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A QFD-MCDM Approach Considering Kano Model Under Uncertainty, Case Study: Automotive Industry in Portugal

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Ph.D. Thesis

Doctoral Program in Advanced Engineering Systems for Industry (AESI)

Work supervised by

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DECLARATION OF INTEGRITY

I declare to have acted with integrity in the preparation of this academic work and confirm that I did not resort to the practice of plagiarism, or, any form of misuse or falsification of information or results, in any of the stages leading to its elaboration.

I further declare that I know and respected the Code of Ethical Conduct of the University of Minho.

Cumprimentos / Best regards,

Ahmad Hariri

A QFD-MCDM Approach Considering Kano Model Under Uncertainty, Case Study: Automotive Industry in Portugal

ABSTRACT

In today's competitive market, most companies aim to improve the quality of their products to acquire new customers and to avoid customer churn. Quality Function Deployment (QFD) is a customer-oriented design tool that aims to meet customer needs in a better way and enhance organizational capabilities, while maximizing company goals. The premise that customer satisfaction is a crucial factor that significantly impacts the outcomes of a business, whether successful or unsuccessful, holds significant weight. Hence, it is important to determine those requirements of a product or service that bring more satisfaction than others. QFD and the Kano model can be integrated effectively to identify customer needs more specifically and yield maximum customer satisfaction. This study proposes an improved refined Kano method for identifying and prioritizing customer requirements (CRs) and engineering characteristics (ECs) called supplier attributes (SAs) in this study—integrated into multi-criteria decision-making (MCDM)-QFD process. This model uses fuzzy theory to rank the suppliers, aiming to enhance black uniformity (BU) as a luminance characteristic on the display surface, by evaluating the CRs and developing the SAs related to CRs.

The main findings of this study were the identification, classification, and ranking of the CRs of a product in an automotive company due to classifying the SAs to satisfy these CRs, and finally, the ranking of the suppliers. As the initial stage of QFD, converting CRs into ECs and determining the technical importance of ECs are the foundation for the successful implementation of the QFD tool. However, as indicated by many researchers, there exist various shortcomings in conventional QFD, which limit its efficiency and potential applications. The first concern that exists in conventional QFD is quantifying the relationships between CRs and ECs based on crisp (exact) numbers. Obviously, in practical situations, it is often hard for experts to provide their opinions by using exact values due to environmental complexity and limited experience. The second concern refers to the determination of the CRs' weights based on customers' evaluations without having a structured pair-wise comparison among CRs. Moreover, ignoring decision-makers' preference behavior by using a linear aggregation method in the traditional QFD could be considered as the third concern. On the other hand, determining the crucial ECs in QFD is often regarded as a MCDM problem. To fill this gap of data uncertainty, the current thesis aimed to integrate the Kano model, QFD, and MCDM procedures into a hybrid methodology.

KEYWORDS: *Customer Satisfaction, Fuzzy Theory, Kano Model, Multi-criteria Decision Making, Quality Function Deployment.*

Uma abordagem QFD-MCDM considerando o modelo Kano sob incerteza, estudo de caso: Indústria automóvel em Portugal

RESUMO

No mercado competitivo de hoje, as empresas têm como objetivo a qualidade e a competitividade dos seus produtos e serviços para captar e reter clientes. Desdobramento da Função Qualidade (QFD) é uma ferramenta de design orientada para o cliente, que visa atender melhor às necessidades deste e aprimorar as capacidades organizacionais, maximizando os objetivos da empresa. A premissa de que a satisfação do cliente é um fator crucial que impacta significativamente os resultados de um negócio, seja bem ou malsucedido, tem um peso significativo. É expectável que existam alguns requisitos que trazem mais satisfação ao cliente do que outros. Portanto, é importante determinar os requisitos de um produto ou serviço que trazem mais satisfação do que outros. O QFD e o modelo Kano podem ser integrados efetivamente para identificar as necessidades do cliente de uma forma mais específica e obter a máxima satisfação do cliente. Ao utilizar o modelo Kano e integrá-lo ao QFD, a equipa de projeto pode entender melhor as necessidades dos clientes, focando adequadamente nelas.

Este estudo propõe um modelo Kano refinado para identificar e priorizar os requisitos do cliente (CRs) e identificar as características de engenharia (ECs) (atributos do fornecedor (SAs) neste estudo) integrado a uma tomada de decisão multicritério (MCDM)-QFD considerando a teoria difusa para classificar os fornecedores devido à melhoria da uniformidade do preto (BU) como uma característica de luminância na superfície de uma tela, avaliando os CRs e desenvolvendo os SAs relacionados aos CRs. Os principais resultados deste estudo foram a identificação, classificação e priorização dos CRs de um produto em uma empresa automobilística devido à classificação dos SAs para atender esses CRs e, por fim, o ranking dos fornecedores. A primeira preocupação no QFD tradicional é quantificar as relações entre CRs e ECs com base em conjuntos clássicos. Obviamente, em situações práticas, muitas vezes é difícil para os especialistas fornecerem as suas opiniões usando valores exatos devido à complexidade ambiental e experiência limitada. A segunda preocupação refere-se à determinação das importâncias dos CRs com base nas avaliações dos clientes sem ter uma comparação estruturada de pares entre os CRs. Além disso, ignorar o comportamento de preferência de quem toma a decisão usando um método de agregação linear no QFD tradicional pode ser considerado como uma terceira preocupação. Por outro lado, determinar os ECs cruciais no QFD é frequentemente considerado como MCDM. De forma a resolver este problema, nesta tese, considerando a incerteza dos dados, pretende-se integrar o modelo Kano, QFD e procedimentos MCDM numa metodologia híbrida.

PALAVRAS-CHAVE: *Desdobramento da Função Qualidade, Modelo Kano, Satisfação do Cliente, Teoria Fuzzy, Tomada de Decisão Multicritério.*

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LIST OF ACRONYMS

Acronym	Description
ACF	Anisotropic Conductive Film
AESI	Advanced Engineering Systems for Industry
AHP	Analytic Hierarchy Process
ANP	Analytic Network Process
BSP	Bike-Sharing Program
BU	Black Uniformity
BWM	Best-Worst Method
CBDS	Cost Breakdown Sheet
CC	Corporate Compliance
CM	Car Multimedia
CNC	Computer Numerical Control
CO_2	Carbon Dioxide
CoG	Chip on Glass
COPRAS	Complex Proportional Assessment
CRs	Customer Requirements
CSF	Critical Success Factors
DEMATEL	Decision-Making Trial and Evaluation Laboratory
DMCS	Daimler Mirror Camera System
DMs	decision makers
DOE	Design of Experiments
DPS	Department of Production and Systems
DRs	Design Requirements
ECs	Engineering Characteristics
EDAS	Evaluation Based on Distance from Average Solution
EDI	Electronic Data Interchange
EGM	Evaluation Grid Method
EHFLTS	Extended Hesitant Fuzzy Linguistic Term Sets
ÉLECTRE	ÉLimination Et Choix Traduisant la REalité

ERP	Enterprise Resources Planning
ESD	Electrostatic Discharge
FAHP	Fuzzy Analytic Hierarchy Process
FANP	Fuzzy Analytic Network Process
FCT	Foundation for Science and Technology
FDM	Fuzzy Delphi Method
FDM	Fuzzy Delphi
FEAHP	Fuzzy Extent Analytic Hierarchy Process
FMCDM	Fuzzy Multi-Criteria Decision Making
FoG	Foil on Glass
FPC	Flexible Printed Circuit
FPD	Flat Panel Displays
FRs	Functional Requirements
GNP	Gross National Product
GQFD	Grey Quality Function Deployment
GRA	Grey Relational Analysis
GUI	Graphical User Interface
HFLTS	Hesitant Fuzzy Linguistic Term Set
HoQ	House of Quality
HSE	Health, Safety, and Environment
IVIF	Interval-Valued Intuitionistic Fuzzy
JIT	Just in Time
K.I.S.S.	Keep, Improve, Start, Stop
LCD	Liquid Crystal Display
LINMAP	Linear Programming Technique for Multidimensional Analysis of Preference
LP	Linear Programming
MaCS	Material Data Management for Compliance and Sustainability
MADM	Multi-Attribute Decision Making
MCDM	Multi-criteria Decision-Making
MDM	Maximizing Deviation Method
ME-MCDM	Multi Expert/Multi-Criteria Decision Making
MEMS	Microelectromechanical systems

MODM	Multi-Objective Decision Making
MSA	Measurement System Analysis
MULTIMOORA	Multi-Objective Optimization by Ratio Analysis
NGOs	Non-Governmental Organizations
NN	Neural Network
NPD	New Product Development
NTC	Negative Temperature Coefficient
OA	Organizational Agility
OEM	Original Equipment Manufacturer
PCB	Printed Circuit Board
PFLSs	Picture Fuzzy Linguistic Sets
PFMEA	Process Failure Mode and Effects Aanalysis
PHFLTS	Proportional Hesitant Fuzzy Linguistic Term Sets
PRE	Process Rules for Engineering
PROMETHEE	Preference Ranking Organization Method for Enrichment Evaluation
PRs	Product Requirements
PWM	Pulse Width Modulation
QC	Quality Characteristic
QFD	Quality Function Deployment
QUALIFLEX	Qualitative Flexible Multiple Criteria
RoHS	Restriction of Hazardous Substances
RST	Rough Set Theory
SAs	Supplier Attributes
SSCM	sustainable supply chain management
SWARA	Stepwise Weight Assessment Ratio Analysis
TFN	Triangular Fuzzy Numbers
TFT	Thin Film Transistor
TO	Transport Order
TOPSIS	Technique for Order Preference by Similarity to an Ideal Solution
TQM	Total Quality Management
TRIZ	Teoriya Resheniya Izobretatelskikh Zadatch or (Theory of Inventive Problem Solving)
TSI	Total Satisfaction Index

VCI	Volatile Corrosion Inhibitor
VIKOR	VIsekriterijumska Optimizacija I Kompromisno Resenje
VMI	Vendor Managed Inventory
VoCs	Voice of Customers

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Academic Papers and Conferences

Publications submitted to peer-reviewed international journals:

Hariri, A., Domingues, P., & Sampaio, P. (2023). Applying SWARA Approach and Refined Kano Model to Classify and Rank Customer Requirements, Case study: Automotive industry in Portugal. International Journal of Management and Decision Making, 23. https://doi.org/10.1504/IJMDM.2024.10052044.

Hariri, A., Domingues, P., & Sampaio, P. (2023). Integration of multi-criteria decision-making approaches adapted for quality function deployment: an analytical literature review and future research agenda. International Journal of Quality & Reliability Management.

Hariri, A., Domingues, P., & Sampaio, P. (2023). A QFD-MCDM approach considering Kano model under uncertainty, Case study: Automotive industry in Portugal. The article is on the “Under review” stage.

Presentations in international peer-reviewed conferences:

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Hariri, A., Domingues, P., & Sampaio, P. (n.d.). An Integration of QFD and Fuzzy-AHP approach in Hospital Services, case study: a Hospital in Iran Perceptions and Experience from Auditors View project. https://www.researchgate.net/publication/362041475.

CHAPTER 1

INTRODUCTION

Fast-growing and rapidly changing markets in a globally competitive environment have made the quality of product or service a determinant of the success of an enterprise. In general, capturing the genuine and major customer requirements (CRs) effectively is a major advantage for both manufacturing and service-oriented firms.

1.1 Statement of the Problem

Nowadays, new competitive conditions for production and service organizations have been generated due to many new innovative scientific and technological advancements. Hence, the development of new technologies made quality and customer satisfaction the most crucial elements in the global market. Attracting and retaining customers in an organization is a category that is affected by various factors and conditions inside and outside the organization, the importance of which varies according to the type of organization and from one organization to another (Suchánek and Králová, 2019; Nguyen et al., 2020). Global competition among companies to capture more market share and increase customer demand for superior quality makes it necessary to have a competitive and effective strategy. Therefore, evaluating the quality of goods and services has become more significant for production and service organizations. Therefore, organizations are often looking for ways to measure (quantity) the quality of their goods and services as much as possible and to improve that quality (Ismail, 2013).

Satisfied customers are the source of companies' profit. For this reason, companies that cannot keep customers satisfied will not remain in the market in the long term. Consistently delivering superior quality products and top-tier customer service yields competitive advantages for the company. This includes fostering customer loyalty, offering differentiated products, cutting marketing expenses, and setting fair prices. Furthermore, meeting ethical standards regarding quality—where customers pay for their expectations—places responsibility on the company to fulfill those needs in its products (Nguyen et al., 2020).

Quality development does not always lead to customer satisfaction, as what a customer wants or expects from goods and/or services is not always high expectations. The critical issue is what the customer expects from the product/service and how much the product/service meets these expectations. It can be said that the product/service that meets these expectations must be of high quality. Therefore, quality can be defined as the characteristics of a product/service that including the ability to provide qualitative satisfaction and implicit expression of customer needs (Mazur, 1997). Different approaches are used in the field of quality improvement, and one of these approaches is quality function deployment (QFD). QFD is a methodology for developing is the deployment of features, properties, and characteristics that provide high-quality goods/services (Hwarng and Teo, 2001). QFD provides an understanding of customer needs and expectations and the characteristics that satisfy these needs and expectations of the product/service. The main focus of QFD is on product/service design that will bring customer satisfaction. As previously mentioned, a company can not ignore the views and needs of its customers and the satisfaction of those customers with the quality of its goods and services as this has a great impact on the success of that company. Therefore, companies should continue to improve the quality of services to gain more success in the competitive market and maintain or increase their market share. The manufactured product must be a product that prioritizes the requirements and desires of customers. Many methods can be applied to evaluate the CRs and the product consumers, such as the Kano model, and the QFD method applied in this study. The Kano model is an efficient tool widely used for identifying the CRs and analyzing the impact of meeting CRs on customer satisfaction levels. Meanwhile, QFD is used to translate CRs which are developed to meet product and service design requirements (DRs). It is therefore reasonable to draw the conclusion that the interaction between these two approaches can be used to translate customers desire and enhance customer service attributes in order to enhance product quality. This thesis covers the classification of CRs and ECs utilizing the refined Kano model, multi-criteria decision-making (MCDM) techniques, and fuzzy-QFD:

1. First, CRs and technical requirements are identified using a literature review analysis and expert opinion. The refined Kano model is used to categorize and weight the CRs.
2. In the next step, using the fuzzy-QFD method, the technical requirements— representing supplier attributes (SAs) in this study—are ranked and prioritized based on the CRs' weights (determined by the refined Kano model).
3. Finally, MCDM techniques are employed to analyze and rank the suppliers.

1.2 Research Justification

It is important for any company to retain existing customers, gain profitable share and improve profit margins. Companies must meet and even exceed the needs of their customers (Witell et al., 2013). Customer satisfaction can be considered as one of the important aspects that plays an important role in the success or failure of a business (Erdem and Gundogdu, 2018). Therefore, companies strive to meet and exceed customer expectations in order to earn their loyalty. An unhappy customer is a critical and challenging problem that can negatively impact a business. An unsatisfied customer can lead to customer "defection" and business failure. Keeping current customers loyal and satisfied is much more important than acquiring new customers (Al Rabaiei et al., 2021). As a result, the true goal of any business is to meet the needs of its customers rather than to supply, sell, or provide services. Organizations that can quickly understand and meet customer needs generally profit more than organizations that can not do this as quickly (Amin et al., 2017).

Certainly, knowing the mental image and perception of customers towards the goods and services provided has particular importance, and while revealing the weaknesses and strengths of an organization, it provides a basis for adopting appropriate strategies and improving the level of performance. Therefore, customer satisfaction has become the operational goal of many organizations. Not surprisingly, companies invest considerable resources in increasing customer satisfaction. As a result, customer satisfaction accounts for the largest portion of the annual marketing budget. In addition, the costs of business marketing account for about 50% of the total costs (Sun and Kim, 2013). In fact, identifying and measuring customer satisfaction is not enough. Additionally, the processes that caused dissatisfaction must be identified and corrected. Therefore, the establishment of a system that can measure customer satisfaction seems vital (Akmal et al., 2020).

The Kano model is one of the models that help determine the features that should be included in a product or service to improve customer satisfaction. This model focuses on highlighting the most relevant features of a product or service along with customers' estimation of how the existence of these characteristics can be used to predict satisfaction with specific services or products (Al Rabaiei et al., 2021). This approach helps managers to better understand the CRs in products or services (Avikal et al., 2020). The Kano model provides a detailed classification of customer needs such as attractive, performance, basic needs, indifferent, and reversed factors (Chen, 2012).

