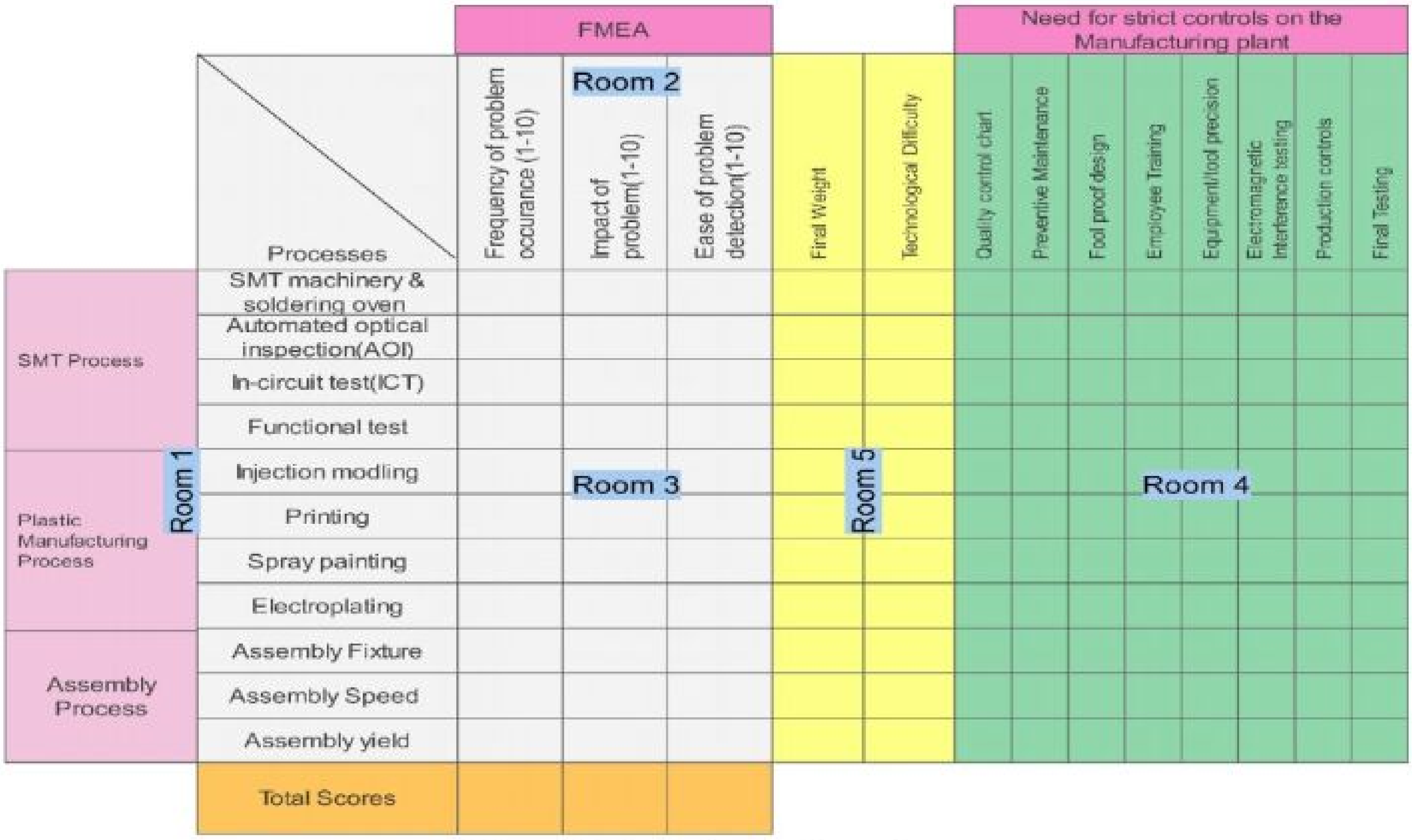


Figure 3. 9 QFD phase four's template

The final phase has a direct relationship with Failure Modes and Effects Analysis (FMEA). So, the data and charts for the FMEA are required to be done before this phase. In the next section,the FMEA part is described.

[**Note**: All Figure has been drawn using the software "Wondershare EdrawMax." & the decisionof the QFD analysis will be listed after data collection which is after chapter 4]

3.4.5 SWARA (FOR FINAL WEIGHT CALCULATION OF QFD)

One of the important multi-criteria decision-making (MCDM) methods is the SWARA method. This stepwise weight assessment ratio analysis (SWARA) is used here to determine the final weight of QFD. This method will be used in the first three phases of QFD. The steps which have been followed for this method are given below with an example.

Step 1: All criteria are taken by own assumption. **[Table: 1]**

Step 2: The comparative importance of the average value (*Sj*) has been determined from the second criterion. One criterion *(j)* has a relationship with the previous criterion *(j-1)*. **[Tables: 2 and 3]**

Step 3: Determine the coefficient (*kj*) **[Table: 3]**

$$k_j = \begin{cases} 1 & j = 1 \\ s_j + 1 & j > 1 \end{cases}.$$

Step 4: Determine the recalculated weight (*wj*) [**Table: 4]**

$$w_j = \begin{cases} 1 & j = 1 \\ \dfrac{x_{j-1}}{k_j} & j > 1 \end{cases}.$$

Step 5: Final weight calculation (qj) **[Table: 5]**

$$q_j = \frac{w_j}{\sum_{k=1}^{n} w_j},$$

Table 1

Order	Decision variable(Customer need)
3	monitor
5	memory
1	cpu
4	keyboard
2	mousepad
6	Software

Table 2

Order	Issue which is more important	percentage	In comparison to the issue
1	cpu	30%	mousepad
2	mousepad	20%	monitor
3	monitor	45%	keyboard
4	keyboard	30%	memory
5	memory	15%	Software

Table 3

Order	Issue which is more important	Comparative importance of average value(Sj)
1	cpu	
2	mousepad	0.3
3	monitor	0.2
4	keyboard	0.45
5	memory	0.3
6	Software	0.15

Table 4

Order	Issue which is more important	Comparative importance of average value(Sj)	Coefficient (kj)
1	cpu		1
2	mousepad	0.3	1.3
3	monitor	0.2	1.2
4	keyboard	0.45	1.45
5	memory	0.3	1.3
6	Software	0.15	1.15

Table 5

Order	Issue which is more important	Comparative importance of average value(Sj)	Coefficient (kj)	Recalculated weight(wj)	Final Weight(qj)
1	cpu		1	1	1/3.5 = 0.28
2	mousepad	0.3	1.3	1/1.3 = 0.77	0.77/3.5 = 0.22
3	monitor	0.2	1.2	0.77/1.2 = 0.64	0.64/3.5 =0.18
4	keyboard	0.45	1.45	0.64/ 1.45= 0.44	0.44/3.5 =0.12
5	memory	0.3	1.3	0.44 / 1.3 = 0.34	0.34/3.5 =0.09
6	Software	0.15	1.15	0.34 / 1.15 =0.3	0.3/3.5 =0.085
				Sum= 3.5	

Figure 3. 10 SWARA template with an example

3.5 FMEA METHODOLOGY

Following three phases of QFD, FMEA can be performed. The FMEA result will be required for the QFD closing phase. Consequently, the FMEA method's methodology is described in detail below.

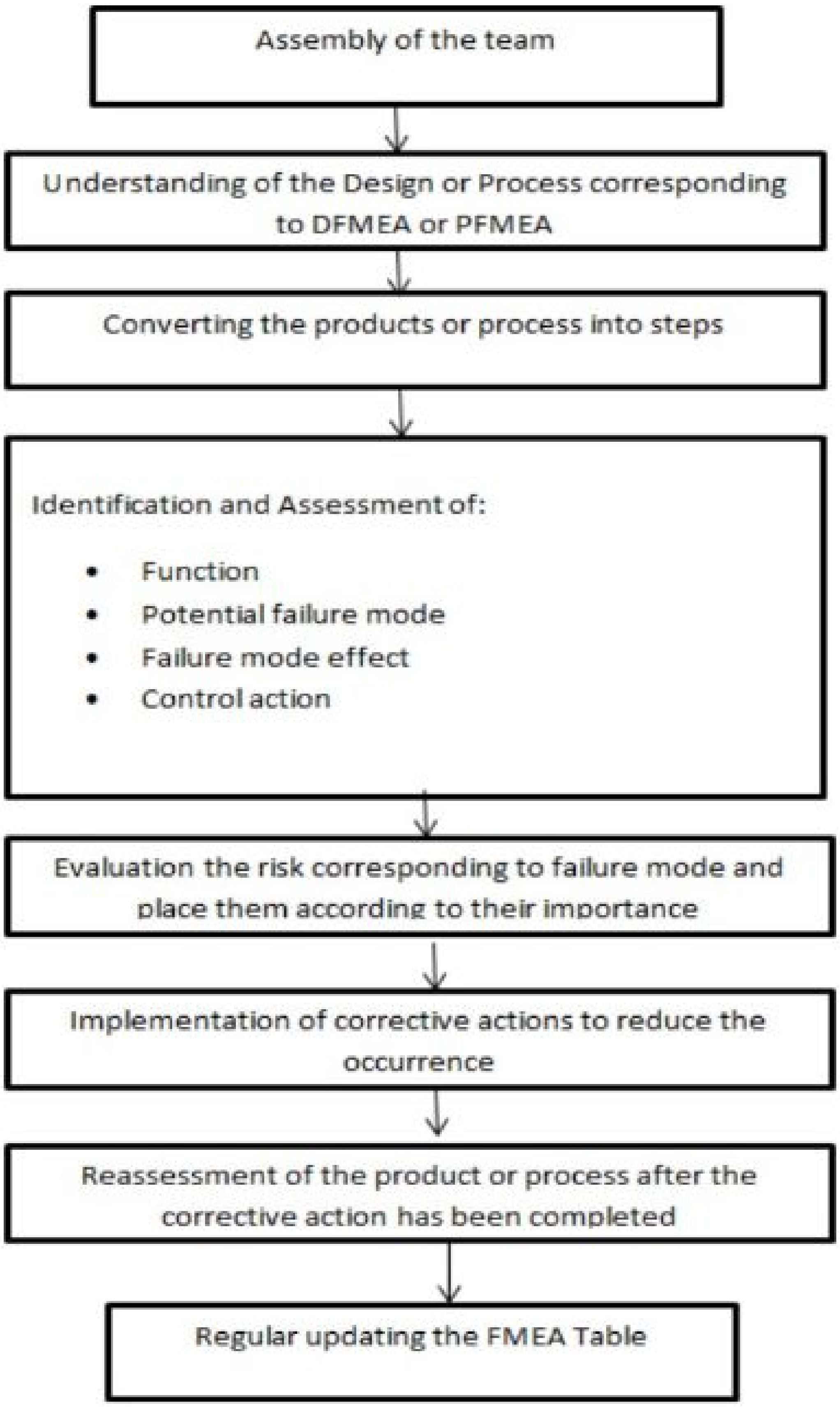


Figure 3. 11 Flow chart for FMEA methodology

3.5.1 TEAM ASSEMBLY

FMEA (Failure Mode and Effects Analysis) team selection must take into account the knowledge and experience required to do an exhaustive analysis. The team should be made up of subject matter specialists with technical expertise and experience pertaining to the system, process, or product under analysis. Additionally, it must to have members from several divisions of the business, such as production, quality control, supply chain, marketing, and customer support. A team of three to eight people works well, though the size will depend on the project's scale and complexity. To guarantee successful collaboration and knowledge exchange among team members, good communication skills are essential. A thorough study of the data, taking into account design specifications, historical failure data, and other pertinent information, requires strong data analysis abilities. To keep the team on task and give everyone a chance to contribute, effective facilitation abilities are required. Organizations are better able to undertake in-depth analyses and spot probable failure mechanisms if they carefully choose team members who possess these traits.

3.5.2 DESIGN AND PROCESS UNDERSTANDING

FMEA's (Failure Mode and Effects Analysis) two essential components are design and process comprehension. In order to recognize and evaluate probable failures and their effects, it is crucialto comprehend the design and process. Understanding the design of a product or system in its whole, including its purpose, intended application, and key components, is referred to as design understanding. The FMEA team can identify potential failure modes that can affect the product's functionality, dependability, or safety thanks to this insight. The team must take into account all potential causes of failure, such as design flaws, flaws in the materials, and probable incorrect applications of the product. Understanding the manufacturing or assembly process that was used to generate the product or system entails having a thorough understanding of it. Understanding the processes involved in the process, the materials utilized, the equipment employed, and the environmental circumstances in which the process takes place are all part of this. The FMEA team can detect potential failure modes, such as process mistakes, material flaws, and environmental factors that could affect the process, thanks to this understanding of how failures might happen during production or assembly. The FMEA team can identify probable failure modes and their causes, evaluate the seriousness and likelihood of their occurrence, and create plans to avoid or lessen their effects when design and process understanding are combined. This makes it easier to make sure the system or product works as intended and is safe and dependable.Organizations can identify potential failure modes before they happen and take proactive steps to limit their impact by undertaking a thorough FMEA analysis that takes into account design and process understanding.

3.5.3 IDENTIFICATION OF POTENTIAL FAILURE

A critical step in FMEA (Failure Mode and Effects Analysis) is the identification of potential failures. This step's goal is to identify all potential failure modes for a product or process, along with their causes and consequences. The FMEA team should compile all pertinent data, including as design specifications, operational circumstances, and historical failure data, regarding the product or process under analysis. After gathering this data, the team should discuss every potential failure mode. This entails taking into account every potential reason why a process or product can fail, such as flaws, malfunctions, or manufacturing mistakes. The FMEA team can then proceed to analyze the seriousness, likelihood, and detectability of each failure mode and build plans to avoid or lessen their effects by recognizing probable failures at this early stage.

<u>Identification of Effects of Failure Modes</u>

The next stage is to determine the effects of each failure mode using FMEA (Failure Mode and Implications Analysis). This entails taking into account the effects that each failure mode would have on the product or process as well as the impact it would have on the end-user or client. The first stage in determining the probable effects of each failure mode on the product or process under analysis is to identify the implications of each failure mode. To determine the potential risks, expenses, and harm to the product or process, the implications of each failure mode mustbe carefully assessed.

<u>Identification of Potential Cause Modes</u>

In FMEA (Failure Mode and Effects Analysis), which entails identifying all potential causes or conditions that could contribute to a particular failure mode, the identification of potential cause modes is an essential stage. In other words, it entails discovering the fundamental reasons for the failure mode. This step's goals are to identify every potential failure mode scenario and

comprehend the reasons why it might occur. The FMEA team should consider every scenario thatcould result in the failure mode that has been identified. This entails taking into account every element that can influence the failure mode, such as design defects, manufacturing mistakes, environmental circumstances, and operator error. In order to pinpoint potential causes of the failure mode, the team should also examine historical data, such as previous failures, customer complaints, and warranty claims. The FMEA team can create suitable measures to prevent or lessen the impact of the failure mode by addressing the fundamental causes by identifying potential cause modes. The effectiveness, dependability, and safety of the product or process under analysis depend heavily on this stage.

3.2.1 RISK ASSESSMENT

Risk assessment is a critical phase in FMEA (Failure Mode and Effects Analysis), and it entails assessing the severity, occurrence, and detection of probable failure modes to establish thedegree of risk associated with each failure mode. The objective of risk assessment is to rank failure modes according to the degree of risk they pose and to determine the most effective countermeasures.

The following are the main factors to think about when conducting risk assessment in FMEA:

- Severity: Assess the potential effects of each failure mode's severity. On a scale of 1 to 10, with 10 denoting the most serious consequences, severity is frequently assessed.
- Occurrence: Evaluate the occurrence that the failure mode will occur. On a scale of 1 to 10, with 10 denoting the highest chance of occurrence, occurrence is frequently scored.
- Detection: Determine whether the failure mode can be identified before it causes injury or damage. A detection rating system of 1 to 10, with 10 being the most detectable, is frequently used.
- RPN: The severity, occurrence, and detection scores are multiplied to arrive at the risk priority number (RPN). A numerical score that quantifies the degree of risk connected to each failure scenario is provided by the RPN.
- Prioritize Failure Modes: Failure modes should be prioritized according to their RPN scores, with the failure modes with the highest scores receiving the most attention.
- Develop Strategies: Develop appropriate strategies to lessen or eliminate the risks related to the failure modes that should be given priority. These actions could entail design modifications,

procedure enhancements, or operator training.