1.3 Motivation

Nowadays, it is significant for companies to retain current customers, share in profitability and improve profit margins. Companies need to meet customers' requirements and even go beyond the expected basic requirements (Witell et al., 2013). Customer satisfaction can be considered one of the aspects that play an important role in the success or failure of a business (Erdem and Gundogdu, 2018). Therefore, companies strive to meet customer expectations and beyond these expectations in order to gain their loyalty. For example, in the automotive industry, technology emerged to present aditional information such as functional indications, navigation systems, and multimedia systems as electronic displays and clusters to the customer. The present thesis aims to categorize and prioritize the CRs to increase customer satisfaction in a product from the automotive industry. In an automotive display, black uniformity (BU) is a feature that refers to the luminance differences on the surface of the display. This thesis provides a means to identify and rank the most significant criteria in producing the display item through the use of the following five main categories: (1) Technical, (2) Quality, (3) Delivery, (4) Sustainability, and (5) Cost. An additional motive behind the study is to provide case studies regarding the vastly different aspects of the production system.

Today, climate change is a significant challenge and a severe customer concern. Although sustainability CRs are not classed as essential items in the production process, suppliers must be diligent in providing them. The results help to improve the automotive industry and other production systems.

This thesis presents a case study of certain technical aspects in the manufacturing of the Daimler Mirror Camera System (DMCS). The decrease in the BU rate of raw displays when the original equipment manufacturer (OEM) receives a semi-complete from the supplier is identified as a shortcoming and problematic stage in the manufacturing process. Regarding the first step of the evolution of product recognition, the CRs, SAs and the rank of the suppliers can optimize the BU rate from supplier delivery using the supplier selection model.

This partnership program was significant for my personal and professional development. Developing my research in one of the largest companies working with cutting-edge technology allowed me to evolve as a professional and to have direct contact with technologies that I had only theoretically studied in my career. This involvement allowed me to understand the complexity of the company's production systems, and monitor the entire process, from the supplier phase to continued production on the assembly lines from the quality management point of view due to the high rejection rate of the BU of the DMCS. It was also important because it allowed me to get in touch with different experts to develop skills and values that were passed to me.

1.4 Research Goals

The research goals are classified into preliminary and secondary objectives. The main research goal is expressed as follows:

- Developing a novel QFD-MCDM approach in the automotive industry under an uncertain environment.

The secondary aims are given as:

- Characterizing the relationships between CRs and measurable ECs considering the uncertainties.
- Evaluating the ECs taking into account their relationships with CRs and the importance of the related requirements.
- Addressing the imprecise dataset inherent in the QFD planning process to determine the level of fulfillment of DRs.

1.5 Research Questions

The research questions include one main question along with some secondary ones. The main question in this research is:

- How can one extend novel QFD-MCDM approach under uncertainty and implement that approach in the automotive industry?

Additional secondary questions are:

- Considering the uncertainties, in what ways can one characterize the relationships between CRs and measurable ECs?
- In what ways can one evaluate the ECs by considering their relationships with CRs and the importance of the related requirements?
- How can one tackle the imprecise dataset inherent in the QFD planning process to determine the level of fulfilment of DRs?

1.6 Contributions

Among the contribution of this research, a large number of criteria regarding the case study was collected by studying the latest research in the field application of the Kano model and QFD in the production systems and automotive industry, and by specific field research such as conducting surveys of experts in technical, cost, delivery, quality, and sustainability. The Kano model was used as a tools for comprehensive classification and determination of the criteria as input of the hybrid MCDM-QFD model. The factors that the OEM, automaker, and final customer (who is the automative end-customer) pointed out either directly or indirectly impacted the product's BU rate and any failure or customer dissatisfaction. Using a comprehensive approach that considers five main criteria (technical factors, cost, delivery, quality, and sustainability) led to the identification of important dimensions from the perspective of customers and experts that were neglected in previous studies. This information made it possible to make better decisions to improve the product.

This thesis adopts the refined Kano model to classify the DMCS display characteristics based on the customer's point of view. This model can comprehensively analyse the CRs and obtain the specific model of the needs to design the product according to the CRs. Among other innovations of this research, it is possible to mention the presentation of combined approaches of Kano and MCDM along with fuzzy theory which helps the accuracy of measurements.

Consequently, the Kano model and the stepwise weight assessment ratio analysis (SWARA) were taken into consideration as two different tools, one as MCDM and the other one as a quality management tool. These tools address the BU challenge as the main cause of customer dissatisfaction (namely OEM or automotive manufacturer, or final customers) from display suppliers. Then, QFD was applied to translate the CRs to SAs. Finally, an MCDM tool was used to rank the suppliers.

1.7 Bosch Group

The Bosch group is a world market leader in cutting-edge technology and services and employs over 390,000 employees worldwide (12/31/2016). In 2016, the company earned around 73.1 billion euros, an amount that represented an increase of around 3% compared to the previous year. The Group operates in four distinct business areas: Mobility Solutions, Industrial Technology, Consumer Goods and Energy and Building Technology. The Bosch Group comprises Robert Bosch GmbH and around 450 subsections and regional companies present in approximately 60 countries. Including sales and service representatives, Bosch's worldwide development, production and distribution network is present in almost every country (Bosch, 2018a).

1.7.1 BOSCH Group History

In 1886, Robert Bosch received official approval to open his company “Precision Mechanical and Electrical Engineering Workshop” in Stuttgart, Germany. The modest company quickly expanded and introduced its technology to the automotive industry, having successfully installed the first low-voltage magnetic igniter in 1897. The following year the company opened its first office in Great Britain, an office for sales of Bosch products in London and later in 1905 the first factory outside Germany was built, located in Paris, France and in the following year the first Bosch branch in the USA (Bosch, 2018d).

In 1921 the first Bosch Service workshop was created in Hamburg. There are currently around 15,000 workshops operating worldwide.

In the years that followed, several important innovations were presented by Bosch, with emphasis on the series production of Bosch fuel injection pumps and nozzles for diesel engines.

In 1942, Robert Bosch passed away, aged 80, due to complications resulting from inflammation in the middle ear.

In 1964, Vermögensverwaltung Bosch GmbH acquired the largest share of Robert Bosch GmbH from the heirs of the company's founder. In 1969, Vermögensverwaltung Robert Bosch changed its name to Robert Bosch Stiftung GmbH (Robert Bosch Foundation), thus highlighting the social focus of its activities. The foundation continues the civic and charitable work of Robert Bosch to this day, in the same spirit as the founder of Bosch.

From then on, several technological milestones were achieved by the Foundation, namely the start of series production of ABS in 1978, the launch of the first independent vehicle navigation system in Europe: TravelPilot IDS in 1989 and the development of ESP, the electronic stability in 1995, a system that can save lives by preventing vehicles from skidding (Bosch, 2018d).

In addition to the Bosch brand, the Bosch Group also offers other brands thinking about the demands of its customers that have been purchased or created over the years, such as: Vulcano, leader in the heating market in Portugal, the Robinair brand, represented at global and market leader in growth of air conditioning treatment, AutoCrew, branches brand, represents in Europe and South Africa with more than 600 branches, among many other brands represented in Figure 1-1 (Bosch, 2018e).

Figure 1-1 – Companies of the Bosch Group (Bosch, 2018e)

1.7.2 BOSCH Portugal

The first introduction of the Bosch group in Portugal took place in 1911, when Gustavo Cudell opened the first Bosch sales office. Bosch is currently represented in Portugal by Bosch Thermotechnology, in Aveiro, Bosch Car Multimedia Portugal, in Braga, and Bosch Security Systems – Sistemas de Segurança, in Ovar. In these locations, the company develops and manufactures hot water tools, automotive multimedia and security and communication systems, 95% of which are exported to international markets. The Group's head office in the country is in Lisbon, where sales, marketing, accounting and communication activities are carried out, as well as shared human resources and communication services for the Bosch Group. In addition, the company also has a subsection of BSH Eletrodomestics, in Lisbon. In 2016, sales reached values of approximately 1.1 billion euros, which accounted for an increase of 18% compared to 2015. In addition, more than 1000 new jobs were created, of which around 250 were for highly qualified engineering profiles, exceeding 4400 employees (December 31, 2016). With these values, Bosch Portugal is one of the 10 largest national exporters and one of the largest industrial employers. Figure 1-2 shows some of these data as well as the location of the various subsets (Bosch, 2018c).

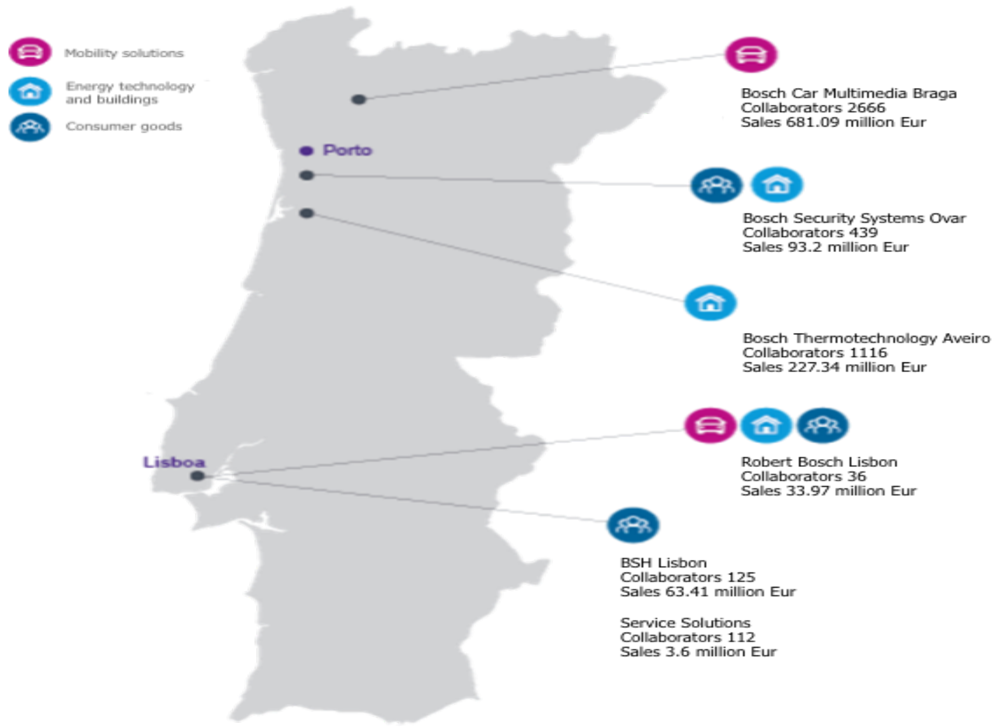

Figure 1-2 – Statistical data of the company in 2016 (Bosch, 2018c)

1.7.3 BOSCH Car Multimedia Portugal, S.A.

Bosch in Braga was founded in 1990 under the name Blaupunkt Auto-Radio Portugal lda. and produced car radios for the Blaupunkt brand. In 2008, the Car Multimedia (CM) division was restructured and the Blaupunkt brand was sold together with the after-sale radio business. Since then, CM has focused only on original equipment for the automotive industry and the factory was renamed Bosch Car Multimedia Portugal, S.A.

Currently, Bosch Car Multimédia Portugal, S.A., is the main production unit of the Bosch Automotive Multimedia Division and also the largest unit of the Group in Portugal. Since 31 December 2016, it employed 2666 employees, and this number has already been largely exceeded and is now close to 3200 employees. Products include in-car navigation systems, head-up displays, and display-based instrument clusters that feature an innovative optical bonding process for a unique glow. Bosch had grown in Braga, and for that, it has invested 38 million euros in the expansion of its infrastructures up to 2019 to support the increase in orders from car manufacturers (Bosch, 2018b).

The quality of Bosch Car Multimedia Portugal, S.A. is proven by different awards it has already received, among others (Bosch, 2018b):

- 2007: Company “Recognised for Excelence”, with a maximum level of five stars, from EFQM - “European Foundation for Quality Management”.
- 2008: Quality Award from the Bosch Group.
- 2008: Distinction of Good Practices, by the Assembly of the Republic, for the work developed in the prevention of musculoskeletal injuries.
- 2011: Quality Award from the Bosch Group.
- 2011: Energy Efficiency Award.
- 2015: EFQM European Excellence Award.
- 2017: CES Innovation Award.
- 2017: EFQM European Excellence Award.

1.8 Organization of the Thesis

Chapter 1

- Provides a context for the theme of this dissertation, presents the company in which the study took place, and provides the objectives and the motivation for the study.

Chapter 2

- Presents the research background and a literature review on quality management in various applications, and provides a survey of decision-making tools especially in the automotive industry.

Chapter 3

- Describes the research method used in the case study. This chapter discusses the Kano model, and the QFD, and MCDM methods in detail. It also presents a proposed hybrid approach that considers the detailed and main critical points identified as the probable cause of defects in BU.

Chapter 4

- Describes the case study developed for the Bosch automotive industry to satisfy the customer needs, and the SAs that resulted from the experts' opinions. Finally, the chapter provides an analysis of the results.

Chapter 5

Provides the study conclusion, discusses limitations, and makes suggestions for future studies.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In this chapter, a review of the literature on the subject has been laid out. This chapter is divided into three main sections: Basic concepts, literature review, and literature review synthesis. The basic concepts section discusses the definitions and concepts related to the Kano model, QFD, Sustainability, and MCDM methods. Afterward, the literature review section investigates the reviewing background of some research which are done by the researchers. Then, the main findings related to the literature review are discussed in the literature review synthesis. Considering the importance and attractiveness of the topic in recent years and the tendency of researchers towards this field, a literature review of integrated QFD-MCDM with differentiation of the various models was accomplished.

2.2 Basic Concepts

Today's business environment is increasingly complex and competitive, and customer satisfaction is becoming the goal of organizations. Customer satisfaction is the feeling or attitude of a customer towards a product or service after using it. In other words, it is the buyer's enjoyment or disgust towards the performance of the product or service after comparing the performance (or the result of the performance) of the purchased product or service compared to what he or she expected (Karatepe, 2016). Customer satisfaction leads to an increase in income and profit through repeated purchases, new product purchases, and product purchases by new customers who have become interested in the product through satisfied customers. In fact, customers who are highly satisfied with the organization pass on their positive experiences to others and thus become a means of advertising for the organization and thus reduce the cost of attracting potential customers (Foroudi et al., 2014). Profit in business requires the return of customers who are proud to have the goods or services and encourage their friends to use the company's goods or services. Therefore, it can be claimed that customer satisfaction leads to customer loyalty and, as a result, increases the company's future profitability. Customer satisfaction is achieved when the actual desire is satisfied and the customer need is met at a specific time and in the desired manner. Therefore, the first principle in the worldwide market is creating customer-friendly values (Lee et al., 2016).

Today, the growing use of information systems leads to databases with huge amounts of data. Maintaining and improving the quality of these large amounts of data is necessary and inevitable. The issue of data cleaning has been raised to improve the quality of data. On one hand, all organizations are trying to use available data and scientific techniques to move toward their success and increase business profitability. Also, the customers of the organization are among the key elements to increase profitability. On the other hand, business managers are interested in customer satisfaction and identifying CRs (Khoo, 2022).
Perceiving the customers and understanding their needs is an effective factor in gaining superiority in providing services to them. Managers should prioritize their customers, focus their attention on main customers, and day by day more understand the cost of losing customers because when customers stop doing business with us and start negotiating with our competitors, situations such as loss of current income due to business relationships or loss of reputation and credibility happen. Our customers will probably share their experiences with other customers. This loss may lead to mistrust of our current and any potential customers. Nowadays, the development of competitive policies and strategies is emphasized by experts, therefore, organizations cannot ignore their basic goals, such as gaining a competitive advantage. Identifying different groups of customers and determining their requirements and needs can lead to customer satisfaction and, as a result, increased customer loyalty. Identifying and retaining customer-perceived value in the long term is more beneficial than attracting new customers to replace those who have cut ties with the organization because the cost of attracting a new key customer is five times more than the cost of keeping a customer (Jiang et al., 2016).

2.2.1 Quality Tools Evolution

Today's turbulent and competitive environment has changed the definition of quality (Geum et al., 2012). Nowadays, customers determine the direction of the market, and the actions of companies are largely influenced by the market. Then, such businesses succeed and have capabilities and resources that meet customers' expectations (Chan and Wu, 2002a).
Before 1920, the inspection was the mainstay of quality control, but neither inspection nor even product control guaranteed the quality of the final product. In reality, a thorough inspection can classify and grade the product, finally leading to the separation of low-quality products that have been identified. This inspection temporarily prevents customer dissatisfaction but does not prevent the production of inferior products. Deming in his book "Out of the Crisis" shows in an example that if 10% of the people in a factory are engaged in reworking and corrective action of a low-quality product, by adding the people who caused these defects, the cost of repairing these defects is not so different with the cost of their production

which shows that the correction and reworking of low-quality products are much more costly than it seems. Due to the fact that such production cannot be competative in a stable economic environment, the only way to handle the current quick change and intense competition is through look-ahead control (Chan and Wu, 2002b).