The FMEA team can prioritize the most important failure modes and take the necessary steps to reduce or eliminate the risks associated with them by doing a risk assessment as part of the FMEA. This helps to ensure the product's safety, dependability, and performance.

Rating	Detection (D)	
	Effect	Effect
10	Almost impossible	Almost impossible
9	Remote	Remote
8	Very slight	Very slight
7	Slight	Slight
6	Low	Low
5	Medium	Medium
4	Moderately high	Moderately high
3	High	High
2	Very high	Very high
1	Almost never	Almost never

Figure 3. 12 Rating of Detection

Rating	Occurrence (O)	
	Effect	Criteria
10	Almost certain	Failure almost certain
9	Very high	Likely very high number of failures
8	High	Likely high number of failures
7	Moderately high	Likely moderate high number of failures
6	Medium	Likely medium number of failures
5	Low	Likely occasional number of failures
4	Slight	Likely few failures
3	Very slight	Likely very few failures
2	Remote	Rare number of failures
1	Almost never	No failures

Figure 3. 13 Rating of Occurrence

Rating	Severity (S)	
	Effect	Criteria
10	Hazardous	Hazardous effect
9	Serious	Very high
8	Extreme	Customer very dissatisfied
7	Major	Customer dissatisfied
6	Significant	Customer experiences some discomfort
5	Moderate	Customer experiences some dissatisfaction
4	Minor	Customer experiences minor nuisance
3	Slight	Customer slightly annoyed
2	Very Slight	Customer not annoyed
1	No	No effect

Figure 3. 14 Rating of Severity

CHAPTER 4

DATA COLLECTION, ANALYSIS, AND DISCUSSION

4.1 INTRODUCTION

This chapter elaborates on the data acquisition and analyses that followed the implementation of the system. An integrated methodology for using QFD and FMEA in the manufacturing of rice milling plant and seed processing equipment and apparatus. Several frameworks detailed in the preceding chapter for the application of QFD and FMEA will be adhered to for the analyses of data. Processing unprocessed data into data that can be synthesized and interpreted requires the application of multiple methods and techniques.

4.2 COMPANY PROFILE

Telephone Shilpa Sangstha (TSS) Ltd. was founded in 1967 under the name "Telephone Manufacturing Corporation" in accordance with a partnership agreement between the then- government Pakistani government and M/S Siemens AG, West Germany.

On April 24, 1973, the Founder of the Country Bangabandhu Sheikh Mujibur Rahman established the Phone Industries Corporation under the name "Telephone Shilpa Sangstha Limited (TSS)" with the intention of fostering expansive growth. TSS commemorates the memory of Bangabandhu Sheikh Mujibur Rah the most famous Bengali of all time, with gratitude.

24/04/1973, in accordance with the Companies Act of 1913 and a fresh contract with the otherpartner in the joint venture M/S Siemens AG, West Germany.

4.2.1 PRODUCT EXPERIENCE

TSS produced and installed EMD telephone exchanges, analog PABX, fax machines, DP/CT boxes, drawers, and telephone lines in the years after independence. The terrible murder of He in 1975 not only slowed growth and development but also transformed TSS into a diseased enterprise. Since then, in 2006, TSS has converted into an electronic device manufacturing/integration firm thanks to Hon'ble Prime Minister Sheikh Hasina's "Digital Bangladesh" construction programmer. At the Bangabandhu World Conference Centre on October 11, 2011, the Hon. Prime Minister unveiled the DOEL-branded branded TSS Laptop. TSS's foray into the internet market marks the start. Over time, TSS has expanded its catalog to include desktops, laptops, tablets, biometric sensors, multimedia projectors, sound bars, and smart pre-paid energy meters from the DOEL brand.

4.3 DATA COLLECTION METHOD

The data collection was done by authors from the well-reputed government organization Telephone Shilpa Sangstha Ltd. (TSS). The data was mainly taken from observation and interviews with the person in charge. The data was collected from 29th January until 31st March 2023 inside the industry.

i) Observation:

The authors visited the manufacturing facility where unprocessed and finished components for laptop production are received. One observation was conducted in which the individual in command demonstrated all processes. A second test was conducted to observe testing and failure mode detection for the FMEA process. The listed procedure was performed to continue QFD Phases 3 and 4 prior to PFMEA. At the outset of the data collection, the responsible party described the organization's methodologies, benefits, and drawbacks. He then comprehended our mission and followed a complex procedure. The interview sessions were then conducted.

ii) Interviews:

In order to acquire data from the industry, a 10-day-long session was held. As this is a qualitativemethod, the majority of the data required for this study were qualitative. The information was gathered by asking Mr. Md. AK Azad, the Junior Assistant Manager (Laptop) of (TSS), numerous queries. He was the only individual who assisted with data collection. He is familiar
with the customer's voice because he is frequently called upon to resolve laptop-related issues for customers. The authors gathered data for all QFD relationships, including phase one customer requirements versus technical specification, phase two technical specification versus criticalparts and their characteristics, phase three critical parts and the applied processes, and phase four processes and FMEA. He was also required to explain the positive and negative relationships between the various varieties of laptop technical components. He has further defined the relative importance of all the WHATs used in every phase. Without his skill, knowledge, and experience in his professional sphere, it was difficult for him to compile all of this data. Mr. Azad was asked a thousand technical inquiries in order to collect all the necessary data and ensure the success of this research.

4.4 SUPPLY CHAIN OF THE PRODUCTION PLANT

The industry is primarily renowned for laptop parts assembling. However, they are required to manufacture certain components in order to improve the assembly experience. To delve deeper into the research procedures and findings, one must be familiar with the industry's supply chain. The supply chain for TSS laptops is depicted in the flowchart provided below.

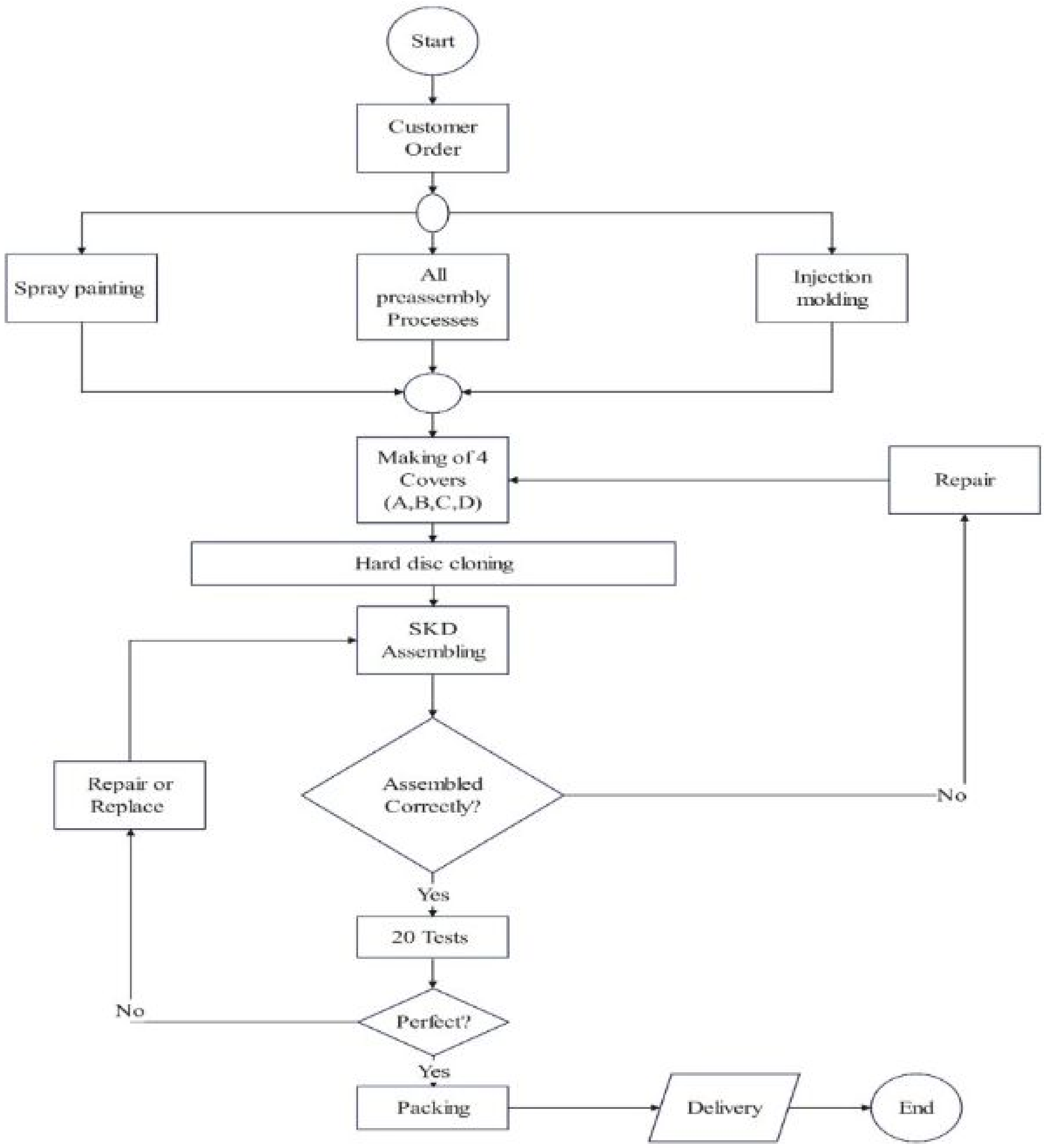


Figure 4. 1 Supply Chain of the production plant

Every production begins with the customer's needs or requests. When the plant receives an order, they promptly begin working on it. Their step-by-step working procedure is outlined in the following section.

i) Making of four covers:

Construction of Four Covers Four covers labeled A, B, C, and D, are used to suit the laptop's monitor and keyboard. If they are not precisely crafted, the LED panel and keyboard will not set up correctly and failure modes will result. These covers are located on the laptop's bottom, top, sides, and back.

To ensure their accuracy, numerous pre-assembly procedures must be followed. Spray painting and injection molding are recognized as essential processes.

In injection molding, plastic resin granules are heated to their melting point and then injected into a mold cavity. The plastic then cools and solidifies in the mold, assuming the cavity's shape. After the plastic has chilled and hardened, the mold is unsealed and the part is ejected.

Typically, the spray-painting procedure entails using a paint gun to apply a coat of paint to the cover or shell of a laptop. This procedure is typically performed in a controlled environment to prevent dust and other contaminants from compromising the finish's quality.

ii) Hard disc cloning:

Hard disc cloning is the creation of an exact, bit-for-bit copy of an existing hard disc drive (HDD) or solid-state drive (SSD) onto another drive. This procedure duplicates the original hard disc, including its data, files, operating system, and settings.

Utilizing specialized software, the cloning procedure typically entails copying the contents of the original hard disc onto another hard disc or SSD. The destination disc must be large enough to accommodate all of the data from the source disc. Depending on the size of the disc and the pace of the devices involved, cloning can take some time.

iii) SKD assembly:

SKD assembly is a manufacturing process used to assemble products that are partially disassembled or prefabricated in a kit or container. Before being delivered to the final assembly location, SKD assembling refers to the process of assembling laptop components that have been pre-manufactured in a semi-finished state.

The industry standard for SKD assembly consists of seven stages. Almost 90% of failure modes rely on the Is process, making it the most vital process. If the product is not flawlessly assembled, it is sent to be repaired or replaced, and the process must be repeated. If everything isin order, they proceed on to the trial phase.

iv) Testing:

They perform 20 tests, including BIOS, charger, keyboard, LED, camera, connectors, speaker, date and time, and so on. Testing is the final second stage and is crucial to the manufacturing facility's output. After testing, the final step is to store the laptop.

v) Packing and delivery:

Packing the laptop refers to preparing it for shipment or storage. This involves arranging the laptop and its accessories, such as the charger and manual, in a receptacle or package that safeguards the laptop during transport.

The laptop will be delivered to the specified location. The parcel may be left at the front door, require a signature for delivery, or be gathered up at a nearby delivery location, depending on thecarrier and delivery method.

Overall, this industry's supply chain is neither complex nor sophisticated. It is simple to comprehend the total procedures involved. In a subsequent section, one can therefore elaborate on the qualitative analysis, which is the study's primary objective.

4.5 IMPLEMENTATION of QFD

At this stage in the report, QFD's implementation, explication, and results or findings have been discussed. As we have seen, four phases of QFD have been completed in this study, so each will be presented individually in this section. Every QFD phase has begun by determining the final rank using a proficiently applied SWARA method. The study then concentrated on locating and explaining each QFD room. Again, QFD is a procedure that must be performed and updated repeatedly. This is a result of a one-time implementation.

4.5.1 QFD PHASE ONE

Phase one as described before will give us a lot of information regarding plant production and quality. Here the study will start with customers' needs. Then, the study will enlist all the needs into categories in order to find the affinity diagram. All categories will go through the SWARA method in order to find the final weight. After that, the correlation matrix and the final matrix which is called HOQ (House of Quality) will be presented. Finally, a decision and discussion will be there before going to the next phase of QFD.

4.5.1.1 CUSTOMERS' NEEDS

QFD Phase 1, also known as "Voice of the Customer," entails gathering and analyzing consumer demands to determine the product's essential requirements. By collecting and analyzing customerrequirements, product developers can gain a deeper comprehension of what customers want fromthe product and use this knowledge to inform the design and development process. This can assist in ensuring that the final product meets consumer expectations and provides the intended benefits and value.

For this study on laptop manufacturing, the following factors were considered to be consumer requirements. These principles were provided by the expert duty member who is continually interacting with the needs of end customers.

Table 4. 1 List of customers' need

Customers' Need:
1. CPU Speed
2. Battery life
3. Video playback quality
4. Monitor resolution
5. Infrequent need to reboot
6. Low failure rate for peripheral component
7. Battery service life
8. Product durability
9. Endurable impact
10. Multimedia Functionalities
11. Feasible for externally docked peripherals
12. Not excessively heavy or unwisely
13. Smaller overall product dimensions
14. Minimal need for externally docked peripherals
15. Minimal weight for externally docked peripherals
16. Easy mouse pad operations
17. Simple internet linkup

18. Wireless transmission
19. Easy extension
20. Large screen size
21. Wrist will not suspend
22. No interference when pressing the keyboard
23. Monitor display clarity

These needs of customers can further be classified into six types according to their characteristics of requirements. The below figure is showing a chart containing every customer requirement in their corresponding type.