Customers were not exposed to a variety of quality options up until the 1950s when industries focused only on quantity. However, in the 1960s, as mass production spread, this problem was solved, and industrial and service businesses will now have to stand out from the competition to survive in a competitive business market. There were other competitors, many of whom defined this distinction caused by competitors as a definition of quality. From this decade, the issue of quality became the most significant feature of a successful product or service, and special attention led to the use and expansion of various quality control tools (Dahlgaard, 1999).

2.2.2 Service Quality

Service quality is one of the most competitive advantages for the service sector (Ladhari, 2010). Since financial service organizations, especially banks, operate in an environment with undifferentiated products, service quality is recognized as the first tool for competition. Bennett and Higgins (1988) believe that competitiveness in the bank originates exclusively from the quality of services. Generally, banks that excel in service quality have separated markets because a better level of service quality is associated with more revenue, customer retention, and market share. Zeithaml et al. (1993) state in the research carried out in the United States of America that services have the 75% of the gross national product (GNP) and 90% of new jobs created. This turn towards a service-oriented economy is a global trend and has become one of the attractive competitive topics.

Service quality has been considered a fundamental competitive factor in all service area markets. Since financial service providers and banks operate in an environment with undifferentiated products, the quality of their services is known as the first advantage of competition (Westman, 2011).

If service companies regularly ask their customers for problems, the quality will improve dramatically (Zeithaml et al., 1993). Customer complaints bring high direct and indirect costs to organizations, but since these complaints include the voice of customers (VoCs) have valuable knowledge that can be used in quality improvement (Bosch and Enríquez, 2005).

2.2.3 Quality Function Deployment (QFD)

The fast-growing and rapidly changing markets in a global competitive environment have made quality of product or service a determinant of the success of an enterprise. In general, capturing effectively the genuine and major CRs is a major advantage for product-oriented firms. Therefore, analyzing the CRs and transforming them into appropriate product or service features are increasingly being explored. In this regard, as a practical quality management tool to fulfil customer needs, the QFD aims to meet the customer needs in a better way and enhance organizational capabilities, while maximizing company goals. QFD emerged in the 1960s in Mitsubishi Heavy Industries as a planning technique for product development (Akao, 1972). QFD is the translation of the Kanji word that the Japanese use to describe the generalization of quality development. Historically, the expansion of quality performance in Japan arose as a concept for developing new products based on total quality management (TQM) (Kahraman et al., 2006). The QFD supports the design of new products/services and the relevant production/supply processes by translating the CRs into measurable ECs of the new product/service and prioritise them, basing on their relationships with CRs and the related weights. This technique has been used for product development since the early 1980s in American industries. The automotive industry was the first group of manufacturing products to adopt QFD in the United States. But soon, other industries and especially services developed QFD. By using QFD, both manufacturing and service industries were able to use its benefits. The Figure 2-1 shows the evolution of QFD.

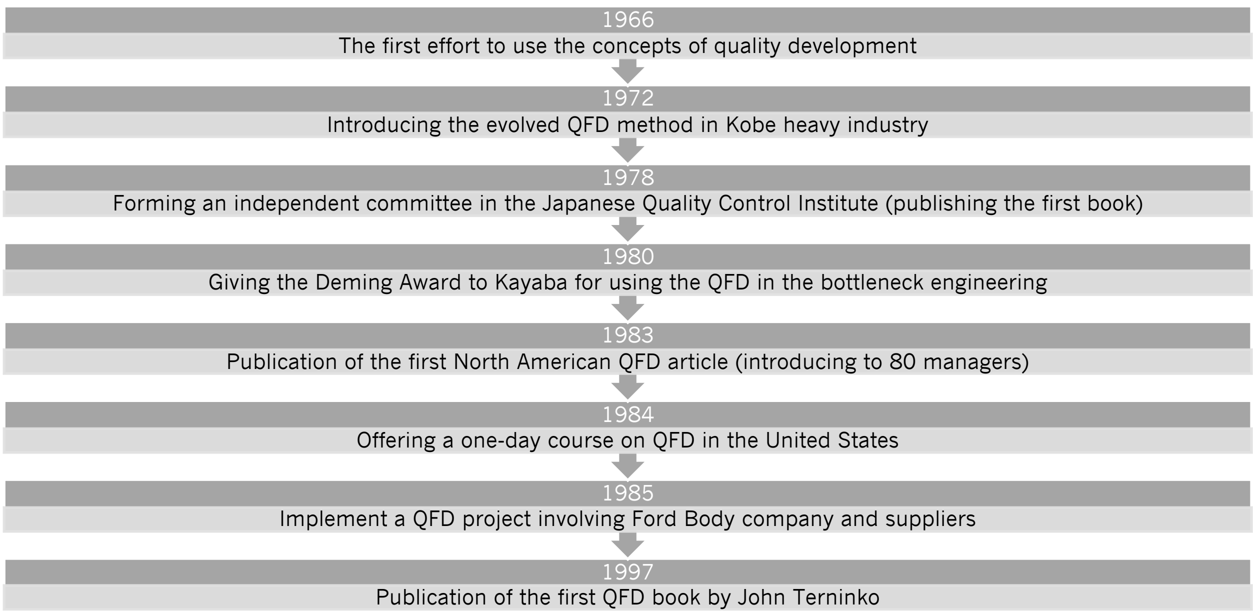

Figure 2-1 – The evolution of QFD (Ficalora, 2009)

2.2.3.1 Definitions of the QFD from Pioneers' Perspective

According to the definition given by who first introduced the QFD technique (Yuji Akao), QFD is a translator of customer needs and expectations for a product, which become product features (Wang, 2010). According to the educational resources of the GOAL/QPC Institute (one of the largest QFD consulting centers), QFD means:

> *A systematic and structured method and process to identify and implement the CRs in each of the stages of product development from initial designs until the final product stage, which requires the comprehensive cooperation of various departments of the organization, including marketing, sales, planning, engineering, production, after-sales services, and other departments for its proper establishment* (Manteghi and Zohrabi, 2011).

According to Walker (2002) , the QFD is a system that transforms the CRs into a suitable desired product. In other words, those CRs that can be satisfied using the product's performance can be implemented in QFD.

Thakkar et al. (2006) consider QFD as a customer-oriented design process that answers the questions of "what" and "how" according to the VoCs (industry and society). In the QFD technique, quality is broken into operational, technical, manageable, and tangible measures. Thus, it is possible to guarantee the fulfillment of the needs and expectations of customers at the appointed time.

2.2.3.2 QFD Goals

The goals of the QFD application can be summarized in design with lower cost, elimination of frequent technical changes, preliminary identification of critical production points, determination of processes for production, significant reduction of product development time, and optimal resource allocation.

In addition to tangible goals, intangible goals have also been recognized in the QFD implementation, which include: Improving customer satisfaction, facilitating group work with several different systems, creating an establishment for product improvement planning, creating and maintaining documentation, creating a transformable source for technical knowledge, encouraging QFD members to transfer their knowledge to other projects and to implement accurately and simultaneously all elements in QFD with complete coordination and coherence with each other. The QFD is for expanding and institutionalizing the CRs to all areas and organizational dimensions. QFD enables organizations to proactively identify and fix problems before customer complaints. QFD is a system that transforms customer needs into the right product or service features for them (Bhattacharya et al., 2010).

2.2.3.3 QFD Elements

QFD involves quality deployment and VoC in the design process. It leads to guaranteeing service quality by identifying design goals and service features related to customer needs (Chen and Ko, 2009).

Identifying customers: The first concept examined in QFD is identifying the customers of the product or service under consideration. To determine the customers of the product or service, different groups of customers (consumers), distributors, subcontractors, sellers, repairmen, after-sales service employees, and other organizational units (assembly, production) that are somehow affected by product characteristics are recognized.

Tools for listening to the VoC: The methods used in this stage include consumer comments on how the product works, reports from legal authorities, interviews (telephone, face-to-face), focus groups, data from the product warranty period, customer complaints, direct observation, in-depth interviews, questionnaires, and other tools were used (Backstrom and Wiklund, 2004).

The research conducted by Griffin and Hauser (1993) shows that the direct interview method is the most efficient if interviews are conducted with 10 to 20 customers which approximately 80% of the customers' need can be identified. The important thing is that the demands, in addition to the final customer's needs, include things such as country regulations and laws regarding the product (safety and health regulations, etc.), the product sellers' requirements (ease and handling, spoilage rate, etc.), and the repairers' requirements (ease of assembly, repair, etc.).

After listening to the VoC, the next step is to evaluate and analyze the customer's requirements (Akbari et al., 2009). To prioritize and analyze the CRs, various tools used such as factor dependency diagram, tree diagram, and Kano model (Jamali, 2011; Koleini Mamaghani and Barzin, 2019). Figure 2-2 shows a schematic example of a tree diagram for customer needs for a restaurant.

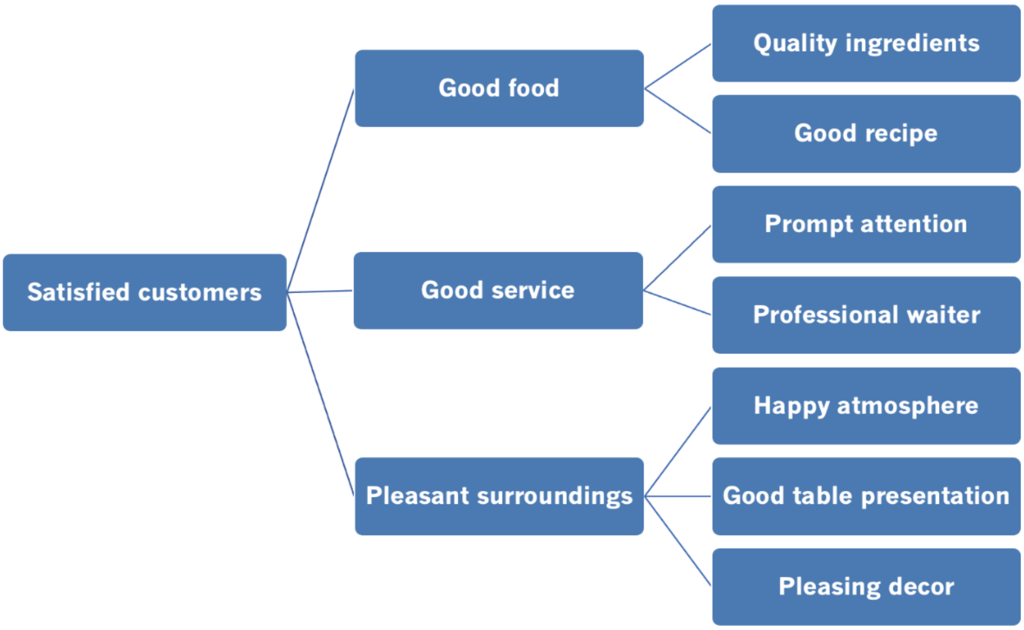

Figure 2-2 – The Tree diagram for an example of a restaurant (Jamali, 2011)

Figure 2-3 shows a schematic example of an affinity diagram for the requirements of writing an essay. Section 2.2.4 provides more information about the Kano model as a tool for identifying and classifying CRs.

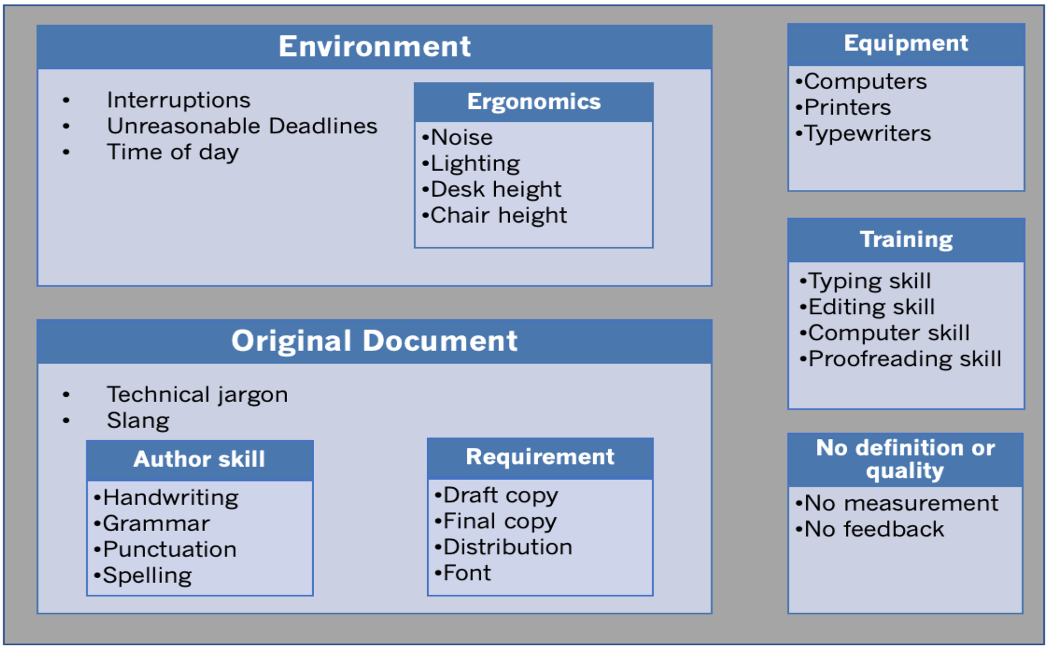

Figure 2-3 – The affinity diagram for writing an essay (Jamali, 2011)

The affinity diagram is quite beneficial in addressing the huge amount of subjective information. It is relevant that OEMs want to standardize the product platforms, at least on fewer and more common sizes, suggesting the need for more collaborative team approaches. It is logic to build the CRs using the findings from the consumer interviews and their analysis, which include the affinity diagram to cluster them (Fonseca et al., 2020).

2.2.3.4 Traditional Design Versus QFD-based Design

To understand the existential philosophy of QFD, it is better to compare design from two traditional and new perspectives (using QFD). According to Figure 2-4, the QFD in new product design activities requires a relatively large initial investment of time, money, and manpower. The remarkable thing about traditional methods is the very slow use of resources at the beginning of the project, which eventually reaches its maximum value. Indeed, in traditional design, the peak point of deployment and use of resources occur when major problems have occurred in the product. At the same time, the customer is still waiting for corrective actions to be taken. Of course, most of the time, it is somewhat difficult to convince managers to inject financial resources from the beginning of the project (Terninko, 1997).

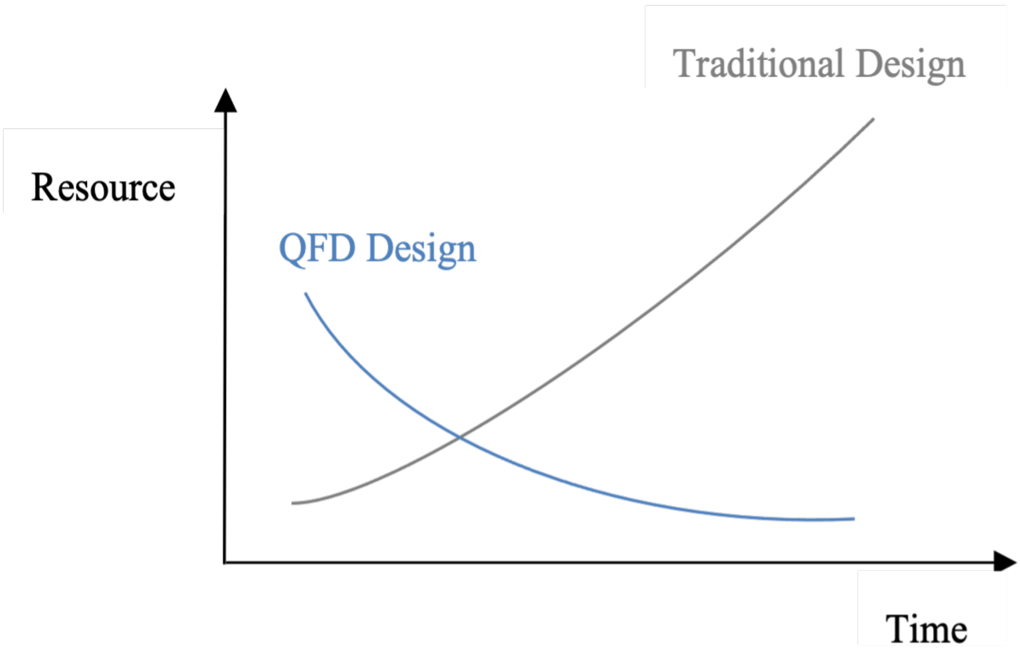

Figure 2-4 – Comparison of traditional design and design with the assistance of QFD (Terninko, 1997)

The research conducted by Kimberly-Clark (automotive company) shows the following results (Scheurell, 1993):

Applying the QFD method:

- Changes peaked 19 months before the first production (point A).
- After manufacturing the first product, there will be almost no change (point B).
- Design processes start 20 to 24 months before the first product is produced (point C).

Traditional method:

- Engineering changes are numerous until a few days before the product enters the market (point D).
- The downward trend of changes stops when the first product enters the market, which depends on the type and number of complaints (point E).
- The second peak is observed shortly after the first day of production (point F).
- There is a 100% inspection, but this 100% inspection does not help to meet the customer's demands at the beginning of the design.

The comparison of the two approaches of the QFD technique and the traditional method considering two criteria of time and change design is presented in Figure 2-5.

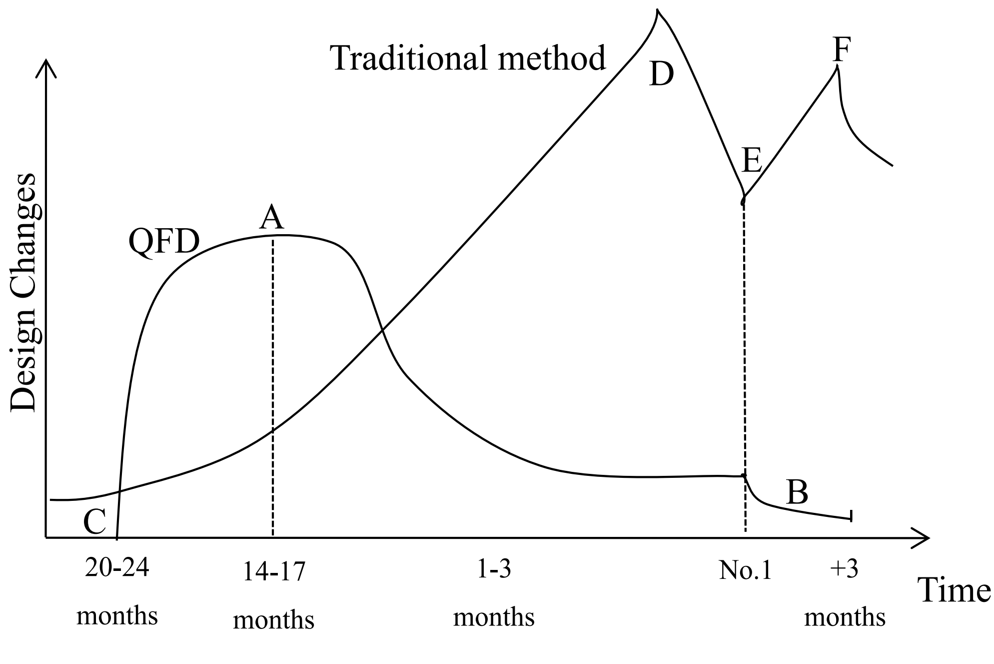

Figure 2-5 – Research in a automotive company (Sullivan, 1986)

2.2.3.5 The Structure of QFD

In global competition, quality is the first word in conquering the sales market. For this reason, quality improvement is the first and most significant factor to surpass competitors and gain a major market share. One of the most successful quality improvement tools is the QFD method. The development of QFD is one of the modern methods of quality engineering, which takes into account the wishes and needs of customers, is the foundation of product quality development and provides the design and manufacturing of products or services that meet the customer's demands and, in some cases, beyond it results.

Product and service quality is a critical aspect of customer satisfaction. The level of customer satisfaction depends on meeting customer needs, and QFD is a tool for translating the VoC into design characteristics. Since the level of customer satisfaction varies for each requirement, it is significant to know which feature keeps the customers satisfied at the maximum level.

The house of quality (HoQ) is one of the powerful tools of QFD, which is used to translate the VoC and needs from the product into quantitative requirements and improves the ability to follow up and include the CRs in the product from the side of the organization. HoQ is the most commonly used part of QFD. This house includes rooms that connect the desired and specified customer' needs called "WHATs" with technical design items called "HOWs". The fulfillment of the HoQ can be analyzed and applied to achieve a product considering customer expectations. Contrary to its complex appearance, the HoQ contains considerable and effective content. The planning matrix of the HoQ starts with the CRs and customer demands. For this purpose, by using methods such as market surveys, focus group interviews, observing how the product works when in use, employee opinions, product sales records, review of complaints and non-compliance records, data obtained from the services provided during the warranty period, the CRs are determined and formulated.

QFD is a technique that is used to develop most products and improve quality in various fields (Tan and Shen, 2000). QFD emerged in Japan in the 1970s and has been successfully applied by many American, Japanese, and European companies (Chan and Wu, 2002). The QFD examines CRs in detail and enables organizations to organize effective competitive strategies. Since QFD is a customer-oriented quality management tool, it is aimed at creating high customer satisfaction.

Among the various stages of QFD, the HoQ is the most critical stage, whose purpose is to reflect the desires and interests of the customer (Geum et al., 2012). If the HoQ prepared and adjusted accurately and appropriately, contains significant and useful contents which provides valuable information about the product due to the breadth and variety of concepts extracted from it, is the end point of many projects to expand the QFD (Zarei et al., 2011).

The HoQ: Quality houses are the most significant part of implementing the QFD. The main and most important of these houses is the first house because the first house acts as the gateway to the QFD process and expresses the main customer need and voices of the customers. The necessary care in the deployment of the steps in this house can serve as the fundamental milestone for the optimal implementation of QFD. The HoQ is a matrix in which the relationship between "WHATs" and "HOWs" is defined. The formation of the HoQ is presented in Figure 2-6.

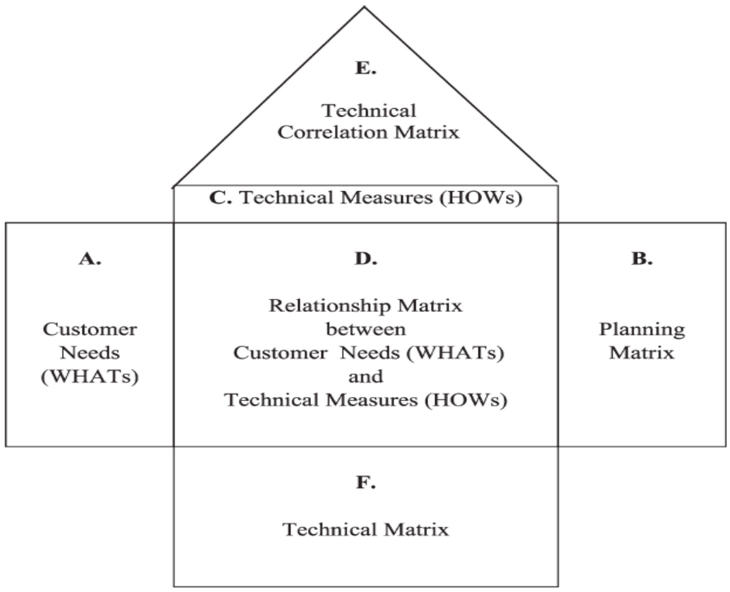

Figure 2-6 – The HoQ matrix (Sularto and Yunitasari, 2015)

The correct implementation of QFD may bring significant improvements in the development of products/services, including earlier and fewer design modifications, fewer start-up issues, improved cross-functional communications, improved product/service quality, reduced time and cost for product/service development, etc. Due to its features and benefits, the QFD has been applied to various fields, such as service quality improvement, supplier selection, and new product planning.

This customer-driven technique includes several operative phases, ranging from the VoC collection to the definition of the technical features of production/supply processes. The first phase entails the construction of the so-called HoQ, i.e., a planning matrix, which translates the CRs into measurable ECs of the product/service. One of the main goals of this phase is the definition of relationships between CRs and ECs, and the prioritization of these ECs, taking into account (1) their relationships with CRs and (2) the importance of the related CRs. Besides, Fiorenzo et al. (2017) have divided the QFD approach into four phases which deploy the CRs throughout the design and development process of the product/service of interest. In the first phase, CRs are related to a set of ECs of the product/service. Concerning the first phase, there are various shortcomings in the conventional QFD, which limit its efficiency and potential applications. The critical ones are enumerated below:

1. In the traditional QFD, the crisp numbers are adopted by domain experts to quantify the relationships between CRs and ECs. However, it is often hard for experts to provide their opinions by using exact values because of environment complexity and limited experience.
2. The classical QFD method determines the weights of CRs based on customers' evaluations without having a structured pair-wise comparison among CRs, which may lead to inaccurate ranking of ECs.
3. The prioritization of ECs is derived by using a linear aggregation method in the traditional QFD, which does not take decision makers' (DMs) preference behavior into consideration.

The QFD is an all-in-one concept that provides a means of translating the CRs into appropriate technical requirements for each stage of product development and production i.e., marketing strategies, planning, product design and engineering, proto-type evaluation, production process development, production as well as sales. QFD was originally proposed, through collecting and analyzing the VoC, to develop products with higher quality to meet or surpass customer's needs. Thus, the primary functions of QFD are product development, quality management, and customer needs analysis. Later, QFD's functions had been expanded to wider fields such as design, planning, decision-making, engineering, management, teamwork, timing, and costing. Essentially, there is no definite boundary for QFD's potential fields of applications. Moreover, the fast development of QFD has resulted in its applications in many manufacturing industries including transportation and communication, electronics and electrical utilities, software systems, manufacturing services, education and research, and other industries (aerospace, agriculture, construction, environment protection, packaging and so on) (Chan and Wu, 2002a).

Let $CR_1, CR_2, \cdots, CR_m$ denotes m identified customer requirements (CRs) and $DR_1, DR_2, \cdots, DR_n$ are n relevant design requirements (DRs). Let also $w_1, w_2, \cdots, w_m$ are the relevant importance (weight) of CRs where $w_i > 0;\ i = 1, 2, \dots, m$, R_{ij} represents the relationship between CR_i and DR_j and r_{jk} is the interrelationship between DR_j and DR_k satisfying $r_{jk} = r_{kj};\ j, k = 1, 2, \dots, n$. The relationship between CRs and DRs reflects the impact of the fulfillment of DRs on the satisfaction of CRs. These relationships should be developed by QFD team members. The relationship between CRs and DRs and the relationship between the DRs themselves are usually determined subjectively by ambiguous or vague judgments. However, they are usually captured using symbols converted into crisp numbers using different measurement scales. The degree of these relationships is usually expressed on a scale system such as 0-1-3-9 or 0-1-3-5, representing linguistic expressions such as "no relationship", "weak/possible relationship", "medium/moderate relationship", and "strong relationship".

In the second phase, ECs are associated with a set of critical part characteristics, through the so-called part deployment matrix. Then, the process planning matrix relates the critical part characteristics to the relevant production processes. Finally, a process and quality control matrix define suitable quality control parameters and methods to monitor the production process. According to Fiorenzo et al. (2017), the four phases of QFD are represented in Figure 2-7.

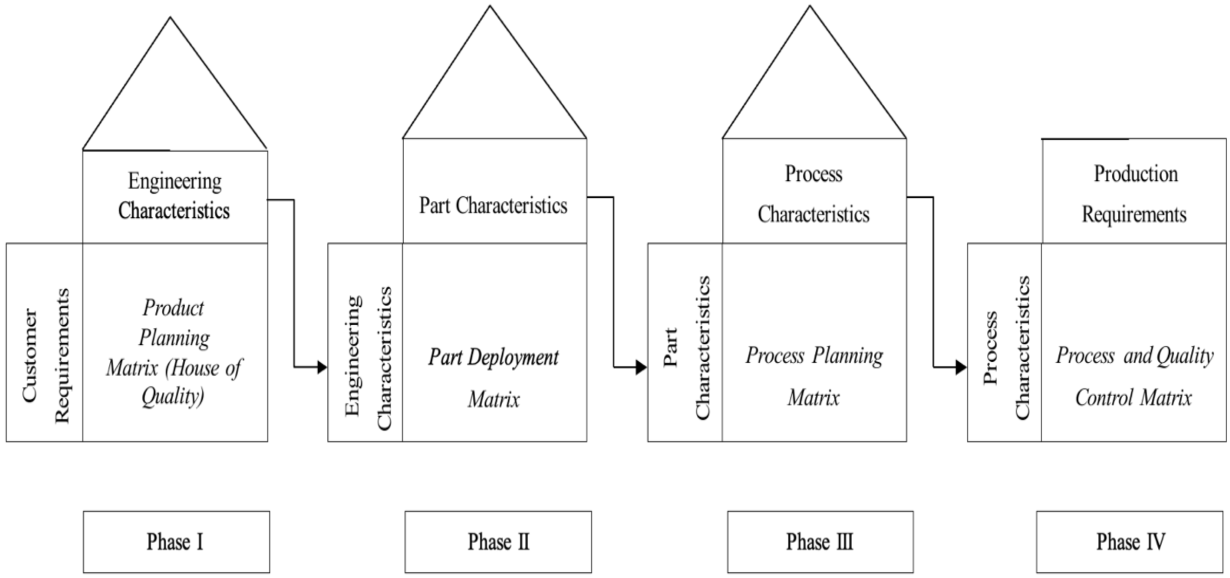

Figure 2-7 – Four phases of QFD in production (Liu and Wang, 2010)

A key objective of QFD is to determine directly what the customer would expect from a specific product or service. One-on-one customer interviews, focus groups, and in-context customer visits are examples of different approaches to achieve this objective. The most effective results are obtained from the QFD process when the team focuses on the customer needs that are most critical to the success of the product under consideration. Customers take part in this process by indicating their relative importance ratings while considering a product. The listing of DRs is a way to lead the team in using measurable and actionable statements which indicate the precise meaning of each customer need in the language of the organization. Brainstorming and making use of a tree analogy are the two main approaches for defining DRs. Relationships between customer needs and DRs are defined by answering a specific question corresponding to each cell in the HoQ.

2.2.4 Kano Model

As the competition for new markets and customers increased, customer satisfaction also became a key factor for business success. According to Reichheld and Sasser (1990), an increase in customer loyalty by 5% can increase the profit of a business by 100%. Customer satisfaction is related to the fulfilment of customer needs. For this purpose, many companies have made their efforts to provide customer-driven products to differentiate themselves from competitors. In this regard, analysis of customer needs information is an important task with a focus on the interpretation of the VoC and subsequently derivation of explicit requirements that can be understood by marketing and engineering. The Kano model can offer a better understanding of how customers evaluate a product and assists companies in focusing on the most important attributes that need to be improved (Chen et al., 2010). In the Kano model, customers' preferences are obtained using a prescribed form to know whether a given product attribute is a "Must-be", "Attractive", "One- dimensional", "Indifferent", or "Reverse attribute" for a given product. The Kano model is depicted in Figure 2-8:

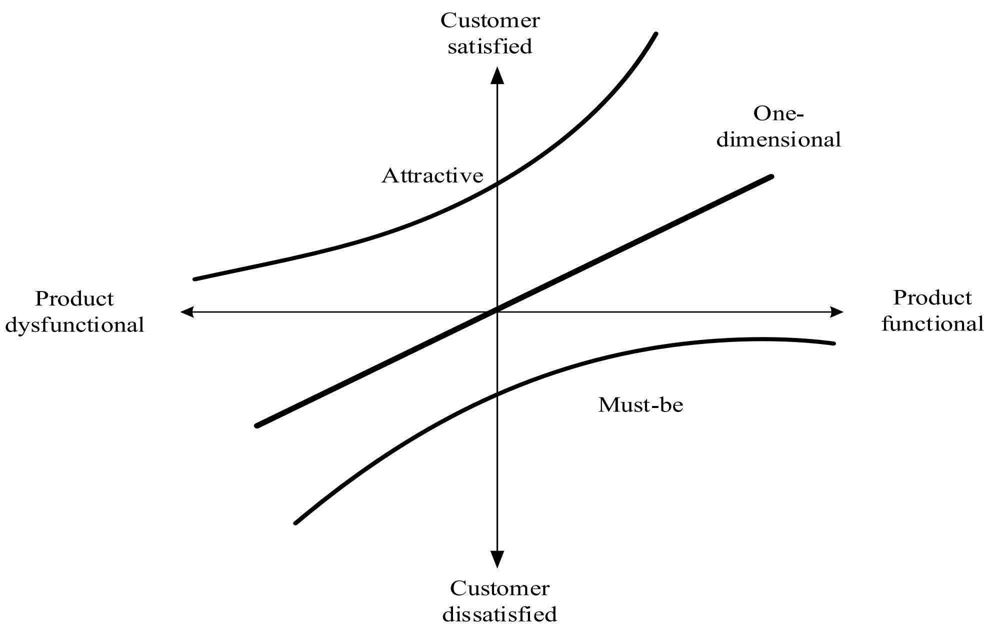

Figure 2-8 – The Kano model (Lo, 2021)

Kano (1984) introduced a model called the Kano Customer Satisfaction Model, which can distinguish three types of requirements of a product that affect customer satisfaction in different manners. These three types of needs are:

(1) *Must-be needs (M):* These needs are typically "unspoken" and if these needs are not fulfilled, the customer will be extremely dissatisfied. Nevertheless, it is imperative to distinguish and recognize them owing to their significance to the customers. This attribute is the existential philosophy of service/goods. For instance, the wheels are a primary requirement for a car, and customers do not mention wheels as a necessity, as this feature belongs to the machine's existential concept.