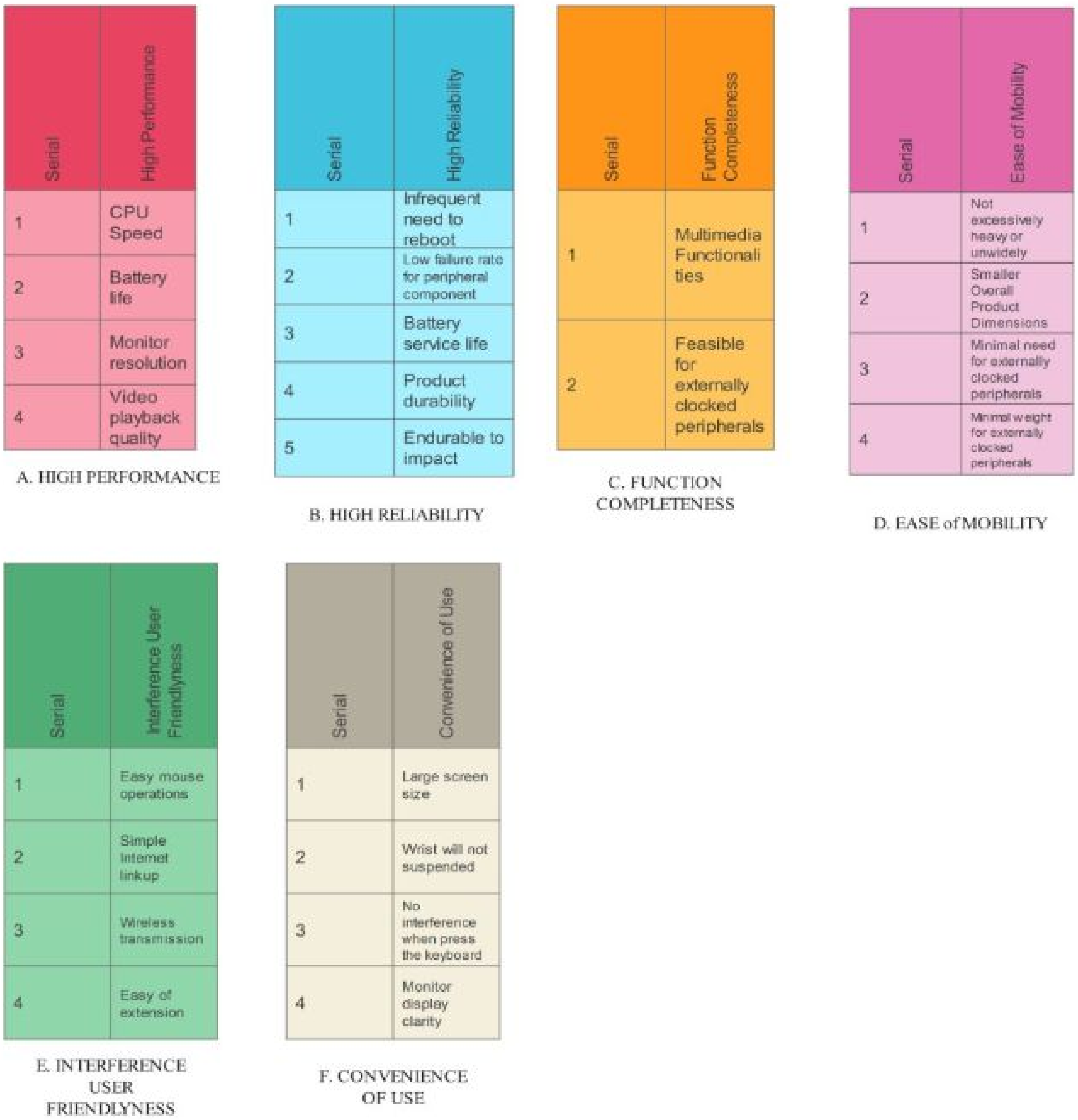


Figure 4. 2 Affinity Diagram

This figure is known as the affinity diagram. An affinity diagram is a tool used in Quality Function Deployment (QFD) to organize and combine consumer needs or requirements into meaningful categories or themes. Now, every section will go through the SWARA method in order to find out the final rank of 1^{st} phase of QFD.

4.5.1.2 IMPLEMENTATION OF SWARA FOR FINAL WEIGHT

For the ultimate weight calculation of customers' requirements in QFD phase one, the SWARA (Stepwise weight assessment ratio analysis) method has been implemented. SWARA as we know before is a very efficient method that is under the category of MCDM (Multi-criteria decision- making) application.

As the CR (Customers' requirements) is selected by one person, the ultimate weight should be given very meticulously. In order to make the QFD calculation more precise this above- mentioned SWARA method has been implemented separately for each and every group ofcustomers' requirements.

A. High performance

Table 1

Order	Decision variable(Customer need)
2	CPU Speed
1	Battery life
3	Monitor resolution
4	Video playback quality

Table 2

Order	Issue which is more important	Relative importance	In comparison to the issue
1	Battery life	80%	CPU Speed
2	CPU Speed	70%	Monitor resolution
3	Monitor resolution	70%	Video playback quality
4	Video playback quality		

Table 3

Order	Issue which is more important	Comparative importance of average value(Sj)
1	Battery life	0.80
2	CPU Speed	0.70
3	Monitor resolution	
4	Video playback quality	0.70

Table 4

Order	Issue which is more important	Comparative importance of average value(Sj)	Coefficient (kj)
1	Battery life		1
2	CPU Speed	0.8	1.8
3	Monitor resolution	0.7	1.7
4	Video playback quality	0.7	1.7

Table 5

Order	Issue which is more important	Comparative importance of average value(Sj)	Coefficient (kj)	Recalculated weight(wj)	Final Weight(qj)
1	Battery life		1	1	1/2.074 = 0.482
2	CPU Speed	0.8	1.8	1/1.8 = 0.556	0.556/2.074 =0.268
5	Monitor resolution	0.7	1.7	0.556/1.7 = 0.326	0.326/2.074 = 0.157
6	Video playback quality	0.7	1.7	0.326/ 1.7= 0.192	0.192/2.074 = 0.0925
				Sum= 2.074	

Figure 4. 3 Final weight for "High Performance" by SWARA method

B. High Reliability

Table 1

Order	Decision variable(Customer need)
1	Infrequent need to reboot
3	Low failure rate for peripheral component
5	Battery service life
4	Product durability
2	Endurable to impact

Table 2

Order	Issue which is more important	Relative importance	In comparison to the issue
1	Infrequent need to reboot	80%	Endurable to impact
2	Endurable to impact	40%	Low failure rate for peripheral component
3	Low failure rate for peripheral component	60%	Product durability
4	Product durability	60%	Battery service life
5	Battery service life		

Table 3

Order	Issue which is more important	Comparative importance of average value(Sj)
1	Infrequent need to reboot	0.80
2	Endurable to impact	0.40
3	Low failure rate for peripheral component	0.60
4	Product durability	0.60
4	Battery service life	

Table 4

Order	Issue which is more important	Comparative importance of average value(Sj)	Coefficient (kj)
1	Infrequent need to reboot		1
2	Endurable to impact	0.8	1.8
3	Low failure rate for peripheral component	0.4	1.4
4	Product durability	0.6	1.6
5	Battery service life	0.6	1.6

Table 5

Order	Issue which is more important	Comparative importance of average value(Sj)	Coefficient (kj)	Recalculated weight(wj)	Final Weight(qj)
1	Infrequent need to reboot		1	1	1/2.356 = 0.424
2	Endurable to impact	0.8	1.8	1/1.8 = 0.556	0.556/2.074 =0.235
5	Low failure rate for peripheral component	0.4	1.4	0.556/1.4 = 0.397	0.397/2.356 = 0.168
6	Product durability	0.6	1.6	0.397/ 1.6= 0.248	0.248/2.356 = 0.105
6	Battery service life	0.6	1.6	0.248/ 1.6= 0.155	0.155/2.356 = 0.065

Figure 4. 4 Final weight for "High Reliability" by SWARA method

C. Function Completeness

Table 1	
Order	Decision variable(Customer need)
2	Multimedia Functionalities
1	Feasible for externally clocked peripherals

Table 2			
Order	Issue which is more important	Relative importance	In comparison to the issue
1	Feasible for externally clocked peripherals	80%	Multimedia Functionalities
2	Multimedia Functionalities		

Table 3		
Order	Issue which is more important	Comparative importance of average value(Sj)
1	Feasible for externally clocked peripherals	0.80
2	Multimedia Functionalities	

Table 4			
Order	Issue which is more important	Comparative importance of average value(Sj)	Coefficient (kj)
1	Feasible for externally clocked peripherals		1
2	Multimedia Functionalities	0.8	1.8

Table 5					
Order	Issue which is more important	Comparative importance of average value(Sj)	Coefficient (kj)	Recalculated weight(wj)	Final Weight(qj)
1	Feasible for externally clocked peripherals		1	1	1/1.556 = 0.642
2	Multimedia Functionalities	0.8	1.8	1/1.8 = 0.556	0.556/1.556 =0.357
				Sum= 1.556	

Figure 4. 5 Final weight for "Function Completeness" by SWARA method

D. Ease of Mobility

Table 1

Order	Decision variable(Customer need)
1	Not excessively heavy or unwidely
2	Smaller Overall Product Dimensions
4	Minimal need for externally clocked peripherals
3	Minimal weight for externally clocked peripherals

Table 2

Order	Issue which is more important	Relative importance	In comparison to the issue
1	Not excessively heavy or unwidely	80%	Smaller Overall Product Dimensions
2	Smaller Overall Product Dimensions	60%	Minimal weight for externally clocked peripherals
3	Minimal weight for externally clocked peripherals	40%	Minimal need for externally clocked peripherals
4	Minimal need for externally clocked peripherals		

Table 3

Order	Issue which is more important	Comparative importance of average value(Sj)
1	Battery life	0.80
2	CPU Speed	0.60
3	Monitor resolution	0.40
4	Video playback quality	

Table 4

Order	Issue which is more important	Comparative importance of average value(Sj)	Coefficient (kj)
1	Not excessively heavy or unwidely		1
2	Smaller Overall Product Dimensions	0.8	1.8
3	Minimal weight for externally clocked peripherals	0.6	1.6
4	Minimal need for externally clocked peripherals	0.4	1.4

Table 5

Order	Issue which is more important	Comparative importance of average value(Sj)	Coefficient (kj)	Recalculated weight(wj)	Final Weight(qj)
1	Not excessively heavy or unwidely		1	1	1/2.151 = 0.465
2	Smaller Overall Product Dimensions	0.8	1.8	1/1.8 = 0.556	0.556/2.151 =0.258
5	Minimal weight for externally clocked peripherals	0.6	1.6	0.556/1.6 = 0.347	0.347/2.151 = 0.161
6	Minimal need for externally clocked peripherals	0.4	1.4	0.347/ 1.4= 0.248	0.248/2.151 = 0.115
				Sum= 2.151	

Figure 4. 6 Final weight for "Ease of Mobility" by SWARA method

E. Interference User Friendliness

Table 1

Order	Decision variable(Customer need)
1	Easy mouse operations
2	Simple Internet linkup
3	Wireless transmission
4	Easy of extension

Table 2

Order	Issue which is more important	Relative importance	In comparison to the issue
1	Easy mouse operations	80%	Large screen size
2	Simple Internet linkup	80%	Wrist will not suspended
3	Wrist will not suspended	70%	No interference when press the keyboard
4	Easy of extension		

Table 3

Order	Issue which is more important	Comparative importance of average value(Sj)
1	Easy mouse operations	0.80
2	Simple Internet linkup	0.80
3	Wireless transmission	0.70
4	Easy of extension	

Table 4

Order	Issue which is more important	Comparative importance of average value(Sj)	Coefficient (kj)
1	Easy mouse operations		1
2	Simple Internet linkup	0.8	1.8
3	Wireless transmission	0.8	1.8
4	Easy of extension	0.7	1.7

Table 5

Order	Issue which is more important	Comparative importance of average value(Sj)	Coefficient (kj)	Recalculated weight(wj)	Final Weight(qj)
1	Easy mouse operations		1	1	1/2.045 = 0.488
2	Simple Internet linkup	0.8	1.8	1/1.8 = 0.556	0.556/2.045 =0.271
5	Wireless transmission	0.8	1.8	0.556/1.8 = 0.308	0.308/2.045 = 0.151
6	Easy of extension	0.7	1.7	0.308/ 1.7= 0.181	0.181/2.045 = 0.089
				Sum= 2.045	

Figure 4. 7 Final weight for "Interference User Friendliness" by SWARA method

F. <u>Convenience of Use</u>

Table 1

Order	Decision variable(Customer need)
2	Large screen size
3	Wrist will not suspended
4	No interference when press the keyboard
1	Monitor display clarity

Table 2

Order	Issue which is more important	Relative importance	In comparison to the issue
1	Monitor display clarity	90%	Large screen size
2	Large screen size	60%	Wrist will not suspended
3	Wrist will not suspended	20%	No interference when press the keyboard
4	No interference when press the keyboard		

Table 3

Order	Issue which is more important	Comparative importance of average value(Sj)
1	Monitor display clarity	0.90
2	Large screen size	0.60
3	Wrist will not suspended	0.20
4	No interference when press the keyboard	

Table 4

Order	Issue which is more important	Comparative importance of average value(Sj)	Coefficient (kj)
1	Monitor display clarity		1
2	Large screen size	0.9	1.9
3	Wrist will not suspended	0.6	1.6
4	No interference when press the keyboard	0.2	1.2

Table 5

Order	Issue which is more important	Comparative importance of average value(Sj)	Coefficient (kj)	Recalculated weight(wj)	Final Weight(qj)
1	Monitor display clarity		1	1	**1/2.128 = 0.469**
2	Large screen size	0.9	1.9	1/1.9 = 0.526	**0.556/2.128 =0.262**
5	Wrist will not suspended	0.6	1.6	0.526/1.6 = 0.328	**0.328/2.128 = 0.154**
6	No interference when press the keyboard	0.2	1.2	0.328/ 1.2= 0.274	**0.274/2.128 = 0.128**
				Sum= 2.128	

Figure 4. 8 Final weight for "Convenience of Use" by SWARA method

The following summary provides a comprehensive overview of the total weight. This weight should always be between zero and one.

Table 4. 2 Final weights of QFD phase 1

Customers' Need:	Final Weight
1. CPU Speed	0.268
2. Battery life	0.482
3. Video playback quality	0.0925
4. Monitor resolution	0.157
5. Infrequent need to reboot	0.424
6. Low failure rate for peripheral component	0.168
7. Battery service life	0.065
8. Product durability	0.105
9. Endurable impact	0.235
10. Multimedia Functionalities	0.357
11. Feasible for externally docked peripherals	0.642
12. Not excessively heavy or unwisely	0.465
13. Smaller overall product dimensions	0.258
14. Minimal need for externally docked peripherals	0.115
15. Minimal weight for externally docked peripherals	0.161
16. Easy mouse pad operations	0.488
17. Simple internet linkup	0.271
18. Wireless transmission	0.151
19. Easy extension	0.089
20. Large screen size	0.262
21. Wrist will not suspend	0.154
22. No interference when pressing the keyboard	0.128
23. Monitor display clarity	0.469

Figure 4. 9 Final weight for QFD Phase one represented by the pie chart

4.5.1.3 CORRELATION MATRIX

In QFD there can be one matrix which is called the correlation matrix which shows the correlation between the technical specification of QFD phase one. The House of

Quality (HOQ) is composed of several chambers. This design correlation matrix occupies one of the chambers. Ithas a triangular form. It is also known as the "Roof of HOQ" due to its location atop HOQ.

Here, four symbols can be used to depict the relationship between each technical specification. Which are:

++ (Strong positive)

+(positive)

0(No correlation)

-(Negative)

--(Strong Negative)

The roof or correlation matrix is given below:

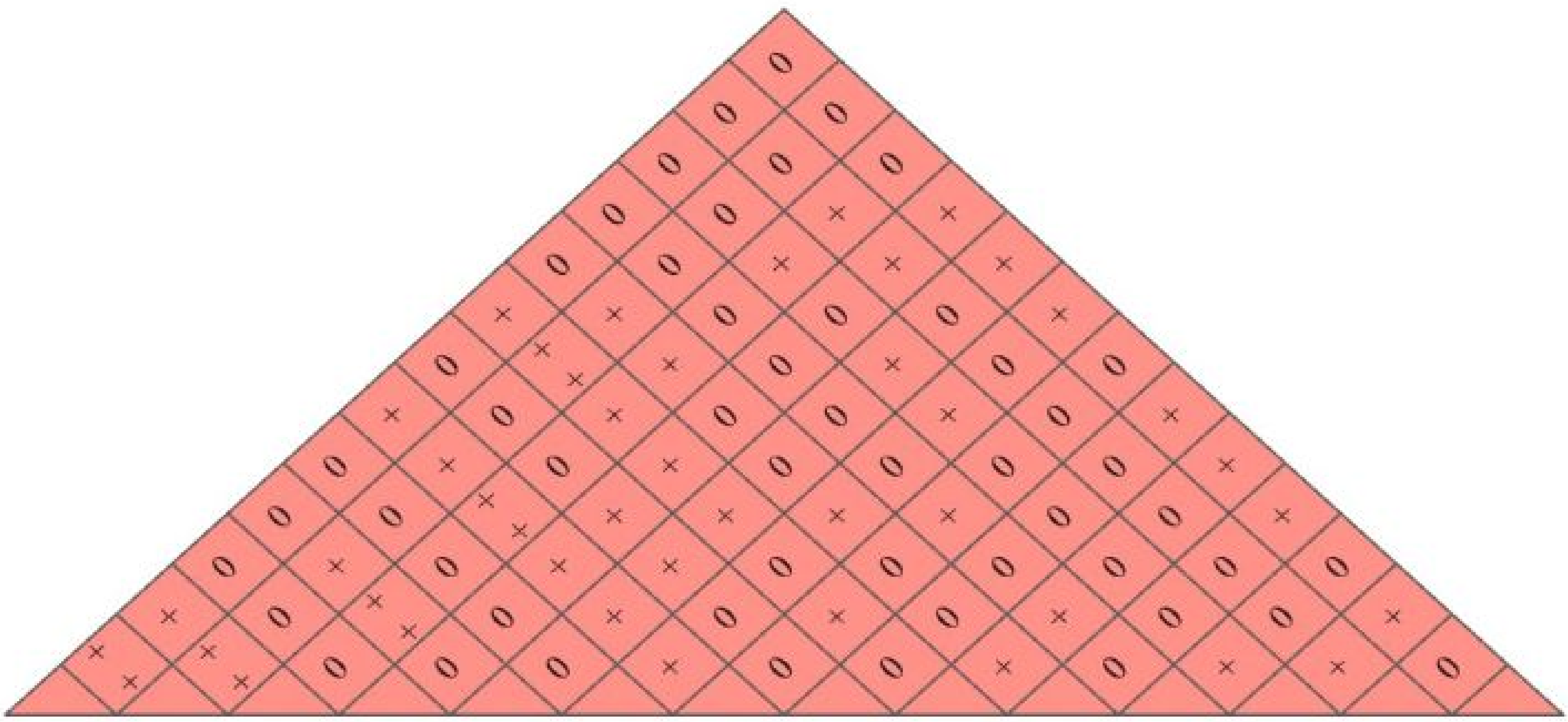
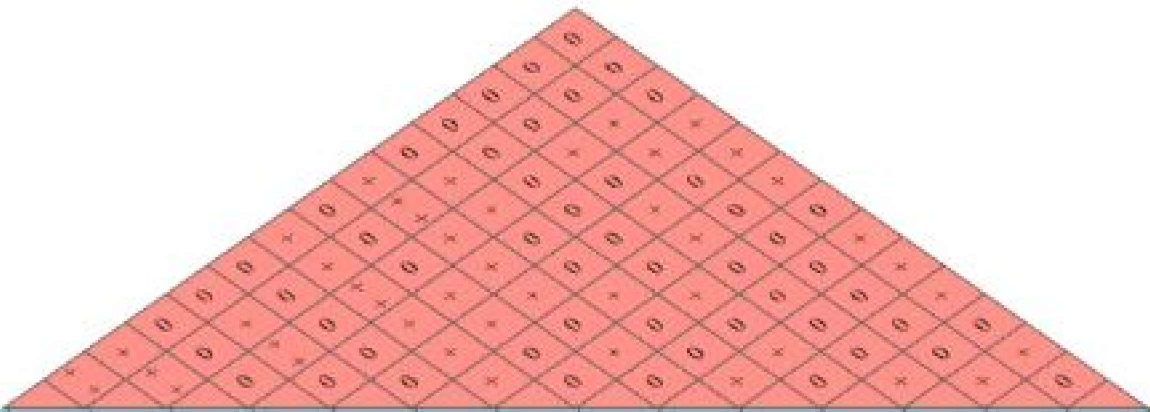