(2) *Performance or One-dimensional (O) needs:* The more of these requirements that are met, the more a client is satisfied by improving performance. These needs are usually articulated by the customer and better performance leads to happier customers. For instance, the consumption of gasoline over at a certain distance in the car is a performance need. One-dimensional features are often identified by scrolling.

(3) *Attractive Needs (A):* These are customers' wishes, so they are not stated. The absence of this feature does not cause dissatisfaction because they are not aware of these needs. If these needs are met product/service will delight the customer. Satisfying attractive needs provides a competitive advantage for the organization as an opportunity to differentiate itself from competitors. For instance, customers will not be dissatisfied if the cars do not use solar energy. Satisfying these needs makes the organization a market leader.

Kano proposes an effective tool for classifying the requirements and understanding their nature (Matzler and Hinterhuber, 1998). Kano's model explains how customer satisfaction changes as its needs are met by the organization discussed in Figure 2-8.

In addition to these three main quality dimensions of the Kano model, the consequences of "Indifferent", "Reverse" and "Questionable or Skeptical" can also appear (Berger et al., 1993; Kano, 1984):

(1) *Indifferent (I):* It means the customer is not worried about this feature of the product and is not very interested in its existence or non-existence.

(2) *Questionable or Skeptical (Q):* This situation occurs when there is a discrepancy in the customer's answers to the positive and negative questions. The skeptical rating indicates an incorrect question phrase, misunderstanding of a question, or incorrect answer.

(3) *Reverse (R):* This means respondents' satisfaction decreases despite this requirement, but they also expect the opposite. Table 2-1 presents the evaluation of the Kano quality attributes.

Table 2-1 – The evaluation of the Kano model quality attributes (Chen et al., 2018)

Customer Preference		***Dysfunctional Form of the Questions (Negative Questions)***				
		like	Must-be	Neutral	Live with	Dislike
Functional Form of the Questions (Positive Questions)	like	Q	A	A	A	O
	Must-be	R	I	I	I	M
	Neutral	R	I	I	I	M
	Live with	R	I	I	I	M
	Dislike	R	R	R	R	Q

To expand the basic Kano model, Yang (2005) proposed a refined Kano model and extended the four main quality features to eight (Figure 2-9): Highly attractive quality, Low attractive quality, High value-added quality, Low value-added quality, Critical quality, Necessary quality, Potential quality, and Care-free quality.

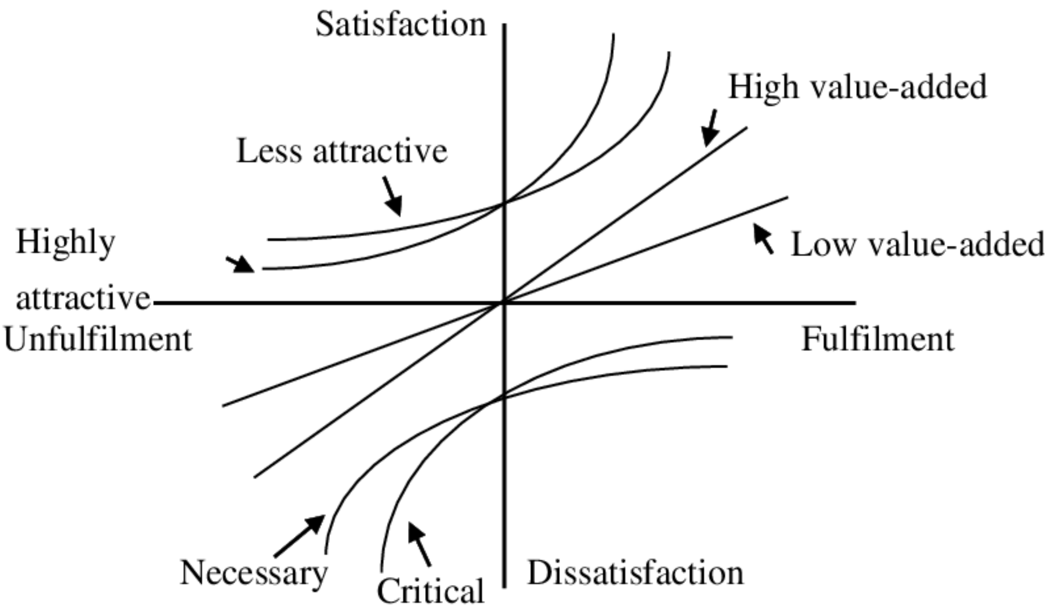

Figure 2-9 – Refined Kano model (Yang, 2005)

Therefore, a refined Kano model is applied to classify customer needs. The refined Kano model refers to the mean importance as the cut-off point for classification. If a feature in the basic Kano is considered as an attractive quality so long as importance value is higher than the mean value of all attractive quality features, it will classify by the refined Kano as a high attractive quality; otherwise, is considered a low attractive quality feature. Table 2-2 shows the different classifications of the features in the basic and refined Kano model.

Table 2-2 – The classification of the Kano model attributes and refined Kano model attributes (Chen et al., 2018).

Kano model	***Refined Kano Model***	
Quality Attribute	**High Important Attributes**	**Low Important Attributes**
Attractive quality	High attractive quality	Low attractive quality
One-dimensional quality	High value-added quality	Low value-added quality
Must-be quality	Critical quality	Necessary quality
Indifferent quality	Potential quality	Care-free quality

For more information concerning Kano model and its modifications see the review paper by Shahin et al., (2013). The main aim of the study is to propose a novel kind of Kano model considering the comparison of three existing proposed models and integrating them. The novel Kano model considers the weakness and strengths of previous models presented in Figure 2-10. The curves of A_1, A_2, and A_3 are defined as less attractive, attractive, and high attractive features, and also, the curves of M_a, M_b, and M_c show less must-be, must-be, and high must-be, respectively.

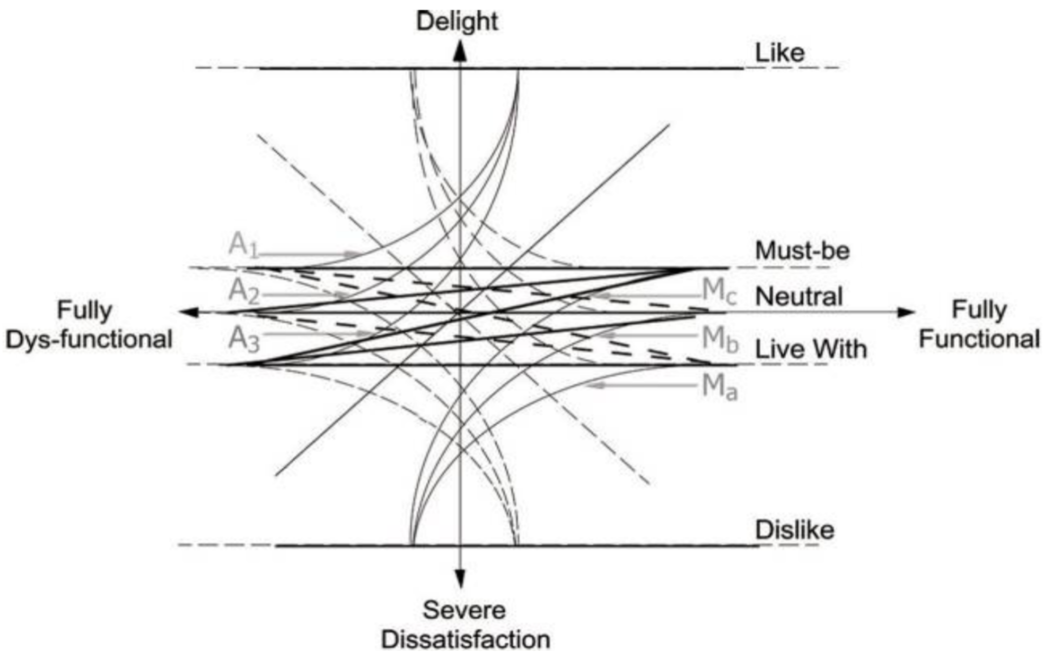

Figure 2-10 – A novel Kano model by integrating three previous Kano model (Shahin et al., 2013)

2.2.5 Sustainability

Sustainability is a development that meets the needs of the current generation without limiting the ability of future generations to develop their requirements. As a challenge in the future, a sustainable global economy must be developed so that the Earth has a large capacity and ability to support it.

2.2.5.1 Sustainability Background

Following the Brundtland Commission report in 1992, the term "sustainable development" became popular. People have been debating what sustainable development means in practice and how it can be achieved in the future. Several definitions of this word have been developed for this purpose. Regardless of the terminology, the core concept in all these terms is the same: society is sustainable when both human conditions and the current state of the ecosystem are satisfactory or improving (Tseng et al., 2018).

Sustainability management is defined as strategic business activities to minimize environmental, economic, and social sustainability risks, maximizing corporation value such as shareholder value (Tseng et al., 2018; Wong, 2014). Díaz-Garrido et al. (2011) pointed out that competitive priorities in industries refer to the goals of production units that enable companies to compete, achieve proven capabilities to operate, and strengthen the company's competitive advantage. Lin and Tseng (2016) stated that dynamic flexibility in operations is a competitive requirement for companies in sustainable supply chain management (SSCM) which is encouraging businesses to expand their supply chain's social, economic, and environmental goals. Chardine-Baumann and Botta-Genoulaz (2014) pointed out that sustainable development in manufacturing is not only a limiting factor but also an approach to improve performance which affects the company's competitive power and the organization of its supply chain.

Sustainability is a strategy for businesses related to the social responsibilities of companies. To achieve a long-term competitive advantage, organizations need sustainable performance, which includes economic, environmental, and social performance (Paulraj, 2011; Thoo et al., 2014).

Companies should focus on long-term profits that can simultaneously increase profits and reduce environmental and social risks. A wide range of sustainable supply chain management is derived from economic, social, and environmental performance concepts and review measures (Porter and Kramer, 2006).

Researchers such as Paulraj (2011), Zhu et al. (2005), and Laosirihongthong et al. (2013) considered three important indicators for sustainable performance, which include the economic performance, environmental performance, and social performance.

Environmental management has employed various initiatives to reduce and minimize the side effects of environmental impacts in executive organizations. It aims to improve environmental performance, reduce costs, improve the perception of cooperation, reduce the risk of non-acceptance, and improve marketing benefits. Nevertheless, many organizations still look at green initiatives as balancing environmental and economic performance (Klassen and McLaughlin, 1996).

The economic performance of companies is affected by their environmental performance. When waste, wether in dangerous or harmless cases, is minimized considering environmental management, the result is a better use of natural resources, improved productivity, and reduced operational costs. Also, when companies' environmental performance improves, this can be a great guide for marketing that can increase revenue and market share and create new market opportunities. Companies are responsible to minimize environmental impacts in production, processes, and waste recycling and create an environmental management system in the firms that are ready to expand the market for their products and can outshine their competitors in environmental performance (Klassen and McLaughlin, 1996).

Although the terms sustainable supply chain management and green supply chain management are frequently used interchangeably in the supply chain field, they are not identical. The SSCM includes economic, social, and environmental dimensions. Therefore, the SSCM concept is broader than green supply chain management, and in other words, it can mean green supply chain management is a part of SSCM (Farahani et al., 2009).

Early in the 1970s, the phrase "sustainable development" was used to refer to both the environment and development. Sustainable development is a method for ensuring the longevity of any activity that needs resources and quick, seamless replacement. In a developed society or economy, sustainable development attempts to study continuous development that goes beyond economic development (Zhu et al., 2005).

Sustainable development is the organizing element that sustains non-renewable resources, i.e. the limited necessary resources for future generations to live on the planet. Sustainable development is a process that envisages a desirable future for human societies in which living conditions and resource use meet human needs without harming the integrity, beauty, and stability of vital environmental systems (Ninlawan et al., 2010).

Sustainable development offers solutions to the structural, social, and economic patterns of development to avoid issues such as the destruction of natural resources, destruction of biological systems, pollution, climate change, excessive population growth, injustice, and the lowering of the quality of life of human beings in the present and the future. Sustainable development is a process of using resources, directing investments, directing technological development, and institutional changes which are compatible with current and future needs.

Sustainable development, which has been emphasized since the 1990s, is an aspect of human development concerning the environment and future generations. The goal of human development is the cultivation of human capabilities. Sustainable development as a process, while it is necessary for improvement and progress, provides the basis for improving the situation and removing the social and cultural shortcomings of advanced societies. It should be the driving engine for balanced, proportionate, and harmonious economic, social, and cultural progress of all societies, especially in developing countries. Sustainable development tries to respond to the following five basic needs: integration of conservation and development, provision of basic human biological requirements, achievement of social justice, autonomy and cultural diversity, and preservation of unity (Ninlawan et al., 2010).

2.2.5.2 Dimensions of Sustainability

The idea of sustainable development is based on the undeniable truth that ecological factors can and should be considered when conducting business. These factors include the notions of establishing a logical setting in which the assertion of development as a means of enhancing the quality of all facets of life is contested. According to what was said, the fields related to sustainable development are social, economic, and environmental (Gómez-Luciano et al., 2018). Figure 2-10 presents the dimensions of sustainability.

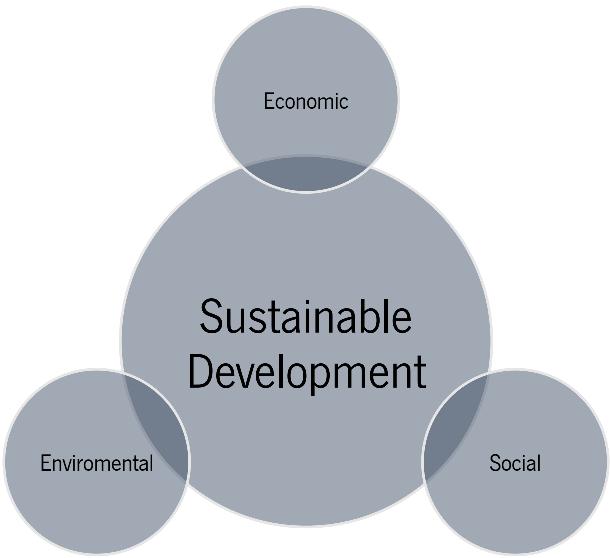

Figure 2-11 – Dimensions of sustainable development (Eadie et al., 2011)

Since 1950, when it was applied in the industrial revolution, the idea that now refers to an organization's social responsibility has been represented as a helpful starting point. One of the early proponents of social responsibility, William Frederick, developed the following three principles in 1950: 1) managing organizations as a general supervisor, 2) establishing a balance for the use of organizational resources, and 3) accepting philanthropy. The period of social responsibility growth runs from 1950 to 1980 (Carroll and Shabana, 2010). This approach has been utilized in organizational decision-making for several decades, and it has complicated the idea of social responsibility (Tu et al., 2013).

Due to the environmental and social effects of industrial activities in the supply chain, social responsibility is critical for many international companies to coordinate the entire chain (Tu et al., 2013).

The cost of the product will be decreased if social responsibility objectives are in line with organizational implementation. The company will then be a great social security optimizer, customers will be encouraged to make larger purchases, and the excess of customers will optimize the supply chain's profits. Supply chain executives are the ones who have the principal influence on the levels of social responsibility implementation. If an executive pays less for using this strategy, he should share his techniques and knowledge with other chain partners, and all supply chain costs will be reduced (Hsueh, 2015).

Today, under the pressure of customers, non-governmental organizations (NGOs), and governments, global supply chains are forced to accept social responsibility and sustainability. Therefore, these supply chains identify opportunities related to creating incentives for sustainability and social responsibility (Boström et al., 2015). Global supply chain networks have been oblivious to the complexity of improving sustainability, especially when it comes to social and environmental responsibility. In terms of social and environmental issues, this study examines how employing sustainability strategies affect the chain's various links in terms of empowerment. Empowering different departments and using new technologies will create a friendly atmosphere and pay attention to environmental factors (Gómez-Luciano et al., 2018).

As mentioned earlier, governments have a significant role in implementing social responsibility because this strategy can bring about many changes in the national structure of countries. Since social responsibility has been a successful strategy in business environments in recent years, it has examined the views of various stakeholders, governments, and society. The flexibility inherent in laws renders them a prime influence for implementing social responsibility by governments, with particular emphasis on certain countries, including the United States and the European Union concept of social responsibility is widely regarded as an imperative undertaking (Govindan et al., 2014). Agan et al. (2013) studied the implementation of social responsibility in 500 companies and concluded that social responsibility is affected by the behavior of the companies. When trust in business decreases, the implementation of social responsibility can create a competitive advantage for the organization.

2.2.6 Fuzzy Sets

Fuzzy set theory, introduced by Zadeh (1965) is designed to model the vagueness or imprecision of the human cognitive process. A fuzzy set is generally defined by a membership function that maps elements to degrees of membership within a certain interval, which is usually $[0,1]$. Triangular fuzzy numbers (TFNs) are convenient in applications and useful in promoting information processing within a fuzzy context due to the computational simplicity (Tadić et al., 2014). Furthermore, the TFNs are applicable to the nature of the linguistic assessments of experts, and widely employed in fuzzy-MCDM studies.
A TFN denoted by $\tilde{a} = (\tilde{a}^l, \tilde{a}^m, \tilde{a}^u)$ and its membership function $\mu_{\tilde{a}}(x)$ can be defined as follows in equation (Eq. 2-1):

$$\mu_{\tilde{a}}(x) = \begin{cases} 0 & x < \tilde{a}^l \\ \dfrac{x - \tilde{a}^l}{\tilde{a}^m - \tilde{a}^l} & \tilde{a}^l \le x \le \tilde{a}^m \\ \dfrac{\tilde{a}^u - x}{\tilde{a}^u - \tilde{a}^m} & \tilde{a}^m < x \le \tilde{a}^u \\ 0 & x > \tilde{a}^u \end{cases} \tag{2-1}$$

Where x takes values on the real line, and $\mu_{\tilde{a}}(x)$ is a continuous mapping from R to the closed interval $[0,1]$, and a fuzzy number is a special fuzzy set $\tilde{a} = \{(x, \mu_{\tilde{a}}(x)), x \in R\}$.

2.2.7 Multi-Criteria Decision-Making (MCDM)

Decision-making is a significant issue for businesses to find an optimal alternative from numerous feasible alternatives. The equations (Eq. 2-2) and (Eq. 2-3) show an MCDM problem in the following matrices format:

$$G = \begin{array}{c} \\ A_1 \\ A_2 \\ \vdots \\ A_m \end{array} \begin{array}{c} \begin{array}{cccc} C_1 & C_2 & \dots & C_n \end{array} \\ \begin{bmatrix} G_{11} & G_{12} & \cdots & G_{1n} \\ G_{21} & G_{22} & \cdots & G_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ G_{m1} & G_{m2} & \cdots & G_{mn} \end{bmatrix} \end{array} \tag{2-2}$$

and

$$\mathbf{W} = \left[W_1, W_2, \ldots, W_n\right] \qquad (2\text{-}3)$$

Where $A_1, A_2, \ldots, A_m$ are feasible alternatives, $C_1, C_2, \ldots, C_n$ are evaluation criteria, G_{ij} is the rating of A_i on C_j and W_j is the weight of C_j.

To develop the QFD technique and establish a more precise ranking process for the CRs, the MCDM methods are adapted to include several stages with several criteria. First, the set of criteria and options are defined, then, it is chosen the appropriate and adaptable decision-making method. The decision environment may be deterministic or uncertain. When the data is based on human perception rather than accurate and sufficient numerical observations, uncertainty can also be used (Gündoğdu and Kahraman, 2020). Figure 2-12 presents the detailed steps of implementing the MCDM method.

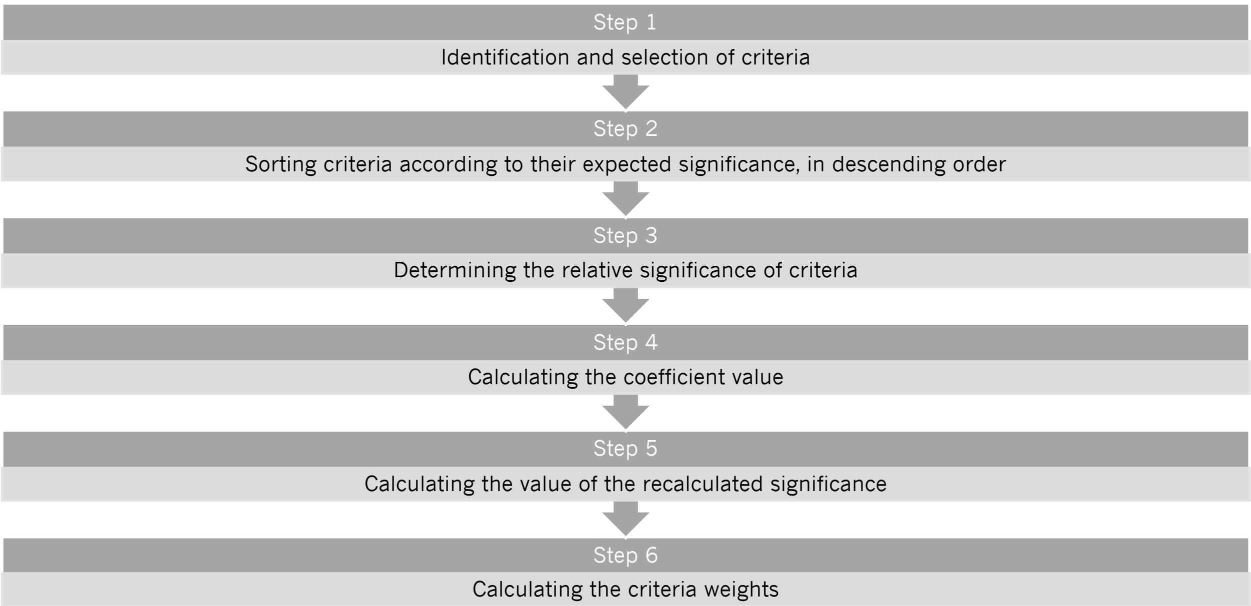

Figure 2-12 – The Steps of the MCDM method (Keršuliene et al., 2010)

2.3 Research Background

This section discusses the application of hybrid integration of QFD and MCDM tools and other methods in various areas of industry, services, and manufacturing. Also, the classifications of publications in various areas concerning hybrid QFD-MCDM procedures are mentioned in Table 2-3. Then, considering the aggregate search of literature related to the research area, the distribution of various methods combined with QFD-MCDM and various MCDM tools are discussed and presented in Table 2-4, aimed to show the importance of using the novel methods that are increased recent years.

Rajagopal (2011) has studied customer clustering in which a demographic clustering algorithm was applied to identify customer clustering. Firstly, customer information is identified using various parameters and developed patterns. Second, after analyzing the data and forming clusters, the low-risk with high-value customers is identified. This study uses the demographic clustering method for customer classification (customers are classified into three clusters), and the amount of income and value of each is determined. A hybrid two-Phase framework by integration of fuzzy analytic network process (FANP), QFD and multi-choice goal programming was proposed by Lee et al. (2010) for facilitating the selection of ECs for product design. Considering the interrelationship among factors and the impreciseness and vagueness in human judgments and information, the. authors first incorporated QFD with the super matrix approach of analytic network process (ANP) and the fuzzy set theory to calculate the priorities of ECs. In the second phase, to select the most suitable ECs, it was established a multi-choice goal programming model was used that considered the outcomes from the first phase and other additional goals. The authors used a case study of the product design process of backlight unit in thin film transistor liquid crystal display (LCD) industry in Taiwan to illustrate the practicality of their proposed method. Song et al. (2014) proposed a novel group decision approach for prioritizing the technical attributes more rationally. In this study, the authors were taken advantage of the rough set theory (RST) approach for handling the vagueness with less prior information and the grey relational analysis (GRA) technique for structuring the analytical framework and discovering necessary information about the data interactions. The authors provided an application in industrial service design for compressor rotors to express the merit of their proposed approach. Liu and Cheng (2016) introduced a grey quality function deployment (GQFD) method based on the integration of interval grey numbers, QFD and theory of inventive problem solving (TRIZ) techniques. In addition, the authors developed a new ranking method to determine the ranking order of interval grey numbers. Finally, the authors highlighted the advantages of their proposed GQFD method using a real industrial data from a computer peripheral product.

Abdolshah and Moradi (2013) analyzed the QFD with a fuzzy approach. This study it was investigated the research background of fuzzy-QFD during the years 2000 to 2011. The results showed that most of the research conducted in the years under review emphasized the quantitative criteria of phase 1 of the QFD method, and the majority used MCDM methods to rank the criteria. Also, the results indicate that few researchers had studied all phases of QFD, and that mostly, such factors as risk and competition had not been considered. The study focused on classifying the combination of the FQFD and six other methods which are common in fuzzy theory in all of them. The comparison of the characteristics of these models is discussed in this article, and Figure 2-13 presented all these combinations.

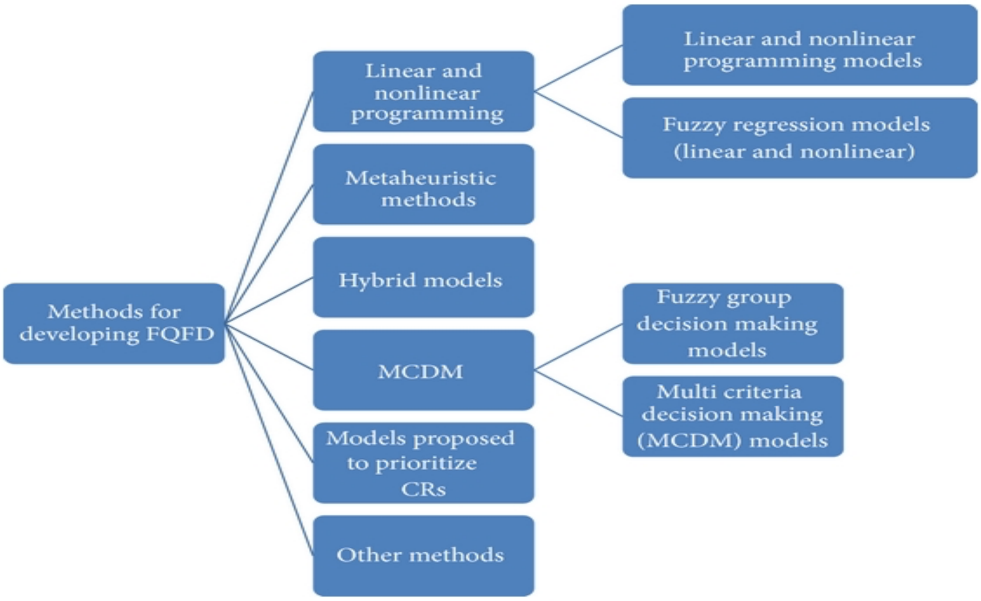

Figure 2-13 – The classification of FQFD and other techniques (Abdolshah and Moradi, 2013)

To derive criteria weights, Wang (2014) integrated the fuzzy-QFD into relative preference relation on fuzzy multi-criteria decision-making (FMCDM) problems. Zaim et al. (2014) proposed a hybrid ANP-weighted fuzzy methodology to represent the multifarious relationships between CRs and technical characteristics, and the relative weights among CRs. The study used a real-world data in polyethylene pipes industry to demonstrate the capability of their proposed methodology. Li et al. (2014) proposed a new MCDM method by combining QFD with technique for order preference by similarity to an ideal solution (TOPSIS) in an intuitionistic fuzzy environment. To accomplish this, the model used intuitionistic fuzzy sets to deal with the linguistic opinions. The authors provided an example to illustrate the applicability of their proposed method. Under fuzzy environment, Ocampo et al. (2016) presented a multi-phase approach based on the combination of fuzzy-QFD and MCDM (analytic hierarchy process (AHP), ANP, and decision-making trial and evaluation laboratory (DEMATEL)) for sustainable product design. The authors evaluated the capability of their proposed methodology through a case study in an oil production. Feiz and Mehrizi (2014) ranked product design factors using the integration of QFD and TOPSIS methods. The ranking determined the criteria for product design by considering the CRs based on the QFD method. Then, the TOPSIS was applied to rank the product's design elements as the CRs taken into consideration. Li et al. (2014) investigated the design of innovative products based on the comprehensive customers' needs.

First, based on the QFD technique, the authors determined the technical requirements of product design considering customer satisfaction, and then it used the AHP method to rank the design and production characteristics of innovative products. Wang et al. (2016) considered the incomplete weight information and extended a new hybrid group decision-making model based on the hesitant 2-tuple linguistic term sets and an extended QUALIFLEX (qualitative flexible multiple criteria method) approach for handling QFD problems. To accomplish that, first the authors first combined the hesitant linguistic term sets with interval 2-tuple linguistic variables to express various uncertainties in the assessment information of QFD team members. Afterward, a multiple-objective optimization model was constructed for determining the relative weights of CRs. Then, it suggested an extended QUALIFLEX approach with an inclusion comparison method was used to rank the DRs identified in QFD.

Akbaş and Bilgen (2017) introduced an integrated model of MCDM methodology and fuzzy-QFD procedure in order to maintain sustainable operations at wastewater treatment plants. To accomplish that, the integrated model utilized the fuzzy analytic hierarchy process (FAHP) for determining the importance weights of attributes in the MCDM model to avoid inconsistent results of crisp QFD analyses caused by the variability of human judgment. The authors also used FANP for considering both symmetrical and asymmetrical relationships between CRs and ECs. Moreover, the comprehensive weight vector of ECs was used as the weights of the selection criteria in the TOPSIS side of their proposed integrated methodology. Fiorenzo et al. (2017) proposed a method based on a hybrid multi expert /multi-criteria decision making (ME-MCDM) technique to compute the EC prioritization in QFD. Hsu et al. (2017) proposed a hybrid approach based on QFD, fuzzy Delphi method (FDM), modified fuzzy extent analytic hierarchy process (FEAHP) and TOPSIS method to prioritize the performance factors for sustainability development of SMEs. Lee et al. (2017) extended a comprehensive model by integration of QFD with fuzzy set theory and decision-making methodologies, including Delphi method, DEMATEL and ANP for implementing new product development (NPD) project. It carried out a case study for a solar cell manufacturer to illustrate the efficiency of their proposed model.

Using multi-phase QFD approach, Tian et al. (2018) introduced a hybrid FMCDM method to cover the performance evaluation of smart BSPs (bike-sharing programs) considering the customer voices under uncertain conditions. For this purpose, the authors combined the fuzzy-BWM, fuzzy maximizing deviation method (MDM), and fuzzy multi-objective optimization by ratio analysis plus the full multiplicative form (MULTIMOORA).

An important objective of the QFD method is to to prioritize customer needs, as. well as to form the relationship matrix between CRs and DRs and interrelationships between the DRs themselves. As the weighting and prioritization methods in the traditional model are not sufficently accurate, the use of MCDM methods helps to achieve reliable results.

The studies mentioned in this dissertation are abstracted from a literature review study during 2004-2021 that show the application of QFD-MCDM methods and hybrid models, which include a combination of several methods using different tools in the final ranking of CRs and DRs (Hariri et al., 2023b). Furthermore, case studies that adapted the DEMATEL method on the roof of HoQ, and as well as the application of fuzzy theory to increase accuracy and reduce vagueness and expert judgment had better results in the final evaluation. In some studies, methods such as Markov and Kano model were used to classify customer needs before entering the QFD process, which is effective in better identifying and classifying customer needs. The literature showed that in the considered time period, the decision-making tools used to prioritize and to weight various factors are much more accurate than the traditional ones. In addition, in combination with fuzzy theory (namely in the healthcare area), the CRs are more qualitative, more effective, and more accurate.

The literature review study categorized the investigations into three main categories, including QFD-MCDM models, which consists of models adapted with QFD and MCDM, hybrid QFD-MCDM, which includes the use of QFD and MCDM and other tools and the third classification is the application of hybrid models in different fields, which includes the use of the mentioned methods in the practical field. In Table 2-3, due to development of the QFD model four main classifications are discussed by authors (Hariri et al., 2023b). Uncertainty was adapted in studies due to the elimination of the vagueness in the VoC. Sustainability is a broad policy concept in the global public discourse and is thought to consist of the environmental, economic, and social dimensions. Various MCDM tools and supplementary models such as mathematical, logical, and quality tools have been discussed in previous literature. The combination of these techniques with QFD has the potential to enhance the output of the hybrid model.