Figure 4. 10 Roof of HOQ aka correlation matrix

In this investigation, there is no evidence of a negative or substantial negative correlation. Additionally, it is observable that there are a small number of robustly positive relationships. It expresses freedom for the manufacturer, as the plant can enhance any required componentwithout considering the potential negative effects on other components.

4.5.1.4 HOQ OF QFD PHASE ONE



	Technical Specification / Customers need	Head dissipation efficiency	CPU speed	Memory Capacity	LCD Functions	Storage media functionality	Audio Quality	Structural integrity	Weight	Power management efficiency	Software integration	Battery efficiency	Material recickibility	Network data transfer convenience	Compatibility with external peripherals	Final Weight
High performance	CPU Speed	0	9	9	3	3	0	0	0	3	9	9	0	9	0	0.268
	Battery life	9	9	0	1	3	1	9	0	9	9	9	9	0	1	0.482
	Video playback quality	0	9	9	9	0	0	9	0	0	9	0	9	9	0	0.0925
	Monitor resolution	0	0	0	9	0	0	3	0	0	0	0	0	3	1	0.157
High Reliability	Infrequent need to reboot	9	0	3	0	3	0	3	0	1	3	0	0	0	0	0.424
	Low failure rate for peripheral component	3	0	3	0	0	0	3	0	9	1	3	3	0	1	0.168
	Battery service life	9	3	0	3	0	0	9	0	9	9	3	9	1	9	0.065
	Product durability	0	0	0	0	0	0	9	9	0	0	0	9	0	0	0.105
	Endurable to impact	0	0	0	0	0	0	9	0	0	0	0	0	9	0	0.235
Function completeness	Multimedia Functionalities	1	9	1	0	0	9	9	0	0	0	0	3	3	9	0.357
	Feasible for externally docked peripherals	0	0	0	0	3	3	3	0	3	3	3	9	0	9	0.642
Ease of mobility	Not excessively heavy or unwidely	0	0	0	9	0	0	1	9	1	0	3	9	0	1	0.465
	Smaller overall product dimensions	0	0	0	3	0	0	9	9	0	0	0	9	0	0	0.258
	Minimal need for externally docked peripherals	0	0	0	0	0	0	3	0	0	0	0	0	1	0	0.115
	Minimal weight for externally docked peripherals	0	0	0	0	0	0	0	0	9	0	0	9	0	0	0.161
Interface user friendliness	Easy mouse pad operations	0	1	1	0	0	0	3	0	0	1	3	9	0	9	0.488
	Simple internet linkup	0	3	3	0	0	0	9	0	1	3	3	1	9	9	0.271
	Wireless transmission	0	1	1	0	0	0	3	0	0	3	0	9	9	9	0.151
	Easy of extension	0	0	0	0	0	0	9	0	1	3	3	1	9	9	0.089
convenience of use	Large screen size	0	0	0	3	0	0	9	0	9	0	0	9	0	0	0.262
	Wrist will not suspended	0	0	0	0	0	0	9	0	0	0	0	9	0	0	0.154
	No interference when press the keyboard	0	0	0	0	0	0	9	0	0	0	0	0	0	0	0.128
	Monitor display clarity	0	3	1	9	0	0	9	0	3	1	0	9	0	0	0.469
	Importance weighting	9.6	13.8	7.2	13.6	5.4	5.6	33.6	7.4	15.6	14	13.3	36.1	10.8	19.8	
	Ranking	10	6	12	7	14	13	2	11	4	5	8	1	9	3	

Figure 4. 11 HOQ of QFD Phase One

4.5.1.5 DISCUSSION

Quality Function Deployment (QFD) The voice of the consumer (VOC) is collected and translated into technical requirements for the product or service during Phase One, also known asthe planning phase. As shown above, the output of this phase is typically a matrix known as the House of Quality (HOQ) that graphically depicts the relationship between customer requirementsand the technical requirements required to meet them. The decisions that can be made based on QFD Phase One depend on the nature of the project andthe data collected during the VOC process. The decision we can make based on the large HOQ isprovided below.

1. <u>Prioritization of customer requirements</u>

The HOQ facilitates the prioritization of customer requirements by designating relative importance weights to each requirement. This information can be used to determine which manufacturing product requirements are most crucial to its success. For this Doel laptop, we can see that the problem or demand that consumers have the most is listed below.

Table 4. 3 Prioritization of customer requirement

Section of Requirement	Most Required Problem	Final weight
High performance	Battery life	0.482
High Reliability	Infrequent need to reboot	0.424
Function Completeness	Feasible for externally docked peripherals	0.642
Ease of Mobility	Easy mouse pad operations	0.488
Interference User Friendliness	Simple internet linkup	0.271
Convenience of Use	Monitor display clarity	0.469

To understand more about this most common problem of customers, it's always important toknow their voice properly. That is why this study has included the problem described in this

discussion section which is viewed below. Going through this problem can come up with abetter solution in the upcoming days.

i. Battery Life

The term "battery life" in reference to laptops refers to how long a laptop may run without needing to be recharged. A laptop's battery life is affected by a number of variables, including thebattery capacity, how the laptop is used, the brightness of the display, and the power settings. Depending on the laptop model, the battery life can typically range from a few hours to several hours. Reducing display brightness, turning off unnecessary features and components, and changing power settings to a more energy-efficient mode can all help to increase battery life. Longer battery life can also be achieved by selecting a laptop with a larger battery and an energy- efficient processor. It's crucial to remember that a laptop's battery life declines over time as it ages and finally needs to be replaced.

ii. Infrequent Need to Reboot

The frequency with which a user must restart the computer to fix performance problems or install updates is referred to as the requirement to reboot a laptop. A laptop that only occasionally needs to reboot is one that operates smoothly and effectively without requiring frequent restarts. The operating system, any installed software, and any hardware components can all have an impact on the requirement to restart a laptop.

iii. Feasible for externally docked peripherals

A laptop's capacity to connect to and use external devices, such as a keyboard, mouse, monitor,or other peripherals, through a docking station is referred to as the feasibility of an external docking peripheral. With the help of a docking station, you may use just one connection to connect your laptop to many accessories. A variety of variables, such as the type of laptop, the kind of docking station, and the kinds of peripherals you want to connect, will determine whetherusing an external docked peripheral is practical.

iv. Easy mouse operations

Typically, there are a few various ways to utilize a laptop mouse, including a touchpad, an external mouse, or a touch screen (if accessible).

The majority of laptops have a touchpad that you may use to move the cursor by gliding your finger across. You can scroll by moving two fingers up and down on the touchpad, right-click by tapping with two fingers, and left-click by touching the touchpad.

External Mouse: You can utilize a USB port on your laptop to attach an external mouse if you'd rather use a real mouse. This works similarly to a desktop mouse and is excellent for precise operations.

v. Simple internet linkup

You'll need the following items to set up a basic internet connection for your laptop:

A gadget that links your laptop to the internet is a modem or router. The router links numerous devices to the same network, whereas the modem connects to your ISP's network.

Ethernet cable: a cable used to link your laptop and modem or router.

Wireless adapter: In order to connect to a wireless network if your laptop does not alreadyhave one, you will need to buy an external wireless adapter.

An organization that provides internet connectivity is an internet service provider (ISP). A monthly access fee and signing up for an internet plan with an ISP are required.

vi. Monitor display clarity

Display clarity is the degree to which text, images, and other visual elements on a computer monitor are precise and distinct. Multiple factors, including resolution, pixel density, contrast ratio, and viewing angle, can influence the lucidity of a computer monitor's display.

2. Identification of technical requirements:

The HOQ also aids in identifying the technical requirements required to meet consumer specifications. The design and development of the product or service can be guided by these technical specifications. To meet the requirements of the product of this study, a laptop, the organization should anticipate the following technical specifications.

Table 4. 4 Identification of technical requirements

Ranking	Technical Specification	Importance Weighting
10	Head dissipation efficiency	9.6
6	CPU speed	13.8
12	Memory Capacity	7.2
7	LCD Functions	13.6
14	Storage media functionality	5.4
13	Audio Quality	5.6
2	Structural integrity	33.6
11	Weight	7.4
4	Power management efficiency	15.6
5	Software Integration	14
8	Battery efficiency	13.3
1	Material receivability	36.1
9	Network data transfer convenience	10.8
3	Compactivity with external peripherals	19.8

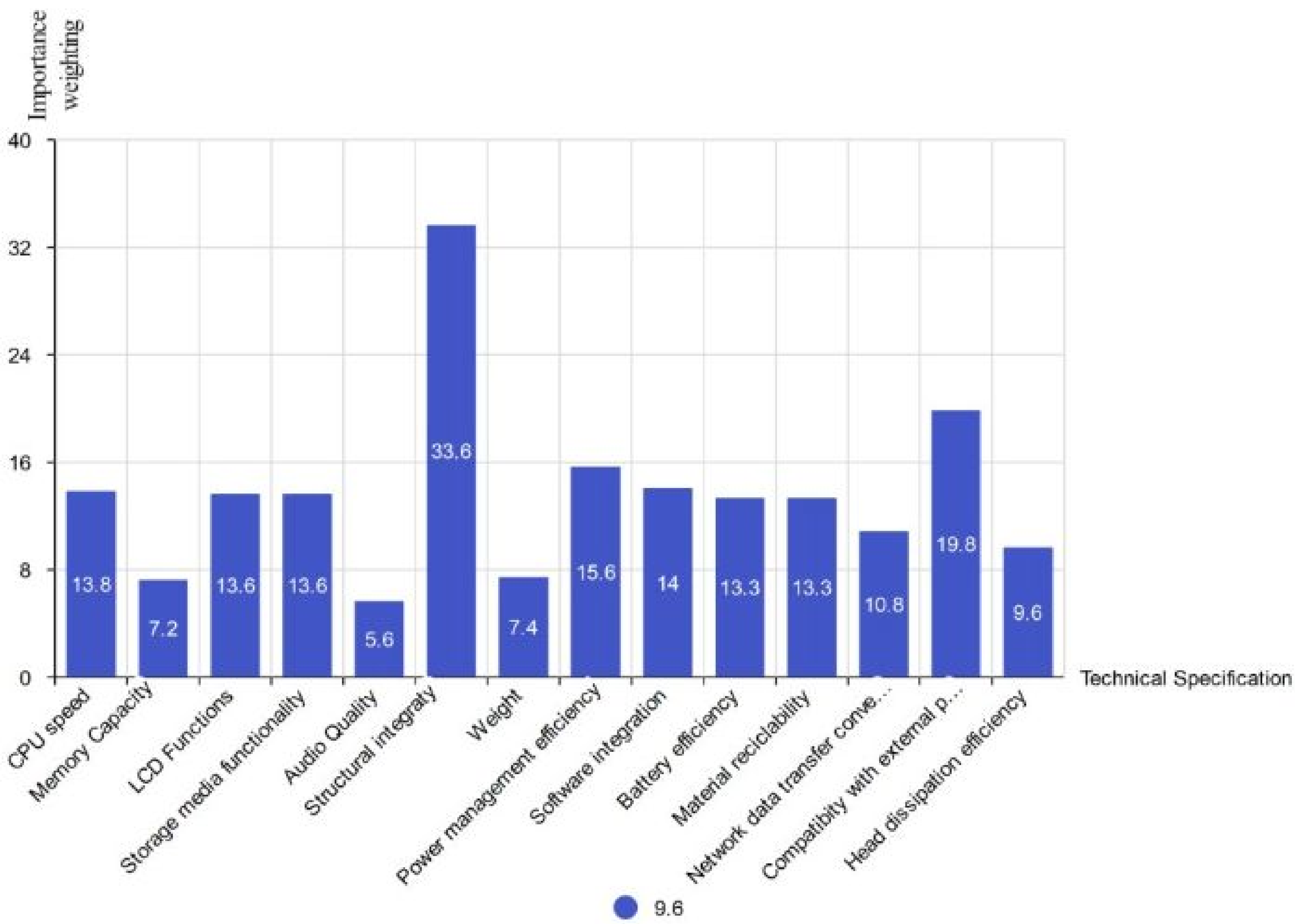


Figure 4. 12 Identification of technical requirements by the column chart

Therefore, the laptop manufacturing plant TSS should continue to concentrate on developing the categories outlined below, as their ranking is high and between 1 and 9. The authors included them because the weight of these technical specifications exceeds 10.

However, this is to alert everyone that the two technical specifications with the most weight are Material receive-ability and Structural- integrity. Every customer requirement is stronglyrelated to enhancing these two technical specifications, so they are given a high priority.

Because of the facility receives high-quality materials, it can enhance all of the product's components and characteristics. Therefore, material receivables are assigned the greatest importance weighting by default. Structural integrity is another similar characteristic. Structural integrity refers to a plant's capacity to improve while precisely positioning all of its components. Therefore, the greater an organization's structural integrity, the higher the quality of its output. Thus, the ultimate weighting of structural integrity is substantial.

Therefore, this research will not proceed with QFD phase two and beyond for these two specifications.

In addition to these two specifications, there are seven others that are crucial for the plant. This isa list of them.

1. Compactivity with external peripherals
2. Power management efficiency
3. Software Integration
4. CPU Speed
5. LCD Functions
6. Battery efficiency
7. Network data transfer convenience

In phase one's HOQ, the relationship between this specification and the CR (customer requirement) is described in terms of its importance. In the subsequent section, the second phase of QFD discusses these requirements in detail.

4.5.2 QFD PHASE TWO

This phase is well known as the product design phase. Here as we discussed before the technical design features will become WHATs and the critical parts and characteristics will be acknowledged as HOWs of the HOQ matrix. So, in this phase, this study will start with this and end with this.

4.5.2.1 TECHNICAL DESIGN FEATURES

It is essential for a production plant to concentrate on the QFD phase one-described technical design characteristics. To continue this research, one must possess exact knowledge of all these specifications. To facilitate familiarity with all these specifications, a brief description of each type is provided below. These enumerated specifications are required to comprehend this work and are also necessary for discussing the decisions.