Table 2-3 – Distribution of studies combined with QFD considering the methodology (Hariri et al., 2023b)

ID	***Methodology***		***Number of studies***	
1	Uncertainty	Fuzzy, RST, Hesitant 2-tuple linguistic, Interval grey numbers, Hesitant fuzzy, Fuzzy Delphi, INS, Neutrosophic set, HFLTS, Fuzzy trapezoidal, PHFLTS, Internal valued fuzzy set, EHFLTS, IT2FS, PFLS, TFN, SFS, HF, IVIF	39	39
2	Sustainability	Sustainability, Green, environmental	12	12
3	Decision - making tools	ANP	10	68
		SWARA	1	
		AHP	13	
		MOORA and Multi-MOORA	6	
		BWM	3	
		Entropy	3	
		TOPSIS	6	
		DEMATEL	10	
		COPRAS	1	
		VIKOR	1	
		Choquet integral	1	
		MODM (linear programming)	5	
		Grey target decision making	1	
		Multi choice GP	1	
		ME-MCDM	2	
		GRA	4	
4	Supplement Models	Risk optimization	1	20
		BOCR	1	
		TRIZ	1	
		Dynamic QFD	1	
		EGM	1	
		QUALIFLEX	1	
		Prospect theory	1	
		DEA	1	
		EDAS	1	
		ERP	1	
		OA	1	
		Cloud model	1	
		Kano model	4	
		PSS	1	
		Delphi	2	
		Means-end chain	1	

Table 2-3 shows that basic decision-making tools are the most implemented (68 times). Thus, it can be concluded that this method is generally a sufficient method to obtain the optimum results. Also, the application of the uncertainty in studies (39 times) shows that the QFD application to translate the VoC, in terms of eliminating the vagueness element can increase the precision.

Figure 2-14 shows the distribution of the various hybrid methods integrating QFD-MCDM. The first category is the integration of QFD with uncertainty, the most significant of which is the fuzzy theory, and it is applied in various studies into QFD (28%). The second category shows the integration of QFD with sustainability, which shows 9% due to the novelty of the topic of sustainability. As sustainability has entered various fields in recent years, it has attracted more attention and is increasing in different hybrid models considering QFD. The third category shows the combination of QFD with decision-making tools, which has the highest number of integrated models with 49% frequency, which shows the importance of decision-making tools to improve QFD results. The last category shows the degree of integrated QFD technique with other quality management, mathematical, and optimization models by a frequency of 14% among the supplement models. The Kano model can be mentioned as one of the quality management that models which will be discussed in the current study.

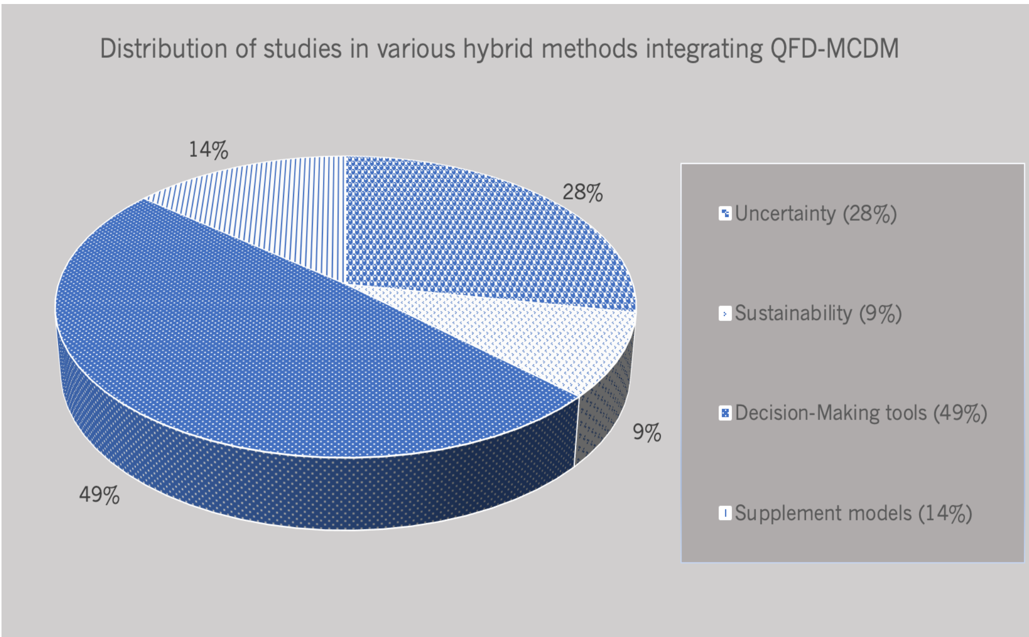

Figure 2-14 – distribution of the various hybrid methods integrating QFD-MCDM (Hariri et al., 2023b)

Figure 2-15 presents the distribution of different decision-making tools. As seen in the figure, the AHP method (19%) is the most adapted tool in the studies, and new MCDM tools like best-worst method (BWM), SWARA are not widely integrated with QFD and can improve the future hybrid models.

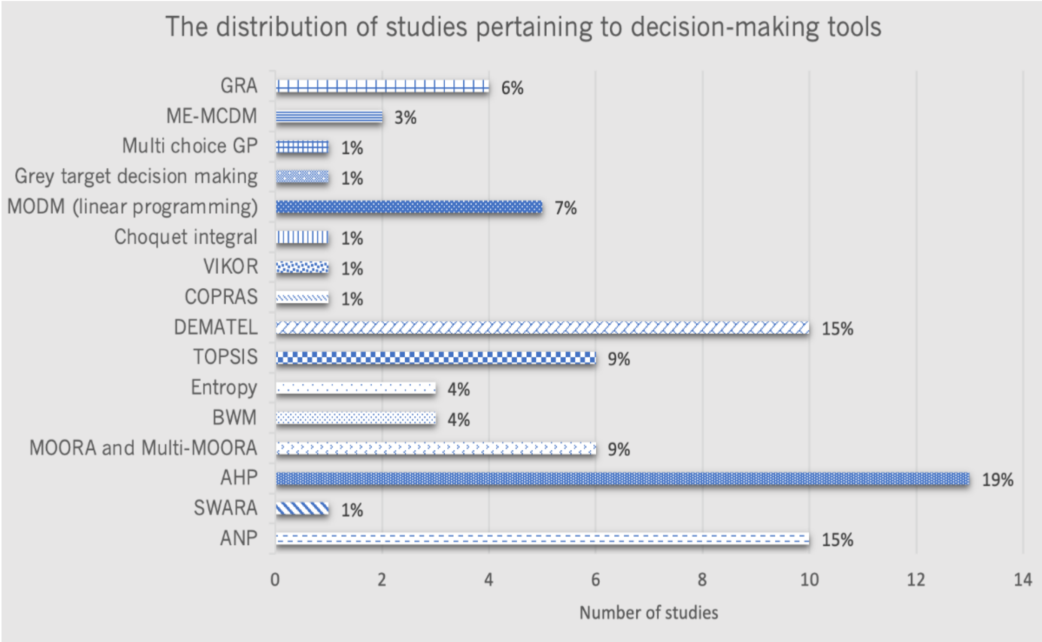

Figure 2-15 – Distribution of studies in Decision-Making tools (Hariri et al., 2023b)

The following section discusses some of the details of some of the methods raised in the literature review study due to present the importance of the models adopted in the dissertation field due to developing the proposed novel model.

Wu et al. (2017) proposed a hybrid analytical model based on the integration of DEMATEL technique and VIsekriterijumska Optimizacija I Kompromisno Resenje (VIKOR) method under hesitant fuzzy environment to obtain the importance ratings of ECs in QFD. The authors used the hesitant fuzzy DEMATEL to analyse the interrelationships among CRs and determine their weights, and the hesitant fuzzy VIKOR to prioritise ECs. Also, it was illustrated the feasibility and practicality of their proposed methodology using an example regarding the product development of electric vehicle.

Tavana et al. (2017) introduced a novel integrated MCDM framework based on the combination of ANP and QFD approaches for sustainable supplier selection problems. It identified a clear hierarchical structure for all the relevant sustainable factors and sub-factors and determined the weights of decision criteria based on the importance given to customer expectations. Afterwards, the authors ranked the suppliers using a multi-objective optimization procedure based on ratio analysis and weighted aggregated sum product assessment. The authors validated the application of their proposed methodology using a case study of a dairy company. Yadav et al. (2017) introduced the integrated approach of QFD, and multi-attribute decision-making (MADM) techniques including AHP, TOPSIS, and preference ranking organization method for enrichment evaluation (PROMETHEE) to analyze the product quality manufacturing industry. The paper formulated a QFD optimization methodology to find the best product design method.

Yazdani et al. (2017) introduced an integrated approach for green supplier selection considering different environmental performance requirements and criteria. For this purpose, the study addressed the inter-relationships between the CRs with the aid of DEMATEL method while constructing a relationship structure. This study utilized a QFD approach to establish a central relationship matrix in order to identify the degree of relationship between each pair of supplier selection criteria and CRs. Finally, the complex proportional assessment (COPRAS) was used to prioritize and rank the alternative suppliers. The article is presented a case study represent the potentiality and aptness of the proposed methodology. Asadabadi (2017) introduced a customer-oriented supplier selection method by considering dynamics of customer needs in finding the best supplier. For this purpose, an integrated method was proposed based on the combination of ANP, QFD, and a Markov chain. To accomplish this, first, a Markov chain model was utilized by authors to trace the changing priorities of customer needs and to find a pattern for them. Then, an ANP–QFD was used to method to connect this pattern to product requirements (PRs) and PRs to supplier qualifications. Afterward, it selected the best supplier based on the changing priorities in customer needs.

Abdel-Basset et al. (2018) extended a framework for supplier selection problem based on the combination of neutrosophic sets and AHP-QFD for supplier selection problem. The study illustrated the effectiveness of the proposed model using a case. An integrated method based on QFD approach and operational research such as ANP and multi-objective decision making (MODM) techniques was proposed by Ahmadipourroudposht et al. (2018) for developing product design process in one-of-a-kind production. A QFD-ANP method for evaluating and selecting suppliers for purchasing decisions was introduced by Bottani et al. (2018). The authors used QFD and ANP approaches to define the suppliers' characteristics and to capture the interrelations among the selection criteria, respectively. The authors considered the relevant criteria for supplier selection and interdependency among the decision criteria and evaluated the positive and negative aspects of the selection process, simultaneously. The study implemented an extensive case study to indicate the application of their proposed model to a selection process of a food machinery company. Galetto et al. (2018) introduced a new method for EC prioritization in QFD which is consistent with the ordinal features of the linguistic scales used for representing the CRs' weight and relationship matrix coefficients. To develop new products, Kang et al. (2018) proposed a hybrid method by integrating the evaluation grid method (EGM) with the fuzzy-QFD. The authors also combined the fuzzy Kano model with the fuzzy-AHP to determine the priority of the development of attractive factors. Then, to validate the feasibility of the proposed method, the study was adopted in the minicars case study. Considering both qualitative and quantitative environmental criteria, Babbar and Amin (2018) extended a hybrid model based on the combination of multi-objective programming model and fuzzy-QFD approach in order to select a set of suppliers. In this study, the authors used a stochastic approach to manage the uncertainty in the order allocation process and trapezoidal fuzzy numbers to handle the vagueness in human thoughts. It was indicated the application of their proposed model using real data in beverages industry. Peng et al. (2018) introduced a systematic decision-making approach for QFD in uncertain linguistic situations. For this purpose, the hesitant fuzzy linguistic term sets were designed to express uncertain linguistic terms. Then, the authors defined the tolerance deviation to restrict innovatively the deviation range of fuzzy linguistic terms in the assessment stage of relative importance for CRs. Finally, the paper presented the use of information entropy to determine the final importance of DRs.

Huang et al. (2019) proposed a novel QFD approach using proportional hesitant fuzzy linguistic term sets (PHFLTSs) and prospect theory in order to overcome the insufficiencies of the traditional QFD. To accomplish this, the relationships between CRs and ECs was presented by means of PHFLTSs and the study derived the weights of the CRs using the BWM. The study utilized an extended prospect theory to prioritize the identified ECs.

Yazdani et al. (2019) proposed a multi-attribute decision support model in a supply chain to solve complex decision problems. To accomplish this, themodel provided a platform to help the decision process through the integration of the QFD and GRA in demonstrating main supply chain drivers under a fuzzy environment. To overcome the limitations of the traditional QFD, Liu et al. (2019) proposed a novel QFD methodology by integrating the extended hesitant fuzzy linguistic term sets (EHFLTSs) and prospect theory. To accomplish this, the authors used the EHFLTSs for hesitant linguistic assessment information elicitation from QFD team members. Then, considering the interrelations between CRs, the authors applied the Choquet integral to obtain the aggregated relationship evaluation results. Afterward, the authors suggested an extended prospect theory to derive the ranking orders of ECs.

Ahmadzadeh et al. (2020) developed a QFD model for prioritizing the critical success factors (CSF) of enterprise resources planning (ERP) based on the enablers of organizational agility (OA). For this purpose, first, the DEMATEL method was adapted to identify and classify the CSFs of ERP and the enablers of OA. Then, a three-phase QFD model was provided to prioritize the influencing and influenced criteria. Finally, a real data banking sector was implemented to validate the proposed approach. Devnath et al. (2020) integrated two methods including QFD and TOPSIS for identifying and ranking the major wastes on a production floor and prioritizing suitable waste elimination tools. To do this, first, the authors identified significant waste signs through interviews and on-field investigation. Afterward, the extracted signs were converted into seven major wastes using the QFD approach. Then, the TOPSIS method, was used to select and ranked several lean tools according to their importance or significance in eliminating waste. Gündoğdu and Kahraman (2020) proposed a hybrid method based on the combination of QFD with spherical fuzzy TOPSIS to evaluate and select the linear delta robots from the user's perspective under spherical fuzzy environment. Haber et al. (2020) integrated the QFD for product-service systems with the Kano model and fuzzy-AHP to properly analyze the inherent uncertainties. The authors implemented the proposed method in a case study in the medical devices sector in a regulated market of product-oriented services. Ping et al. (2020) proposed a new QFD approach by integration of picture fuzzy linguistic sets (PFLSs) and the evaluation based on distance from average solution (EDAS) method to rank the ECs. For this purpose, the PFLSs was utilized to express the judgements of experts on the relationships among CRs and ECs. Then, the EDAS method was developed under picture fuzzy linguistic environment for prioritizing the ECs identified in QFD. Finally, the authors established a combined weighting method based on TOPSIS, and maximum entropy theory to calculate the weights of experts objectively.

Considering the interdependence and vagueness, Neira-Rodado et al. (2020) proposed a novel approach by integration of fuzzy Kano, AHP, DEMATEL, and QFD to translate customer needs into product characteristics and prioritize design alternatives. To do so, first the authors established the CRs and then used the fuzzy Kano model to determine the impact of each requirement. Afterward, the design alternatives were defined while calculating the requirements' weights by using AHP. Also, the DEMATEL was developed to evaluate the interdependency among alternatives and to select the best design. Yazdani et al. (2020) developed an interval type-2 fuzzy sets-DEMATEL-QFD model to evaluate and rank sustainable supply chain drivers in a group decision-making environment. The authors connected their proposed fuzzy decision model to a real research project for eliminating risks in the supply chain related to agricultural production systems. Through sensitivity analysis, the stability of their proposed model was confirmed and concluded that the outcomes and advantages of the newly developed model will profit academic and non-academic partners.

Haiyun et al. (2021) defined the criteria of green supply chain for each stage of QFD and proposed hybrid framework by integrating IVIF (interval-valued intuitionistic fuzzy)- DEMATEL and IVIF MULTIMOORA (Multi-objective optimization by ratio analysis) respectively. The authors showed that understanding the customer expectations with customer relation management is the most important innovation strategy for the green supply chain management in energy industry with the consecutive stages of QFD whereas benchmarking the competitive market environment has relatively the last seat in the ranking.

In order to improve QFD, Chen et al. (2021) presented a hybrid MCDM method by integrating the hesitant fuzzy linguistic term set (HFLTS), DEMATEL, and MULTIMOORA. To this end, first, the HFLTS was used to deal with ambiguity in the evaluation process. Secondly, concerning the interaction relationships among quality characteristics (QCs), the authors utilized fuzzy DEMATEL technology to capture their influence weights. Furthermore, the MULTIMOORA and entropy weight methods were combined for obtaining the objective weights of CRs and prioritizing QCs. Finally, the efficiency of the proposed method was highlighted using an example of product design of computer numerical control (CNC) machine tool. Wu and Liao (2021) proposed a three-stage QFD framework by considering the complex linguistic evaluations of experts. In the first step, the BWM method was used in determining the importance degrees of the CRs and additional requirements. In the second step, the relative importance of the DRs were determined. Finally, the authors calculated the interval weights of alternatives according to the uncertainty degrees of evaluations and the DRs weights. The study applied in the aviation service development for Sichuan Airlines in China to illustrate the practicability of the proposed framework.