1. Heat Dissipation Efficiency

The ability of a laptop to dissipate heat produced by its parts (such as the CPU, GPU, and power supply) into the environment is referred to as heat dissipation efficiency. This is crucial because, over time, prolonged exposure to high temperatures can permanently damage the laptop and affect its stability and performance.
The internal component arrangement and design, the material used for the casing and cooling components (such as fans, heat sinks, and thermal paste), and the ambient temperature all affect how effectively a laptop dissipates heat. Components that are evenly positioned to allow for air circulation and a cooling system that can efficiently move heat away from the components are characteristics of a laptop with good heat dissipation efficiency. A properly constructed laptop should also have adequate ventilation to let hot air out and cool air in, maintaining the internal temperature within acceptable ranges.

2. CPU Speed

The number of instructions a laptop's CPU can execute in a second is measured by its clock speed, which is frequently referred to as just speed. The unit of measurement is often GHz (gigahertz), where 1 GHz equals 1 billion cycles per second. A faster CPU has a higher clock speed because it can finish more jobs in a given period of time. The clock speed should not be taken into account in isolation, though, as it is only one of several elements that affect a laptop's overall performance. The number of cores, the effectiveness of the CPU architecture, and the accessibility of additional hardware resources like memory and storage are further factors.

3. Memory capacity

The amount of RAM (Random Access Memory) that is installed in a laptop is referred to as its memory capacity. The processor of the laptop uses RAM, a volatile memory, to temporarily store data and instructions while they are being processed. A laptop's memory capacity is often represented in GBs (gigabytes), with higher numbers suggesting a greater capability for memory storage. This may have an effect on the laptop's overall performance because more memory allows for quicker data access and more seamless multitasking. It's crucial to remember that other elements, including as the processor's clock speed and the effectiveness of the laptop's architecture, can also influence how well a device performs overall.

4. LCD Functions

Laptops frequently use the display technology known as LCD (Liquid Crystal Display). The LCD works by illuminating microscopic pixels on a screen using a backlight, which is subsequently utilized to show text and images. The backlight, which is situated behind the screen, is commonly made up of either CCFL (cold cathode fluorescent lamp) or LED (light emitting diode) lights. The images that are displayed are then produced by a layer of liquid crystals manipulating the pixels on the screen to let or block light. The purposes of an LCD screen in a laptop include showing text and graphics, displaying video, and offering a visible image in a small package. Additionally, a lot of LCD screens have brightness and contrast settings that can be altered, enabling users to customize the display for various lighting situationsand tastes. Some LCD screens have touch capabilities as well, enabling users to interact with the screen directly as opposed to only using a keyboard and mouse. Overall, a laptop's LCD screen is essential since it serves as the main interface for interacting with and viewing content.

5. Storage Media Functionalities

The devices, such as the hard drive or solid-state drive (SSD), used to store data and files are referred to as storage media in a laptop. Even when the laptop is off, these storage media continue to function by using magnetic or flash memory to store and retain data. Storage media on a laptop serve primarily as a permanent and convenient repository for data and files. Users may now save and access a lot of data, including documents, photographs, movies, and programs, even after turning off their laptops. The operating system and other applications can also be kept on storage media, enabling the laptop to start and function properly. The kind and size of a laptop's storage device can affect the device's overall performance and user interface. For instance, a greater capacity drive can store more data and files while an SSD is typically speedier and more dependable than a conventional hard disk. When buying a laptop, it is crucial to carefully analyze your storage media alternatives because they can significantly affect the device's functioning and usability.

6. Audio Quality

The sound quality that is produced by a laptop's speakers or headphones is referred to as its audioquality. The kind and caliber of the speakers, the laptop's processing power, and the audio software being utilized can all have an impact on this. The main goal of a laptop's audio system is to give the user a pleasant and clear listening experience when they are listening to music, videos, or other audio content. While a lower-quality audio system could provide tinny ormuffled sound, a higher-quality audio system can produce rich, detailed sound with distinct highs, minds, and lows. It is crucial to remember that a laptop's audio quality might differ significantly from model to model and even from laptop to laptop within a single model. The overall audio quality can be affected by elements such as the speaker's design and the materials utilized in its manufacturing. Although the internal speakers are still a vital component of the overall audio experience, a laptop can also be linked to external speakers or headphones to improve the audio quality.

7. Weight

A laptop's physical weight, which is typically stated in pounds or grams, is referred to as its weight. Many users value this number because it has an effect on the laptop's portability and use. The main purpose of a laptop's weight is to demonstrate how lightweight and transportable the gadget is. A lighter laptop is typically more portable and convenient to carry, whereas a heavier laptop may be more difficult to move around. Users that must carry their laptops with them whenon the road, such students or business travelers, may find this to be of particular importance. It is crucial to remember that a laptop's weight can vary significantly depending on its size and design, with larger and more feature-rich machines typically weighing more than smaller, simpler models. The weight of the laptop can also be affected by the components used to make it, such as carbon fiber, metal, or plastic. When weighing a laptop, it's crucial to strike a balance between portability requirements and the necessity for a larger, more powerful computer that canhandle demanding tasks.

8. Power Management Efficiency

A laptop's capacity to manage and preserve energy is referred to as its power management efficiency. This may have an effect on the laptop's battery life and general performance. The main goal of effective power management in a laptop is to make sure that the machine makes efficient use of its energy sources. This may entail lowering the power consumption of inactive components, modifying the device's performance in accordance with its workload, and utilizing power-saving modes to increase battery life. extended battery life for the laptop may enable consumers to utilize it for extended periods of time before recharging thanks to superior power management efficiency. The effectiveness of the laptop's power management system can also have an impact on how well it performs because a more effective system may be better able to handle demanding workloads. The hardware components of the laptop, the software and drivers the device uses, and the settings and preferences made by the user can all have an impact on how effectively power is managed. It is crucial to consider the user's unique wants and requirements when evaluating the effectiveness of a laptop's power management system, as well as the battery life and performance capabilities of the gadget.

9. Software Integration

Software integration is the process of combining multiple software components to produce an integrated and useful system. Software integration in the context of a laptop refers to the blending of several software applications and programs to produce a cohesive user experience. This can involve integrating the operating system (like Windows, Mac OS, or Linux), drivers for hardware elements (such the touchpad, camera, and speakers), and a variety of programs and utilities (including a web browser, email client, and media player). The purpose of software integration is to provide the user with a seamless experience in which all software and hardware components are recognized and function as intended. APIs, defined protocols, and software development tools can all be used to create this connection.

10. Battery Efficiency

The amount of energy that a laptop battery can efficiently store and utilize is referred to as battery efficiency. It establishes how long a laptop can operate between charges and how well it can manage demanding tasks that use more power.

The size of the battery, the type of battery cells used, the technology utilized to control and regulate the power, and the power consumption of the internal laptop components, such as the processor, graphics card, and screen, all affect how effective a laptop battery is.

Due to their high energy density, lengthy lifespan, and low self-discharge rate, lithium-ion batteries are now the most popular battery type used in laptops. By maintaining the temperature of the battery, controlling the power flow, and preventing overcharging and over-discharging, battery management systems can also aid in improving the battery's performance.

11. Network Data Transfer Convenience

The simplicity and speed with which data can be transported over a network using a laptop is referred to as network transfer convenience. This is an essential component of utilizing a laptop since it affects your capacity to share data, transfer large files, and work in real-time collaboration with others. The type of network connection (such as Wi-Fi, Ethernet, or cellular), the speed of the network connection, and the software and hardware used to manage the network transfer are some of the elements that affect how convenient a laptop is for network transfers.

12. Compatibility with external peripherals

The capacity of a laptop to operate with and connect to other gear, such as printers, scanners, external hard drives, and more, is referred to as compatibility with external peripherals. The operating system of the laptop, the connectivity choices and ports that are available (such as USB, HDMI, and Bluetooth), and the drivers and software that support the peripheral devices are just a few of the variables that affect compatibility. An external hard drive, mouse, keyboard, and other peripherals that use the USB interface should all be able to connect to a laptop that has a USB port, for instance.

4.5.2.2 IMPLEMENTATION OF SWARA FOR FINAL WEIGHT

For the purpose of calculating the ultimate weight, the SWARA method proceeded in phase two. As there is no subgroup in the WHATs (Technical Design Features), the SWARA method has been implemented once, and the ultimate weight for phase two has been determined. Theimplementation result is depicted in the figure below.

Table 1

Order	Decision variable(Customer need)
1	CPU
2	Memory
3	Battery
4	Software
5	Storage
6	LCD Functions
7	Network
8	Weight
9	Peripheri
10	Power
11	Heat
12	Audio

Table 2

Order	Issue which is more important	Relative importance	In comparison to the issue
1	Cpu	57%	Memory
2	Memory	0%	Battery
3	Battery	35%	Software
4	Software	33%	Storage
5	Storage	0%	LCD Funtions
6	LCD Functions	0%	Network
7	Network	88%	Weight
8	Weight	0%	Peripheri
9	Peripheri	88%	Power
10	Power	88%	Heat
11	Heat	75%	Audio
12	Audio		

Table 3

Order	Issue which is more important	Comparative importance of average value(Sj)
1	Cpu	0.57
2	Memory	0
3	Battery	0.35
4	Software	0.33
5	Storage	0
6	LCD Functions	0
7	Network	0.88
8	Weight	0
9	Peripheri	0.88
10	Power	0.88
11	Heat	0.75
12	Audio	

Table 4

Order	Issue which is more important	Comparative importance of average value(Sj)	Coefficient (kj)
1	Cpu		1
2	Memory	0.57	1.57
3	Battery	0	1
4	Software	0.35	1.35
5	Storage	0.33	1.33
6	LCD Functions	0	1
7	Network	0	1
8	Weight	0.88	1.88
9	Peripheri	0	1
10	Power	0.88	1.88
11	Heat	0.88	1.88
12	Audio	0.75	1.75

Table 5

Order	Issue which is more important	Comparative importance of average value(Sj)	Coefficient (kj)	Recalculated weight(Wj)	Final Weight(qj)
1	Cpu		1	1	1/4.37 = 0.229
2	Memory	0.57	1.57	1/1.57 = 0.636	0.636/4.37 =0.146
3	Battery	0	1	0.636/1 = 0.636	0.636/4.37 = 0.146
4	Software	0.35	1.35	0.636/ 1.35= 0.471	0.471/4.37 = 0.109
5	Storage	0.33	1.33	0.471/ 1.33= 0.356	0.355/4.37 = 0.081
6	LCD Functions	0	1	0.355/ 1= 0.355	0.355/4.37 = 0.081
7	Network	0	1	0.355/ 1= 0.356	0.355/4.37 = 0.081
8	Weight	0.88	1.88	0.355/ 1.88= 0.189	0.189/4.37 = 0.043
9	Peripheri	0	1	0.189/ 1= 0.189	0.189/4.37 = 0.043
10	Power	0.88	1.88	0.189/ 1.88= 0.10	0.10/4.37 = 0.023
11	Heat	0.88	1.88	0.10/ 1.88= 0.053	0.053/4.37 = 0.012
12	Audio	0.75	1.75	0.053/ 1.75= 0.03	0.03/4.37 = 0.007
				Sum= 4.37	

Figure 4. 13 Final weight for "QFD Phase two" by SWARA method

The result of our investigation is complete. That is the final QFD phase two weight. The following summary provides a comprehensive overview of the total weight. This weight should always be between zero and one.

Table 4. 5 Final weights of QFD phase 2

Technical Design Features	Final Weight
Heat dissipation efficiency	0.012
CPU speed	0.229
Memory capacity	0.146
LCD Functions	0.081
Storage media functionality	0.081
Audio quality	0.007
Combability with external peripherals	0.043
Weight	0.043
power management efficiency	0.023
Software integration	0.108
Battery Efficiency	0.146
Network data transfer convenience	0.081

In the next section one pie chart has given to have better overview of the final weight of thisphase.

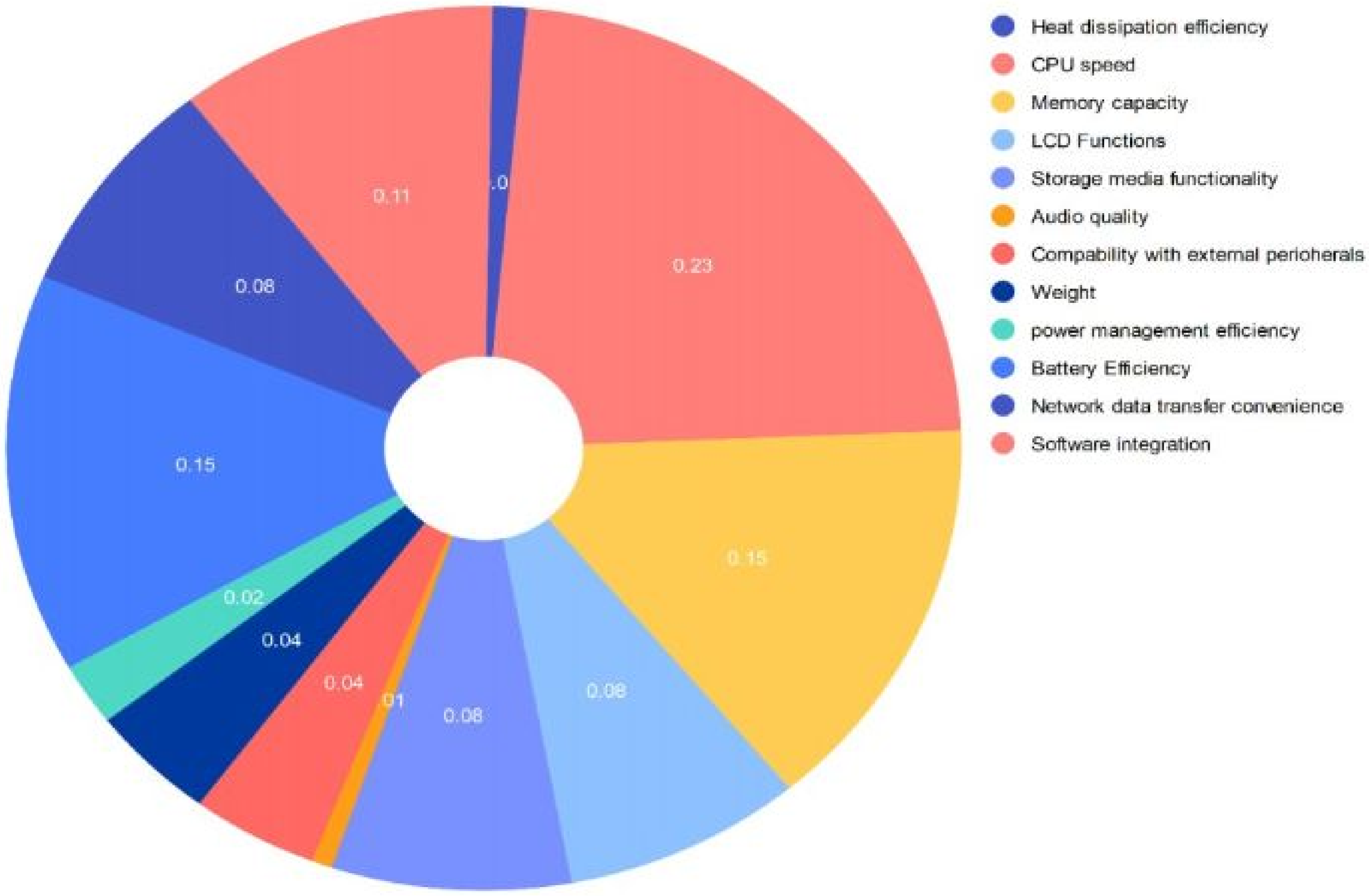


Figure 4. 14 Final weight of QFD phase 2 represented by the pie chart

In the next section whole HOQ of the QFD phase, two have been presented. This matrix also contains the calculated importance weightage for decision-making.

4.5.2.3 HOQ OF QFD PHASE TWO

The SWARA method has been implemented in order to calculate the ultimate weight for QFD phase two. Now is the moment to display the actual matrix of QFD phase two, also known as HOQ (House of Quality). The WAHTs (Technical Design Features) do not exhibit any group formation. Consequently, this HOQ is much simpler than the previous one. The importance weight describes the significance of vital components and attributes. Also ranked similarly to the QFD phase. The technological difficulty section describes the challenges involved in enhancing the HOWs. The final component indicates whether the TSS organization needs to purchase or manufacture the item.

	A cover	B cover	Backlight lamp(LED)	D cover	C cover	PCB assembly	Keyboard	Speakers	Heat dissipation module	Hard disk drive(HDD)	Optical disc drive(ODD)	Memory module	Wireless Internet card	Battery module	External ports	Operating system	Associated components	Final Weight
Heat dissipation efficiency	0	0	0	0	0	0	0	0	9	0	0	0	0	0	0	0	0	0.012
CPU speed	0	0	0	0	0	3	0	0	0	3	0	9	0	0	0	3	0	0.229
Memory capacity	0	0	0	0	0	9	0	0	0	9	9	9	0	0	0	9	0	0.146
LCD Functions	9	9	9	0	3	9	9	0	0	0	0	0	0	0	0	9	0	0.081
Storage media functionality	0	0	0	0	0	9	0	0	0	9	9	3	0	0	0	9	0	0.081
Audio quality	0	0	0	0	0	9	0	9	0	0	0	0	0	0	0	1	0	0.007
Compability with external periopherals	0	0	0	0	0	9	0	0	3	9	9	0	3	0	9	9	0	0.043
Weight	1	1	1	1	1	3	0	0	0	0	0	0	0	3	0	0	0	0.043
power management efficiency	0	0	3	0	0	9	0	0	9	3	0	0	0	1	0	0	0	0.023
Software integration	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9	0	0.108
Battery Efficiency	0	0	1	0	0	3	0	0	3	0	0	0	0	9	0	1	0	0.146
Network data transfer convenience	0	0	0	0	0	1	0	0	0	0	0	0	9	0	0	1	0	0.081
Importance weighting	0.772	0.772	0.987	0.043	0.286	4.764	0.729	0.063	0.768	3.186	2.43	3.618	0.858	1.466	0.387	5.052	0	
Rank	10	9	7	16	14	2	12	15	11	4	5	3	8	6	13	1	17	
Technological dificulty (1-10)	8	8	6	8	8	9	8	5	6	7	5	8	5	9	6	7	5	
Make(m) or Buy(B)	m	m	b	m	m	b	b	b	b	b	b	b	b	b	b	b	m&b	

Figure 4. 15 HOQ of QFD phase two

4.5.2.4 DISCUSSION

Typically, the analysis of the House of Quality matrix from the second phase of QFD entails identifying the key relationships between technical design features and engineering characteristics and determining which engineering characteristics are most crucial for meeting the technical specification. This analysis can be used to inform the design and development of the product or service, ensuring that it satisfies the requirements and expectations of the target market. We've discovered some discussion points for the HOQ of QFD phase two.

1. Important Technical specification

There are several technical design elements that are crucial to consider. These are discovered in phase one of QFD. In addition, the duty person has affirmed the relative significance of the crucial technical specification. Following our standard SWARA procedure, the ultimate weight has been determined. According to this ultimate weight, the four technical characteristics listed below are the most essential to consider for plant TSS.

Table 4. 6 Important technical design features

Technical Design Features (Important)	Final Weight
CPU speed	0.229
Memory capacity	0.146
Battery Efficiency	0.146
Software Integration	0.108

2. Critical parts to focus on

On the basis of the final importance weighting calculation, we can make numerous decisions.

The operating system is the component that requires the most attention in order to meet thetechnical specification requirement.

Backlight lamp, PCB assembly, ODD, HDD, and battery are five additional features to enhanceafter the operating system. These bear a weight of significance greater than 1. The following column chart provides additional insight into this matter

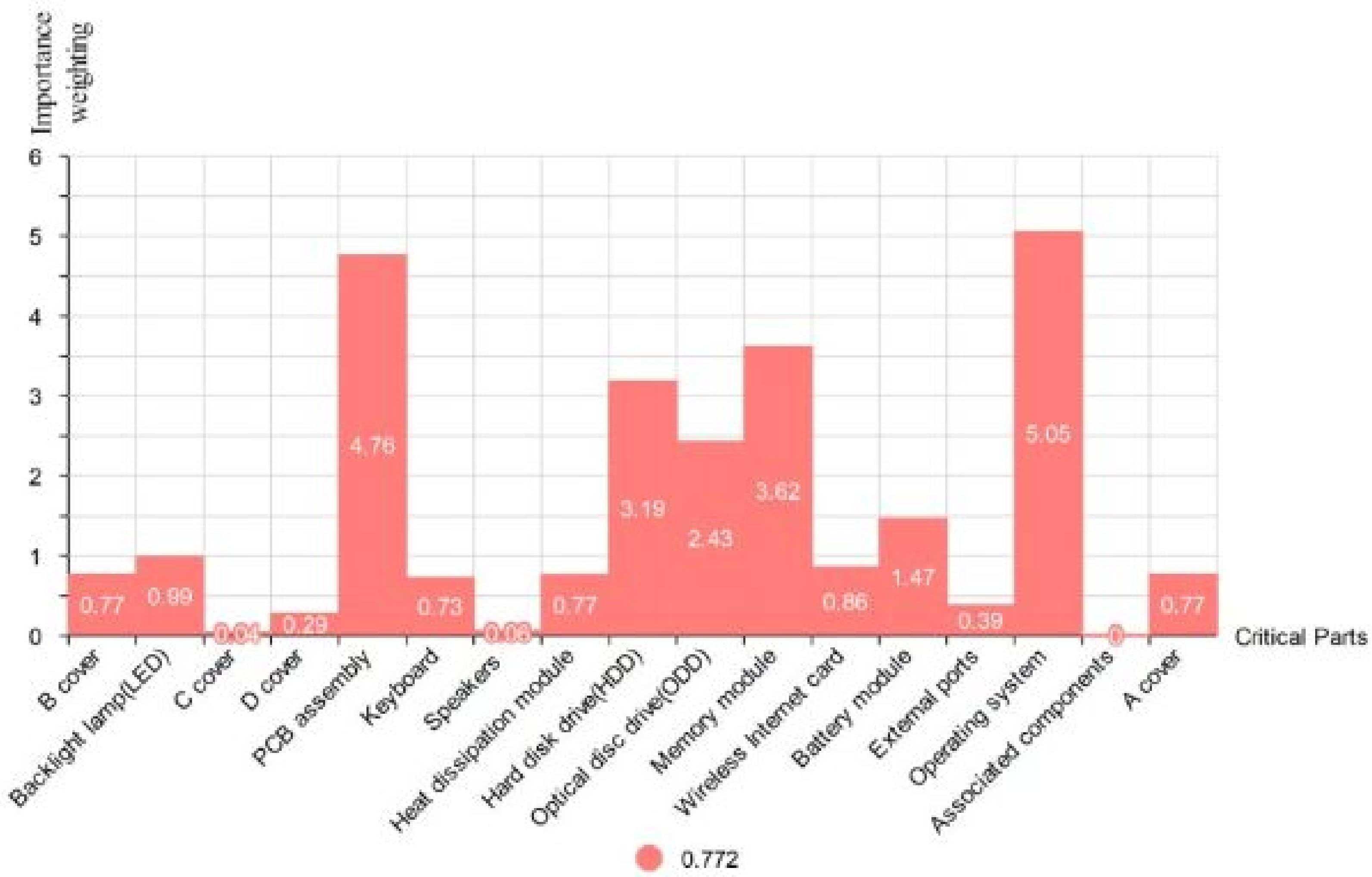
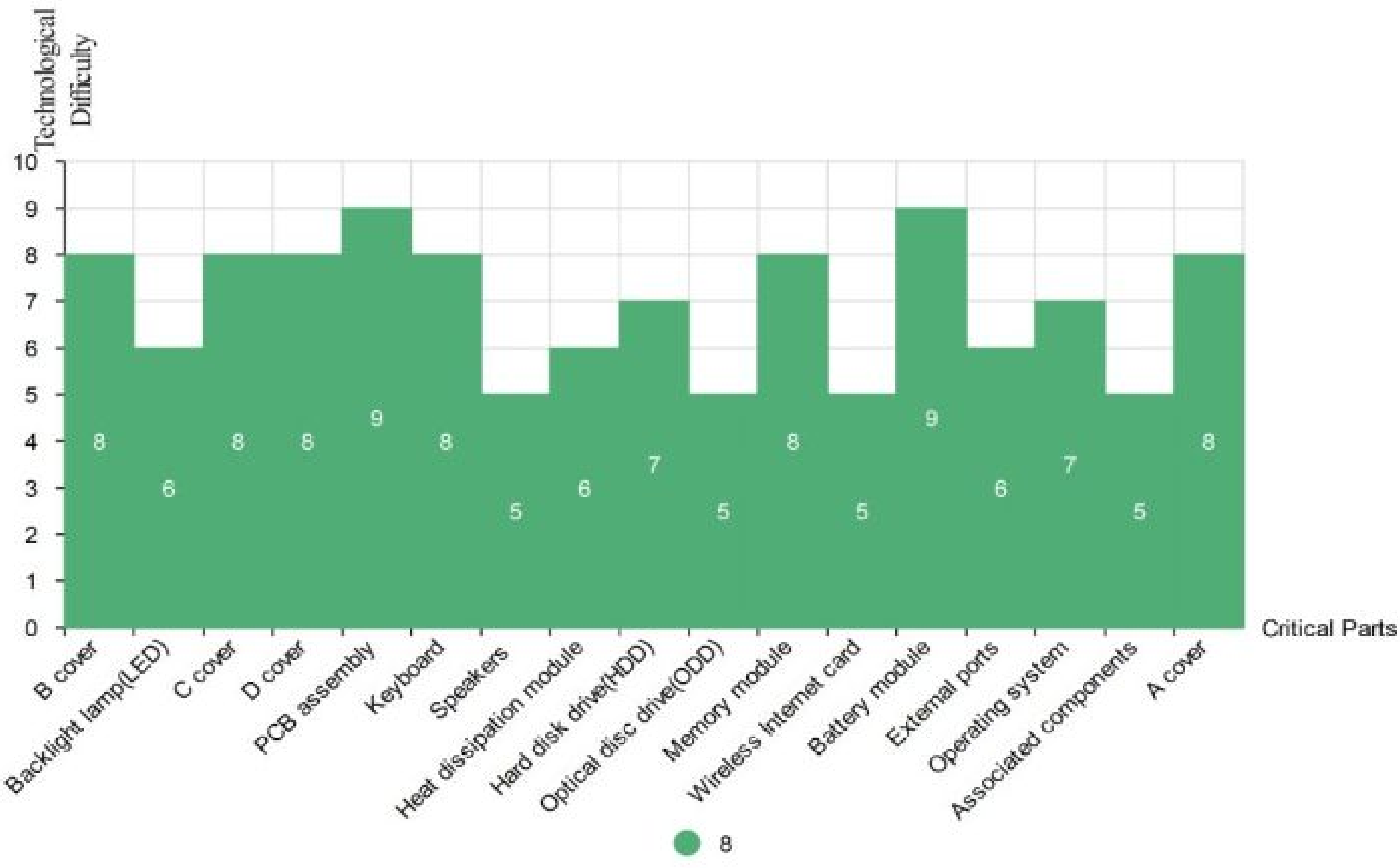


Figure 4. 16 Importance weighting column chart of QFD phase two

According to the significance weighting, there is also a ranking that indicates the critical sections with the highest and lowest importance. All of these items are detailed in the phase two HOQ andthe preceding column chart.

3. Technological difficulty

Despite the fact that the plant TSS should prioritize the critical weighting of the essential component in order to improve their laptop product, the plant TSS should strive for the improvement of their laptop product. However, there is a technological difficulty. Not all components are equally difficult to manufacture, repair, or acquire. Therefore, based on this information, the organization can generate the difficulty rating depicted above at HOQ and below at the column chart.



4. Make or Buy decision:

These all-important components are not purchased by TSS. They are producing A, B, C, and D covers, which are essential for all the components and elements. This laptop cover carries less significance, which is not a negative thing. Now is the time for the plant to expand their facilities and begin manufacturing more and more components as opposed to purchasing and assembling them.

4.5.3 QFD PHASE THREE

The third component of QFD is known as the process planning phase. As a result, the third phase of QFD will focus on the relationship between processes and the crucial elements contained therein. These mechanisms are crucial to the production of various product components. Modifications will be made to the processes based on the findings of the second phase of QFD's development-requirements analysis. To determine which processes are most crucial and imperative to modify, the production team must determine the relationship between each process and its critical components. Phase three of QFD is therefore the most useful instrument. The information and decisions derived from the third phase of QFD are extremely beneficial to the production and quality teams. Here, as we already know, the WHATs will be essential components and qualities, and the HOWs will be Processes.

4.5.3.1 CRITICAL PARTS AND CHARACTERISTICS

Phase two of QFD was characterized by a total of 17 critical components and characteristics, as previously observed. However, not all of them were as significant as their importance weighting suggests. In phase three of the QFD process, 8 such essential components have been selected for further examination. These are enumerated below with brief discussion.

Table 4. 7 Selected Critical parts for QFD phase Three

Serial	Critical parts and characteristics
1	LED
2	ODD
3	SSD
4	Battery

5	PCB assembly
6	HDD
7	Ram
8	OS

1. LED (Light Emitting Diode)

LEDs are a common form of solid-state illumination found in gadgets and lighting fixtures. Theyare composed of a semiconductor device encapsulated in plastic or epoxy resin. When a current of electricity is transmitted through the chip, the material of the chip determines the color of lightemitted. LEDs are renowned for their high energy efficiency, extended lifespan, and minimalheat output. Color (e.g., red, green, blue), luminosity (measured in lumens), voltage rating, and current rating are the primary characteristics of an LED.

2. ODD (Optical Disc Drive)

ODDs are used for reading and writing data on CDs, DVDs, and Blu-ray discs. The disc is spun by a spindle motor and read by a laser head. The optical disc drive's essential components are thelaser head, spindle motor, and tray motor (for opening and closing the disc container). Read and write rates (measured in MB/s), disc format support (e.g., CD, DVD, Blu-ray), and interface type(e.g., SATA or IDE) are the most important characteristics of an optical disc drive.

3. SSD (Solid State Drive)

SSDs are storage device that stores data using NAND-based flash memory. They are quicker andmore reliable than traditional hard disc drives (HDDs) because they lack moving components. Flash memory processors, the controller, and the interface connector (e.g., SATA, NV Me) are the essential components of a solid-state drive (SSD). Capacity (measured in GB or TB), read and write speeds (measured in MB/s), endurance (measured in TBW or DWPD), and power consumption (measured in volts) is the primary characteristics of an SSD.

4. Battery

Batteries are devices for storing and supplying electrical energy. They are frequently utilized in portable electronic devices like smartphones, laptops, and digital cameras. Important battery components include the anode (positive electrode), cathode (negative electrode), electrolyte (conducting solution), separator (to prevent short circuits), and casing (to secure the cell).

Voltage (measured in volts), capacity (measured in ampere-hours), energy density (measured in watt-hours per kilogram), charging time (measured in hours), and cycle life (number of charge/discharge cycles before capacity degradation) are the key characteristics of a battery.

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5. OS (Operating System)

An operating system is a variety of software that manages the computer's resources and provides a platform for launching applications. The operating system controls hardware resources including the CPU, memory, and storage, as well as input/output devices including the keyboard,mouse, and display. Microsoft Windows, macOS, and Linux are popular examples of operating systems. The essential components of an operating system are the kernel (the core componentthat manages resources and communicates with hardware), the device drivers (software that enables the communication between the OS and hardware devices), and the user interface (the visual interface that enables users to interact with a computer). The primary characteristics of an operating system are stability, security, application and hardware compatibility, and usability.

6. Assembling a PCB (Printed Circuit Board)

PCBs are boards that connect and sustain electronic components via conductive traces and terminals. They are utilized in virtually all electronic devices, from smartphones to automobiles. The critical components of a printed circuit board assembly are the substrate material (typically fiberglass or epoxy resin), the copper traces (to connect the components), the vias (to connect various layers), the pads (to attach components), and the solder mask (to secure the board). The main characteristics of a PCB assembly are dimensions (measured in inches or millimeters), number of layers (typically 1-10), thickness (typically 0.6-1.6mm), and electrical performance (such as impedance and signal integrity).

7. HDD (Hard Disc Drive)

HDDs are storage device that stores data using rotating discs and magnetic heads. They have been extensively used in computers for decades, but are being progressively replaced by solid- state drives (SSDs). The important components of a hard disc drive are the platters (spinning discs), the read/write heads (to receive and write data), the spindle motor (to rotate the discs), and the actuator arm.

8. RAM (Random Access Memory)

RAM is a form of computer memory used to temporarily store data that the CPU (Central Processing Unit) requires fast access to. RAM is volatile, so its contents are gone when the computer is powered down. Memory modules (typically DIMMs or SO-DIMMs), memoryprocessors (typically DRAM or SRAM), and the memory controller (integrated into the CPU or motherboard) are essential RAM components. RAM's main characteristics are capacity.

4.5.3.2 IMPLEMENTATION OF SWARA FOR FINAL WEIGHT

Here, the SWARA method will be utilized for the final time. As there are only eight WHATs in this phase three, there is no subgroup available. The SWARA method has enabled the placement of eight weights in the HOQ of QFD phase three. As before, these 8 values will range from zero to one. The heavier the object, the more likely and difficult it is to modify the critical component. Consequently, the quality control and plant process teams should anticipate the processes with care based on the relative weight of the components.

Table 1

Order	Decision variable(Customer need)
1	PCB Assembly
2	LED
3	SDD
4	HDD
5	RAM
6	Battery
7	OS
8	ODD

Table 2

Order	Issue which is more important	Relative importance	In comparison to the issue
1	PCB Assembly	57	LED
2	LED	33	SDD
3	SDD	57	HDD
4	HDD	0	RAM
5	RAM	33	Battery
6	Battery	53	OS
7	OS	75	ODD
8	ODD		

Table 3

Order	Issue which is more important	Comparative importance of average value(Sj)
1	PCB Assembly	0.57
2	LED	0.33
3	SDD	0.57
4	HDD	0
5	RAM	0.33
6	Battery	0.53
7	OS	0.75
8	ODD	

Table 4

Order	Issue which is more important	Comparative importance of average value(Sj)	Coefficient (kj)
1	PCB Assembly	0	1
2	LED	0.57	1.57
3	SDD	0.33	1.33
4	HDD	0.57	1.57
5	RAM	0	1
6	Battery	0.33	1.33
7	OS	0.53	1.53
8	ODD	0.75	1.75

Table 5

Order	Issue which is more important	Comparative importance of average value(Sj)	Coefficient (kj)	Recalculated weight(wj)	Final Weight(qj)
1	PCB Assembly	0	1	1	1/2.89 = 0.346
2	LED	0.57	1.57	1/1.57=0.636	0.636/2.89 =0.221
3	SDD	0.33	1.33	0.636/1.33=0.478	0.0.478/2.89 = 0.166
4	HDD	0.57	1.57	0.478/1.57=0.305	0.305/2.89 = 0.106
5	RAM	0	1	0.305/1=0.305	0.305/2.89 = 0.106
6	Battery	0.33	1.33	0.305/1.33=0.229	0.229/2.89 = 0.0796
7	OS	0.53	1.53	0.229/1.53=0.15	0.0.15/2.89 = 0.0519
8	ODD	0.75	1.75	0.15/1.75=0.086	0.0.086/2.89 = 0.0297
				Sum= 2.89	

Figure 4. 17 SWARA for QFD phase three

The look into the matter has been concluded and the findings are comprehensive. This represents the conclusive weight of the second phase of the Quality Function Deployment (QFD) process. The ensuing synopsis offers a thorough and all-encompassing examination of the aggregate mass.

Table 4. 8 Final weights of QFD phase 3

Serial	Critical parts and characteristics	Final weight
1	LED	0.221
2	ODD	0.0297
3	SSD	0.166
4	Battery	0.0796
5	PCB assembly	0.346
6	HDD	0.106
7	Ram	0.106
8	OS	0.0519

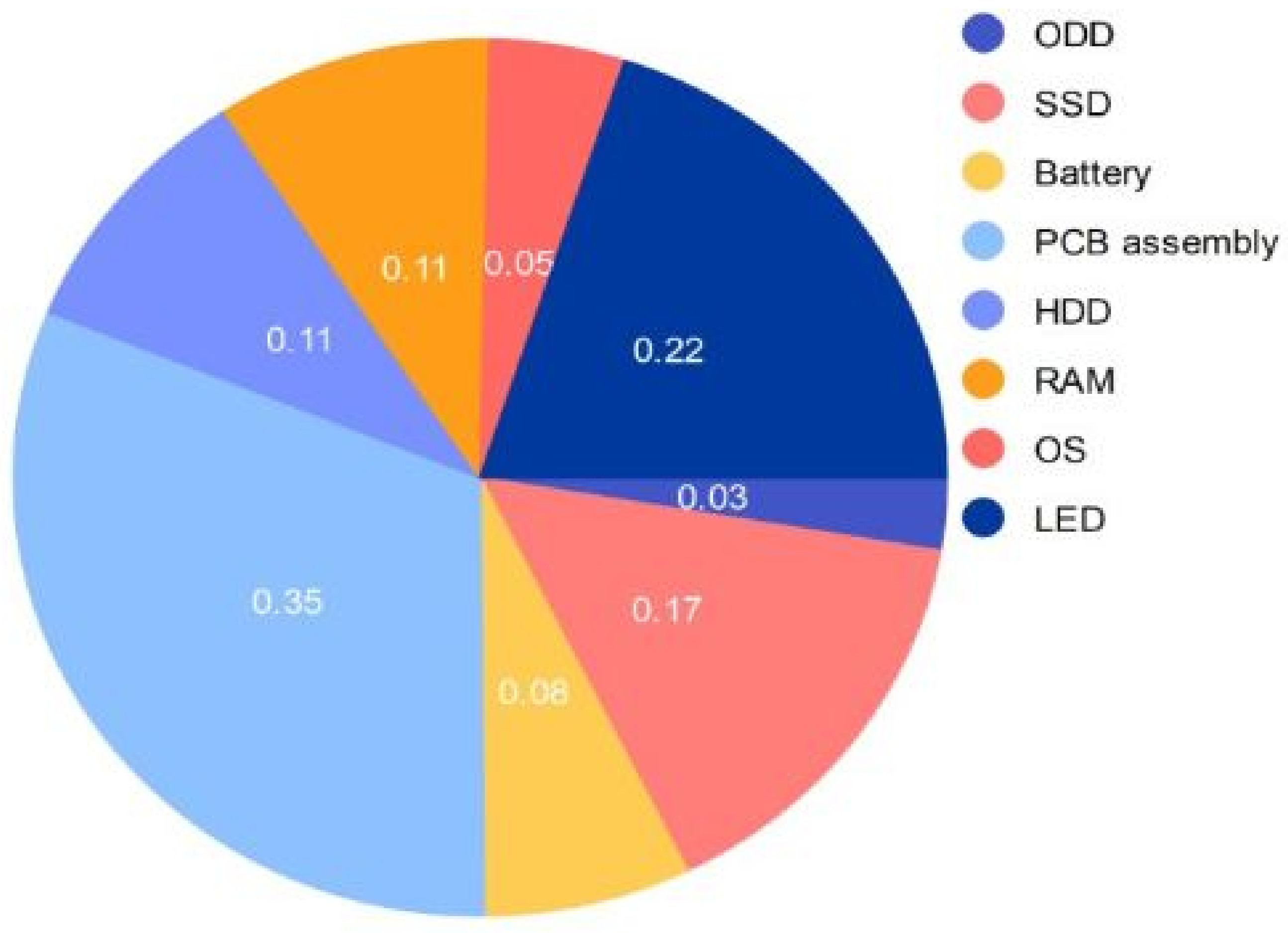

Figure 4. 18 Final weight of QFD phase 2 represented by the pie chart

4.5.3.3 HOQ OF QFD PHASE THREE

The SWARA technique has been employed to determine the final weightage for the Quality Function Deployment's second phase. Presently is the opportune time to exhibit the factual matrix of Quality Function Deployment's second phase, commonly referred to as the House of Quality (HOQ). The critical components and characteristics of the WAHTs do not display any discernible patterns of group formation. Thus, it can be inferred that the House of Quality (HOQ) in question is comparatively less complex than the preceding two. The concept of importance weight pertains to the relative significance of essential elements and characteristics. Likewise positioned in rank with the QFD phases one and two.

Parts \ Processes	Injection Molding	Spray Painting	Hard-disc Cloning	SKD Assembly	Testing	Packing	Final Weight
LED	0	0	0	9	9	0	0.221
ODD	0	0	0	9	9	0	0.0297
SSD	0	0	9	9	9	0	0.166
Battery	0	0	0	9	9	0	0.0796
PCB assembly	0	0	3	9	9	0	0.346
HDD	0	0	9	9	9	0	0.106
RAM	0	0	0	9	9	0	0.106
OS	0	0	9	9	9	0	0.0519
Importance weighting	0	0	3.95	9.956	9.956	0	
Rank	-	-	3	1	2	-	
Technological Difficulty (1-10)	8	8	6	7	5	4	

Figure 4. 19 HOQ of QFD phase three

4.5.3.4 DISCUSSION

Drawing from the product and part specifications obtained in the preceding phase, this section delineates the requisite procedures for constructing features and providing operational capabilities. The information in question holds significant importance for the production and quality assurance teams involved in production quality assurance.

The left-hand side of the Home of Quality matrix is reserved for critical components or product specifications, while the control factors represent the necessary steps for constructing said product specifications. Determining the most effective process for developing the product specifications is recommended to determine the most effective process for developing the product specifications. The following things can be concluded as a decision from the HOQ of QFD phase three. That conclusion is very useful for the production plant TSS.

<u>Importance weighting of processes</u>

One column chart with a rank table is showing the importance weighting of processes below.

Table 4. 9 Importance weighting and Rank of QFD phase Three

Processes	Importance weighting	Rank
1. Injection Molding	0	-
2. Spray Painting	0	-
3. Hard-disc Cloning	3.95	3
4. SKD Assembly	9.956	1
5. Testing	9.956	2

6. Packing	0	-

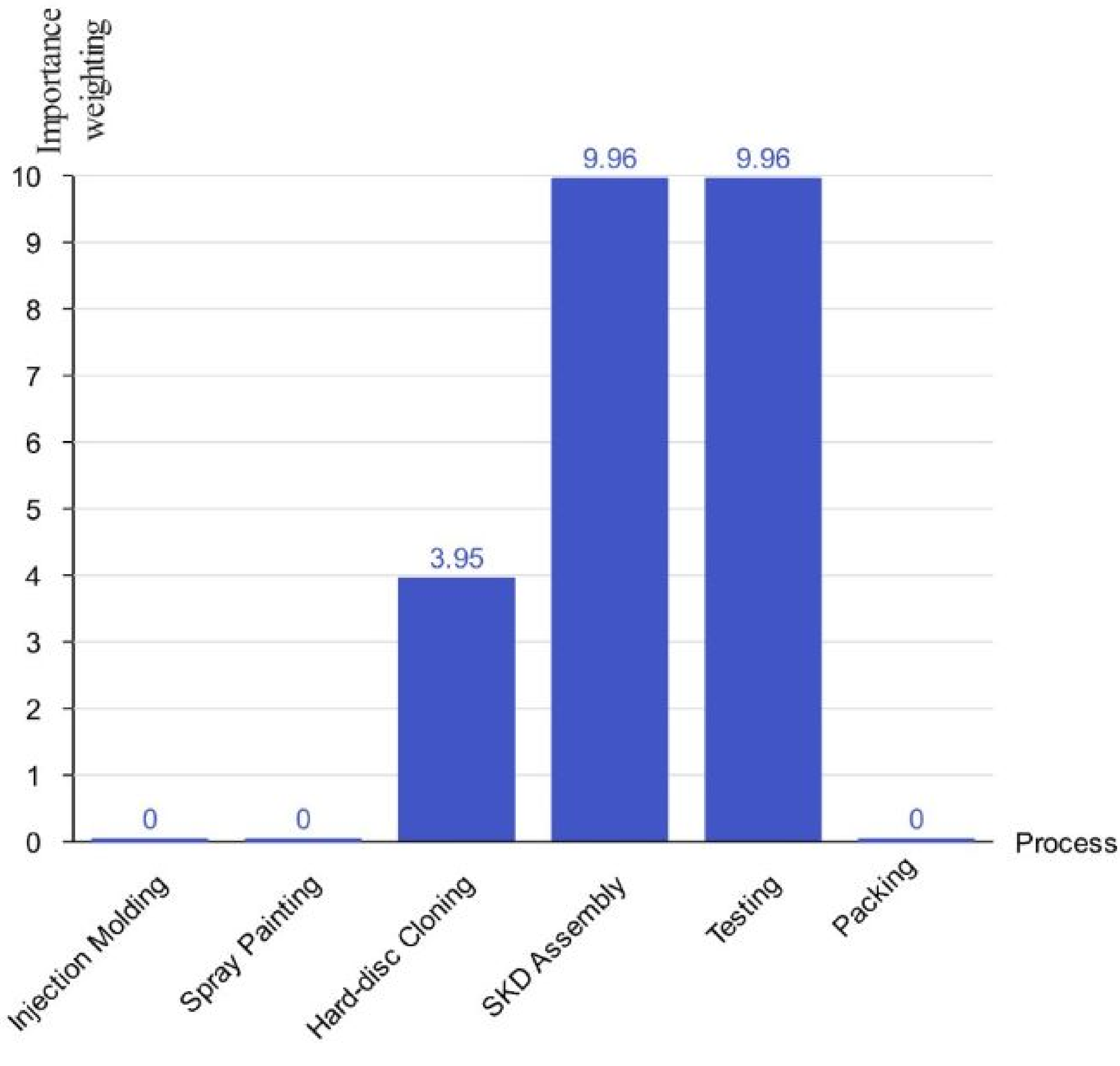

Figure 4. 20 Importance weighting column chart from QFD phase three

The HOQ matrix, SKD assembly, and testing have been identified as crucial processes for this industry, as evidenced by the available data. This was evidently apparent. The production plant is primarily oriented toward the assembly of laptop components. Therefore, an increased level of concentration will be necessary for the assembly process. The process of SKD assembling constitutes a significant proportion, approximately 80%, of all assembly operations. Therefore, its relative significance is of utmost importance. Another procedure that is commonly employed is testing. Empirical evidence has demonstrated that testing holds equivalent significance to the process of software development kit (SKD) assembly. Inadequate testing may result in the provision of substandard and faulty products to the market by the organization. It is imperative toconduct a thorough examination of these two factors in relation to the TSS laptop production facility.

The process of hard disc cloning holds significant importance as the second most crucial procedure. The mitigation of human error is a crucial area of concern that warrants the industry's attention in relation to this particular process. In addition to the aforementioned three processes, there exist three other procedures that are not associated with the manufacturing of critical components. Injection molding and spray painting are associated with the production of covers A, B, C, and D, which are not included in this stage of Quality Function Deployment (QFD).

<u>Relationship Matrix</u>

The relationship matrix, derived from the third phase of the House of Quality Function Deployment, is a remarkable discovery. The production plant, such as TSS, enables the observation of the correlation between the constituent components of a product and the associated manufacturing procedures. It is possible to identify the degree of correlation between a specific component of a laptop and a particular process. The strength of a relationship can be classified into four categories: strong, normal, mild, and zero. This will facilitate making decisions related to operations.

4.5.4 QFD PHASE FOUR

The fourth and final phase of the Quality Function Deployment (QFD) process is commonly referred to as QFD phase four. The phase in question may be referred to as the production planning phase. Phase four of Quality Function Deployment (QFD) was conducted subsequent to the completion of the Failure Mode and Effects Analysis (FMEA) component in this investigation. The utilization of PFMEA (Process Failure Mode and Effects Analysis) outcomes have been observed in phase four of QFD. The processes identified as WHATs will be accompanied by critical process parameters, referred to as FMEA results, which detail the HOWs. This section provides a description of Phase Four in detail. This section establishes the correlation between Quality Function Deployment (QFD) and Failure Mode and Effects Analysis(FMEA).

4.5.4.1 PROCESSES

This study comprises six distinct processes. The authors pursued the FMEA process primarily on the assembly of laptop parts and components, as the laptop production plant TSS primarily prioritized this aspect over manufacturing. The procedures employed for the production of their laptops are enumerated as follows.

Table 4. 10 Process listed for QFD phase four

Serial	Processes
1.	Injection Molding
2.	Spray Painting
3.	Hard-disc Cloning
4.	SKD Assembly
5.	Testing
6.	Packing

One brief description is required in order to be familiar with all these processes. These processeswill come repeatedly in the following sections.

Injection molding

The initial stage of laptop manufacturing entails the utilization of specialized machinery for injection molding, which facilitates the creation of plastic constituents of the device, including the keyboard, cover, and casing. Accurate temperature regulation and meticulous supervision arenecessary for ensuring that every constituent is shaped according to the appropriate standards.

Spray painting

Following the molding process, the plastic components undergo a spray-painting procedure, during which a coating of paint or finish is applied to bestow the laptop with its ultimate visual characteristics. The aforementioned procedure is imperative in augmenting the visual attractiveness of the product and safeguarding it against potential harm.

Hard disc cloning

Subsequently, the process of hard disc cloning is initiated, whereby the operating system and other crucial software are transferred onto the hard disc. The successful completion of this procedure necessitates meticulous compliance with established norms and rigorous oversight to guarantee the optimal performance and operational readiness of the apparatus.

SKD assembly

The process of SKD assembly involves the integration of distinct laptop components to produce the ultimate product. The successful execution of this procedure necessitates the expertise of proficient technicians and employment of sophisticated machinery to guarantee precise alignment and proper interconnection of every constituent part.

Testing

Upon completion of the assembly process, the device is subjected to a comprehensive testing regimen to verify its compliance with exacting quality criteria. The aforementioned procedure entails conducting a sequence of assessments on the apparatus to verify its operational capabilities, efficiency, and dependability.

Packing

Ultimately, the laptop has been assembled and readied for distribution to a global clientele. The aforementioned procedure entails meticulous packaging and labeling measures to guarantee the secure delivery and immediate usability of the product upon receipt. In general, these procedures are essential in the production of laptops that are dependable and of superior quality, which satisfy the requirements of contemporary consumers and enterprises.

4.5.4.2 HOQ OF QFD PHASE FOUR

The absence of a definitive weight for the fourth phase of Quality Function Deployment, commonly referred to as the final phase, precludes the utilization of the SWARA method. Alternatively, there exists an additional column within the House of Quality (HOQ) denoted as RPN. The acronym RPN, which pertains to Risk Priority Number, has been expounded upon in the sections pertaining to Failure Mode and Effects Analysis (FMEA). The House of Quality (HOQ) is presented in the following section.

The following section includes a brief discussion aimed at enhancing understanding of the process relationship with the FMEA.

	FMEA				
Processes / FMEA	Frequency of problem occurance (1-10)	Impact of problem(1-10)	Ease of problem detection(1-10)	RPN	Technological Difficulty
Injection Molding	6	2	4	48	8
Spray Painting	8	2	2	32	8
Hard-Disc Cloning	4	3	2	34	6
SKD	7	3	5	105	9
Testing	8	2	2	32	5
Packing	5	1	2	10	4
Total Scores	38	13	17		

Figure 4. 21 HOQ of QFD phase four

4.5.4.3 DISCUSSION

As QFD phase four is completely related with the FMEA. The discussion of phase four will bediscussed in the next section.

4.6 FMEA METHODOLOGY

Failure Mode and Effects Analysis (FMEA) is a method to determine or identify potential difficulties or failures that may happen in a product or manufacturing process. It is used to assess the risk and improve the design and manufacturing process of the product. It also delivers the safety of the products by eliminating risk. To assess the risk, at first, the failure modes need to be determined and then the risk associated with these failure modes is determined by using Risk Priority Numbers.

Risk Priority Number (RPN) = Severity (S) x Occurrence (O) x Detection (D)

Severity Scale

We should give each potential failure effect a severity rating. The impact of a failure on the clientor process user is referred to as severity. On a scale of 1 to 10, with 10 being the most severe.

Occurrence Scale

We should give each potential reason for failure an occurrence ranking. The probability or frequency of the cause of failure occurring is known as the occurrence. Rankings of occurrencescan be determined on a scale of 1 to 10, with 10 being the most common.

Detection Scale

The team needs to give each current control or measurement a detection ranking. The ability of the control or measure to identify a potential failure mode before it affects the customer or user isknown as detection. On a scale of 1 to 10, with 10 being the most effective.

Two types of FMEA are used in this paper. They are Process FMEA and Design FMEA. Process- FMEA is interconnected with the QFD method. After QFD phase three, the processes are determined that need to be modified most. These processes are also identified as the main processes for the PFMEA. After that, DFMEA is used to identify the flaws in the design of the product. It gives us the concepts to improve the design and reduce the risk.

4.6.1 PFMEA

The PFMEA result table is built using the manufacturing process of the laptop as the basis. The severity value that was determined to be the most severe by the RPN analysis will be the primary topic of discussion. When the RPN score is high, it indicates that there is a greater potential danger of the product failing due to the particular flaw.

According to the PFMEA table, the process of injection molding and the testing procedure both have the greatest severity value among those processes. The SKD assembly process has an RPN value of 105, making it the one with the highest RPN. It is necessary that the SKD assembly process be given attention on the potential failure risk. This is due to the fact that the occurrence of the failure would produce dangerous inoperable of the laptop manufacturing, which would then diminish both product dependability and customer happiness.

Table 4. 11 Process FMEA

Functions/ Process steps	Potential FailureMode	Potential Effects of Failure	SEVERITY	Potential Causes / Mechanisms of Failure	Current Process Controls Prevention	OCCURRENCE	DETECTION	RPN
Injection Molding	Screws and motherboard doesn't fit properly inside the laptop	The structure of the laptop doesn't be created.	6	Doesn't get the mold at a perfect shape	Do the molding again	2	4	48
Spray Painting	Damage the internal components and poor aesthetics	Can cause the poor ventilation and also the laptop looks bad	8	Poor machine and color quality, human error	Use the better machine and color quality	2	2	32
Hard Disc Cloning	Insufficient space in the disc and incorrect software settings.	The laptop doesn't function properly	4	Defected master copy	Recheck again and again	3	2	24
SKD Assemblin	LED , Wi-Fi module, RAM, Touchpad failure	No display, Wi-Fi signal unavailable, overheating, touchpad doesn't operate	7	Low material quality and human error	Quality control and remove human error	3	5	105

Testing	Inadequate test coverage, defective test cases, lack of testing environment standardization, hardware or software compatibility issues	Decreased product quality, increased cost, security risk	8	Lack of testing standards	Increase the testing standard when there is any testing defects	2	2	32
Packing	Physical damage to laptop	Reduced Quality	5	Poor packet quality, human error	Improve packet quality and decrease human error	1	2	10

4.6.2 DFMEA

A product's design phase uses DFMEA to spot possible issues and address them before they become problems. DFMEA is used to make sure that a product is reliable, safe to use, and that it complies with design criteria and customer expectations. A cross-functional team composed of designers, engineers, quality experts, and other stakeholders often performs DFMEA. The DFMEA result table is built using the manufacturing process of the laptop as the basis. The severity value that was determined to be the most severe by the RPN analysis will be the primary topic of discussion. When the RPN score is high, it indicates that there is a greater potential danger of the product failing due to the particular flaw.

According to the PFMEA table, the design of LED, Camera, Microphone, Speaker and Ports have the greatest severity value among those part. The designing of ports has an RPN value of60, making it the one with the highest RPN. It is necessary that the designing of ports be given attention on the potential failure risk. This is due to the fact that the occurrence of the failure would produce dangerous inoperable of the laptop manufacturing, which would then diminish both product dependability and customer happiness.

Functions/ Process steps	Potential FailureMode	Potential Effects of Failure	SEVERITY	Potential Causes / Mechanisms of Failure	Current Process Controls Prevention	OCCURRENCE	DETECTION	RPN
Injection Molding	Screws and motherboard doesn't fit properly inside the laptop	The structure of the laptop doesn't be created.	6	Doesn't get the mold at a perfect shape	Do the molding again	2	4	48
Spray Painting	Damage the internal components and poor aesthetics	Can cause the poor ventilation and also the laptop looks bad	8	Poor machine and color quality, human error	Use the better machine and color quality	2	2	32
Hard Disc Cloning	Insufficient space in the disc and incorrect software settings.	The laptop doesn't function properly	4	Defected master copy	Recheck again and again	3	2	24
SKD Assemblin	LED , Wi-Fi module, RAM, Touchpad failure	No display, Wi-Fi signal unavailable, overheating, touchpad doesn't operate	7	Low material quality and human error	Quality control and remove human error	3	5	105
Testing	Inadequate test coverage, defective test cases, lack of testing environment standardization , hardware or software compatibility issues	Decreased product quality, increased cost, security risk	8	Lack of testing standards	Increase the testing standard when there is any testing defects	2	2	32
Packing	Physical damage to laptop	Reduced Quality	5	Poor packet quality, human error	Improve packet quality and decrease human error	1	2	10

Table 4. 12 Design FMEA

4.6.3 DISCUSSION

When analyzing potential reliability issues during the production process and design of laptop, PFMEA and DFMEA both play significant roles. RPN values are utilized to anticipate the product's failure modes using the conventional FMEA method. Any function mode with a higher RPN is assumed to be of greater relevance and to be given priority over function modes with a lower RPN. Due to the inadequacy of the quantification of the risk-influencing components, this attempt to measure risk has inherent inconsistency. The relative importance of severity (S), occurrence (0), and detection (D) is ignored by the RPN ranking technique. It is assumed that these three criteria are equally important. As a result, some S-O-D scenarios result in RPNs that are lower than those from other combinations but may be riskier.

In light of the aforementioned conditions, the company made the decision to concentrate on failure modes with extremely high severity, low recurrence rates, and limited detectability—even if those higher RPN values should be assigned higher priority for corrective action. The corporation implemented engineering assessments based on high severity values with little respect for any RPN values in order to take preventative or remedial action. Rankings are reduced in the following order: severity, occurrence, and detection. Both PFMEA and DFMEA are applicable in this circumstance.

CHAPTER 5
CONCLUSION

5.1 INTRODUCTION

Quality Function Deployment (QFD) is a highly effective technique applicable to all types of products and services in terms of consumer and manufacturer interactions. Failure mode and effects analysis (FMEA) is a well-established and effective engineering tool utilized in numerous industries to find potential failure modes of system elements, evaluate their effects on system behavior, and propose appropriate remeasures to prevent those defects.

During the product development cycle, the QFD and FMEA would be jointly implemented with a focus on customer demands and expectations for product reliability. To achieve the objectives of this study, Telephone Shilpa Sangstha (TSS) Ltd. is subjected to a combined methodology with the assistance of other pertinent instruments. QFD determined the critical aspects of manufacturing so that more effort is expended to improve those aspects in order to deliver maximum customer satisfaction and ensure the success of the product; FMEA is capable of assigning preventive/corrective actions towards the potential failures of the manufacturing and design processes in order to reduce late changes and associated costs in troubleshooting product problems.

A comprehensive case study on the joint implementation of QFD and FMEA had been successfully completed. In the interim, the objectives of this investigation have also been met.

5.2 CONCLUSION

1. The plant has found this result effective for its production. They desired to keep this book for their betterment and also wanted to postering the QFDs on their production wall. There is a high hope of growth in their production after using this paper's theme and idea.

2. Through this study, they come to know that their customers mostly complain about different things according to their affinity diagram. The technical specification where they should focus on is "compactivity on external peripherals". there most critical part of the product is "the operating system" and the most important process is "testing and SKD assembly".

3. The plant TSS should give their focus on "input-output ports" according to their design. They should reduce the severity of "LED, camera, microphone and ports" and should reduce the occurrence of failure of "LED" though their detection is good.

4. As the process is the most vital part of a manufacturing plant, they should be very careful with "SKD assembly". They are getting high severity on "spray-painting" but in terms of occurrence and detection "SKD assembly" is the highest again.

5.3 LIMITATIONS

1. In the investigation of the QFD area, collected data through interviews, and due to time constraints, the majority of survey respondents come from the customer's facilities and limitations. The results of the analyses do not universally reflect the opinions of the customers.

2. Both the DFMEA and PFMEA required a review of highly sensitive information. documents in the organization. Consequently, there are some challenges in obtaining pertinent data for the study.

3. The four phases of QFD relating to the means of achieving the objectives entailed extensive analyses that could lead to calculation errors if precautions are not taken. If errors occur in the development of unnecessary consumer requirements, it may result in a loss of associated costs. In addition, the success of QFD phases required extensive ideation, discussions, and meetings, as well as a large, cooperative team.

4. During the analyses, the traditional FMEA utilized in my case study is quite perplexing. RPN values and assumptions had to be determined in order to select the study's scope. Corrective and preventative measures.

References

[1] ASQ, "Cost of Quality (COQ)," ASQ, [Online]. Available: https://asq.org/quality-resources/cost-of-quality. [Accessed 23 05 2023].

[2] A. C. O. J. L. D. J. a. L. T. G. Michael P. Gallaher, "Cost Analysis of Inadequate Interoperability in the," *U.S. Department of Commerce,* vol. 4, no. 867, p. 210, 2004.

[3] M. H. H. T. T. M. A. M. Ajmal, "A QFD strategy for improving customer satisfaction: case study of telecom companies of Pakistan," *Asian Journal on Quality,* vol. 12, no. 3, pp. :282-295, 2011.

[4] J. W. Herrmann, "New Directions in Design for Manufacturing," in *ASME*, American city, 2004.

[5] S. R. R. I. I. S. Saati, "A Novel Method on Customer Requirements Preferences Based on Common Set of Weight," *Australian Journal of Basic and Applied Sciences* , vol. 5, no. 6, pp. 1544-1552, 2011.

[6] M.-L. W. 1. Lai-Kow Chan, "Quality function deployment: A literature review," *European Journal of Operational Research,* vol. 143, no. 3, pp. 463-497, 2002.

[7] R. G. G. I. Ishak, "An Integrated of AHP–QFD Methodology For Poduct Design: A Review," *Jurnal Ilmiah Teknik Industri* , vol. 8, no. 1, 2020.

[8] R. M. N. M. d. Oliveira, "QFD and TRIZ integration in product development: A Model for Systematic Optimization of Engineering Requirements," *Produção* , Vols. Production, 28,, no. ISSN 1980-5411, p. 15, 2018.

[9] H. A.-M. Raid Al-Aomar1, "Quality Function Deployment for Service: A Case Study of Enhancing the Planning," *International Journal of Advanced Trends in Computer Science and Engineering,* vol. 1, no. 4, pp. 1-8, 2012.

[10] L. P. P. C. C.-C. Petrescu, "Failure Mode and Effect Analysis in Automotive Industry: A Case Study," *The Scientific Bulletin of Electrical Engineering Faculty,* vol. 19, no. 2, pp. 10-15, 2019.

[11] N. A. W. Yoshio, "Failure mode effect analysis and fault tree analysis as a combined methodology in risk management," *IOP Conference Series Materials Science and Engineering,* vol. 337, no. 1, p. 012033, 2018.

[12] A. S. c. D. D. C. d. M. A. e. Madjid Tavana a b, "An integrated and comprehensive fuzzy multicriteria model for supplier selection in digital supply chains," *Sustainable Operations and Computers,* vol. 2, pp. 149-169, 2021.

[13] J. S. Krouwer, "An Improved Failure Mode Effects Analysis for Hospitals," *Archives of*

Pathology & Laboratory Medicine , vol. 128, no. 6, pp. 663-667, 2004.

[14] N. S. L. S. S. L. S. G. T. G. T. W. Y. W. Y. a. 5. a. C. T. C. Tai, "Applying Triz for Production Quality Improvement," *MATEC Web of Conferences,* vol. 95, no. 11, p. 10009, 2017.

[15] ś. transportu, "The application of failure mode and effects analysis (FMEA)," *TECHNICAL TRANSACTIONS,* vol. 1, no. 1, pp. 2-13, 2019.

[16] B. E. E. F. E. F. Efe, "Quality function deployment based failure mode and effect analysis approach for risk evaluation," *Neural Computing and Applications,* vol. 33, no. 2, pp. 1-16, 2021.

[17] G. H. H. S. S. T. Tauterat, "Quality Function Deployment in software development -State-of-the-art-," in *21th International Symposium on QFD*, Hangzhou, China, 2015.

[18] D. J. R. R. Z. Zairi, "The "QFD/FMEA interface"," *European Journal of Innovation Management* , vol. 1, no. 1, pp. 7-20, 1998.

[19] N. U. P.-K. W.-K. Wang, "Integrating quality function deployment and failure mode and effect analysis in subcontractor selection," *Total Quality Management & Business Excellence* , vol. 31, no. 5, pp. 1-20, 2018.