Below, Table 2-4 shows a brief classification regarding the research background studies in terms of the MCDM, objective, practical context, and the country methods applied.

Table 2-4 – Classifications of publications concerning hybrid QFD-MCDM procedure (Hariri et al., 2023b)

Authors	***Approach***	***Goal***	***Practical context***
Karsak (2004)	Fuzzy multiple objective programming method	Determining the level of fulfillment of DRs	Textile industry (Turkey)
Bayraktaroğlu and Özgen (2008)	AHP, Kano	Evaluate the CRs of the library users	Library service improvement (Turkey)
Lee et al. (2010)	ANP, multi-choice goal programming model	Prioritizing and selecting suitable ECs	Thin film transistor LCD industry (Taiwan)
Ho et al. (2011)	AHP, Supply chain	Determine the weight of factors and rank the suppliers	Automobile company (UK)
Raharjo et al. (2011)	AHP, dynamic QFD, uncertainty	Improving education quality and optimizing the QFD-MCDM	Education quality in a University (Singapore)
Alinezad et al. (2013)	Fuzzy, AHP	Supplier selection, obtain the CRs weights	Pharmaceutical company (Iran)
Li et al. (2014)	TOPSIS	Ranking and selecting best alternatives	Aviation design (China)
Wang (2014)	Relative preference relation	Deriving criteria weights in FQFD	Bank credit card (Taiwan)

Table 2-4 – Continued on the next page

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Authors	***Approach***	***Goal***	***Practical context***
Zaim et al. (2014)	ANP	Determining relative weights among CRs and the interrelationship with DRs	Polyethylene pipes (Turkey)
Song et al. (2014)	Hybrid approach based on an RST and GRA	Prioritizing the technical attributes, handling the vagueness	Industrial service design for compressor rotor (China)
Ocampo et al. (2016)	AHP, ANP, and DEMATEL	Calculating weights CRs and relationship with ECs	Edible oil production (Philippines)
Wang et al. (2016)	Hybrid group decision-making model based on hesitant 2-tuple linguistic term sets and QUALIFLEX	Expressing uncertainties, determining the relative weights of CRs, ranking DRs	Market segment selection problem (Vietnam)
Liu et al. (2016)	Interval grey number, GQFD, TRIZ	Highlighted the advantages of proposed GQFD	Computer peripheral product (Taiwan)
Akbaş and Bilgen (2017)	FAHP, FANP, TOPSIS	Determining weights of CRs and ECs	Wastewater treatment plants (Turkey)
Asadabadi (2017)	ANP	Supplier selection	Manufacturer of air coolers (Iran)
Hsu et al. (2017)	Fuzzy Delphi (FDM), modified FEAHP, TOPSIS method	Prioritizing performance factors	Manufacturing SMEs (Taiwan)
Lee et al. (2017)	Delphi method, DEMATEL and ANP	Extract important CRs and ECs and interrelationships among them	Solar cell manufacturing (Taiwan)
Fiorenzo et al. (2017)	Multi expert/ MCDM	Prioritizing ECs	Design of a new model of a climbing safety harness (Italy)
Tavana et al (2017)	ANP, Ratio analysis, Weighted aggregated sum product assessment	Determining the importance weights of CRs	Supply selection in a dairy company (Iran)
Wu et al. (2017)	Hesitant fuzzy DEMATEL, Hesitant fuzzy VIKOR	Analyzing the interrelationships among CRs, Prioritizing ECs	Product development of electric vehicle (China)
Yadav et al. (2017)	AHP, TOPSIS, PROMETHEE	Ranking and prioritizing alternatives	Bike selection
Yazdani et al. (2017)	DEMATEL, COPRAS	Prioritizing and ranking the suppliers	Supplier selection in a dairy company (Iran)
Abdel-Basset et al. (2018)	AHP	Calculating weights of alternatives	Pharmaceutical manufacturing (Egypt)
Ahmadipourroudposht et al. (2018)	ANP, MODM techniques	Prioritizing and characterizing relative importance of CRs and ECs	Dry gas filter
Babbar and Amin (2018)	Multi-objective programming model	Determining the suppliers' weight	Beverages industry (Canada-USA)

Table 2-4 – Continued on the next page

Table 2-4 – Continued from the previous page

Authors	***Approach***	***Goal***	***Practical context***
Bottani et al. (2018)	ANP	Computing, identifying and modeling the network connection of criteria selection	Food machinery industry (Italy)
Kang et al. (2018)	AHP	Product development prioritization	Designing minicars
Peng et al. (2018)	HFLTS, Group decision-making approach	Assessing the relative importance for CRs and DRs	Vortex recoil hydraulic retarder (China)
Galetto et al. (2018)	Multi expert/MCDM	Prioritizing ECs	Design of a new model of a climbing safety harness (Italy)
Tian et al. (2018)	Fuzzy BWM, fuzzy MDM, fuzzy MULTIMOORA	Determining priorities, ranking alternatives	Bike sharing project, Two-oriented society (China)
Van et al. (2018)	INS, TOPSIS, Sustainability	Supplier selection	Green supply chain (Vietnam)
Huang et al. (2019)	BWM	Deriving the weights of the CRs, prioritizing the ECs	Manufacturing system of electric vehicles (China)
Sobhanallahi et al. (2019)	TOPSIS	Finding important CRs, rank the suppliers	Private bank (Iran)
Yazdani et al. (2019)	Internal valued fuzzy set, MADM support model, GRA	Ranking of indicators	Supply chain and logistics
Liu et al. (2019)	EHFLTSs, Choquet integral, prospect theory	Extracting the linguistic information/Ranking the ECs	Electric vehicle manufacturing (China)
Ahmadzadeh et al. (2020)	DEMATEL, ERP, OA	Identifying and classifying critical success factors, Prioritizing the influencing criteria	Banking sector (Iran)
Gündoğdu and Kahraman (2020)	Spherical fuzzy TOPSIS	Evaluate and selecting the linear delta robots	Design of linear delta robot technology
Devnath et al. (2020)	TOPSIS	Identifying and ranking major wastes, prioritizing waste elimination tools	Manufacturing industries (Bangladesh)
Haber et al. (2020)	AHP	Rank receiver state parameters	Medical devices (Sweden)
Mistarihi et al. (2020)	ANP	Determining the weights for ECs	Wheelchair design (Jordan)
Ocampo et al. (2020)	AHP, DEMATEL, MADM, ANP, Sustainability	Calculating stakeholder requirements impact relations	Meat processing industry (Philippines)
Neira-Rodado et al. (2020)	AHP, DEMATEL, Fuzzy Kano	Prioritizing and evaluating interdependency among design alternatives, calculating CRs' weights	Designing of medical devices (Italy)
Yazdani et al. (2020)	IT2FS, DEMATEL, Sustainability	Evaluating and ranking sustainable supply chain drivers	Agricultural supply chain (Spain)

Table 2-4 – Continued on the next page

Table 2-4 – Continued from the previous page

Authors	***Approach***	***Goal***	***Practical context***
Ping et al. (2020)	PFLSs/ EDAS/ TOPSIS/ maximum entropy theory	Calculate the weight and rank the ECs	Product-service system design (China)
Wu et al. (2020)	MULTIMOORA	Determining the ranking of ECs	Electric vehicle manufacturing (China)
Kaya and Erginel (2020)	HF-SQFD, HF-SWARA, Sustainability	Identify weights and improvement of criteria	Airport sustainable design (Turkey)
Wang et al. (2020a)	Cloud model MCDM, Interval-valued fuzzy-rough sets	Determining and Prioritizing CRs and ECs	Air compressor company (China)
Wang et al. (2020b)	Multi-attribute grey target decision-making method, supply chain management	Identifying the optimal quality scheme	Launch vehicle design (China)
Haiyun et al. (2021)	IVIF DEMATEL, IVIF MOORA	Defining and ranking the criteria of green supply chain for QFD stages	Green supply chain (China)
Chen et al. (2021)	HFLTS, DEMATEL, MULTIMOORA, Entropy	Capturing relationships among QCs, obtaining the weights of CRs	CNC machine tool (China)
Wu et al. (2021)	BWM, Interval-valued linguistic	Determining the importance of CRs, DRs, and alternatives	Aviation service development (China)
Ocampo et al. (2021)	Fuzzy, DEMATEL, AHP, ANP, Sustainability, Means-end chain	Sustainable product design framework	Vegetable cooking oil (Philippines)
Fetanat and Tayebi (2021)	Fuzzy, linear programming (LP)	Analyze the sustainability indicators	Water treatment system (Iran)

2.4 Literature Review Synthesis

This section presents the main findings related to the literature review. There is the potential for using integrated QFD for customer satisfaction analysis in various fields. However, there is a lack of conceptual and theoretical research on the context and content of its application. As QFD was developed almost from the 1960s. But, only the integrated models appeared in the studies when one of the first studies by Karsak (2004) presented a fuzzy multiple objective programming approach by considering the imprecise and subjective information inherent in the QFD planning. The study used linguistic variables to represent the imprecise design information and the importance degree of each design objective. Also, there is a strong emphasis on MCDM tools with not deep and aggregated implementation in the textile industry as the central focus of the research.

Many studies in terms of the early objective of emerging the QFD applied on the part design to determine the ECs' weights for the wheelchair design, Mistarihi et al. (2020) proposed a hybrid method based on the integration of a QFD model with fuzzy-ANP approach. Also, Wu et al. (2020) extended a modified MULTIMOORA method based on cloud model theory (called C-MULTIMOORA). The authors conducted a comparative analysis as well as an empirical case in an electric vehicle manufacturing organization to validate the advantages of their proposed method. Whereas to find the most related criteria and obtain an optimized solution, Sobhanallahi et al. (2019) proposed a supplier selection model based on integrated QFD-TOPSIS methods which show the other applications of the integrated QFD models are highlighted more recently.

Nowadays, the integrated MCDM-QFD methods have been extensively used to solve practical problems using the functionalities and properties of MCDM methods. In this regard, DMs need to combine and extend MCDM techniques for certain objectives and requirements. After 2017, the use and application of novel and advanced tools increased. For instance, a hybrid multiphase fuzzy-QFD-MADM framework by integrating QFD, AHP, DEMATEL, and ANP along with fuzzy set theory was developed by Ocampo et al. (2020). The authors implemented a case study in a Philippine meat processing industry to indicate the application of their proposed approach.

To improve traditional QFD in an industry 4.0 environment, the application of methods considering clouds and big data will be necessary for the future. For example, Wang et al. (2020a) used an improved QFD methodology by integrating of cloud model and GRA. In this study, a comparative analysis of different approaches was implemented as well as the sensitivity analysis of criteria weights to demonstrate the stability of the proposed method. Wang et al. (2020b) provided a novel collaborative quality design framework for large complex product supply chains by integrating the fuzzy-QFD and the grey decision-making approach.

To improve the QFD-MCDM models to a sufficient model, many recent studies have considered some concepts including uncertainty, sustainability or supplement quality, manufacturing, optimization, statistical tools which are represented in this section as a hybrid QFD-MCDM method in various fields of applications in industries and services.

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Introduction

Research can be defined as a systematic activity that discovers and cultivates a body of organized knowledge. After choosing and determining the topic, a researcher needs to determine the research method. The choice of research method depends on the goals and nature of the research topic and its implementation possibilities. Therefore, it is possible to decide on the manner of investigation and conducting research if the essence, subject, and objectives are clear. In other words, the nature of the research helps the researcher to choose a method to obtain the answer or answers considered for research questions as quickly as possible. Therefore, the methodology is based on research, hypotheses, and questions. Scientific methods seek to know the surrounding world, and since new problems arise in today's world, scientific methods change over time. It is essential to use an appropriate research method, and the research method depends on the goals, subject, and facilities. It depends on the temporal requirements and generally on the nature of the research. The purpose of choosing the research method is to get accurate answers to the research questions (Denzin and Lincoln, 2011).

In this chapter, the research method is presented to achieve the research objectives. For this purpose, the type of research, statistical population, sampling method, data collection method, data collection tool, variables and research data analysis methods are described. First, the author will discuss the research methodology, then the data collection and sample selection methods, and finally, the data analysis methods used in this study.

3.2 Research Method

Every research project must first define its nature, objectives, and scope to obtain data in a reliable manner using established rules and mechanisms. Through the application of research and data processing, the researcher attempts to test the hypotheses or provide answers to the research questions (Saunders et al., 2009).

The current research from an objective point of view is applied research, and the target is the development of applied knowledge in the automotive Industry. Also, the research method from the data gathering point of view is the Survey-descriptive method which is a community of respondents of the comparative questionnaire of this research will include experts of the Bosch company.

This study aims to identify the outstanding customer needs in the manufacturing industry at Bosch, particularly for the product (DMCS) in line to enhance BU. Additionally, this study wants to compare the identified requirements in terms of the customer satisfaction they produce. The refined Kano, SWARA method, fuzzy-QFD, and COPRAS are used to accomplish the research goal. It has been categorized and weighted, and the fuzzy-QFD method is applied to weight the technical requirements (The focus is on SAs in terms of a survey done on the manufacturing process) using the weight of CRs (as determined by the refined Kano approach).

The research questions are as follows:

- What are the notable CRs and SAs of the DMCS?
- Each CR is classified into which category of one-dimensional needs, Must-Be, attractive, or indifferent?
- What is the relative importance of each SA?

3.3 The Theoretical Framework of the Research Method

The new manufactured products and services, which lead to a competitive market with many stakeholders, participant organizations, and variables lead to supplier selection becoming a remarkable process for developing the companies. The DMs, managers, commercial experts, quality management department, and experts in different areas of companies play a critical role in the supplier selection system. Identifying and ranking the suppliers to find the suitable supplier to provide a product or service more productively can improve the product technically and help the organization to reduce costs, as well as help to better understand the CRs used to maintain and gain the organization's position among the competitors. Therefore, supplier selection management applies MCDM tools to evaluate the SAs and classify them properly.

The research methodology is depicted in Figure 3-1. As seen the research methodology could be categorized into five general steps which are described as follows:

Step 1: This step first presents the problem definition containing the specific issue, difficulty, contradiction, or gap in knowledge. It considers the practical problems aimed at contributing to change or theoretical problems aimed at expanding knowledge. The overall direction and scope of the research will be determined based on the problem definition and research objectives. Next, it justifies the importance as well as the necessity of the Ph.D. subject which helps to extract the research questions. The statement of research area or research territory identification is the context required to both understand and conduct the research being explored. As the most important part of this step, the research methodology explains what will be done and how it will be done in the Ph.D. dissertation, thus allowing readers to evaluate the reliability and validity of the research. This section includes data gathering tools and procedures to evaluate the obtained information.

Step 2: This step, establishes the executive team to carry out the concept of the project under the scope of the Ph.D. thesis. To this end, it needs to evaluate the current situation involving understanding the position from which are started. Note that, understanding the current system helps us to know what to improve and whether the innovations will be successful or not. Afterward, the decision criteria are extracted to rank or choose between the alternatives being evaluated related to customer satisfaction. The effective use of QFD requires team participation and discipline inherent in the practice of QFD, which has proven to be an excellent team-building experience. Followed by QFD team establishment, the appropriate MCDM techniques considering both quantitative and qualitative criteria are developed.

Step 3: This step introduces the process of research implementation. In this regard, the population (a comprehensive group of individuals, institutions, objects, and experts) with common characteristics that are an interest of this research is determined. Afterward, the tools which are required to collect the information from the determined population are introduced. It worth mentioning that before the data analysis, the tools should test the accuracy and consistency of research questionnaires known as validity and reliability, respectively. In the data analysis section, the proper statistical methods along with the software package will be utilized to evaluate the obtained information from the population. Finally, the case study in the automotive industry will be discussed.

Step 4: This step collects the distributed questionnaires from the target population allow the implementation of the research methodology. It should be noted that the risk of collecting inaccurate and incomplete information is high in the questionnaire because (1) the respondents may not be able to understand the question correctly, and (2) the rate of non-response may be high. In this stage, the Kano model to prioritize potential new features is developed based on the gathered data. At the end of this step, it incorporates the QFD technique into the hybrid method based on MCDM and Kano model.

Step 5: The final conclusion section as the last part of the dissertation (1) provides answers to the main research questions (2) expresses the research limitations, (3) highlights the contributions to the knowledge of the field, (4) summarize the findings, and (5) provides recommendations for future researches on the topic.

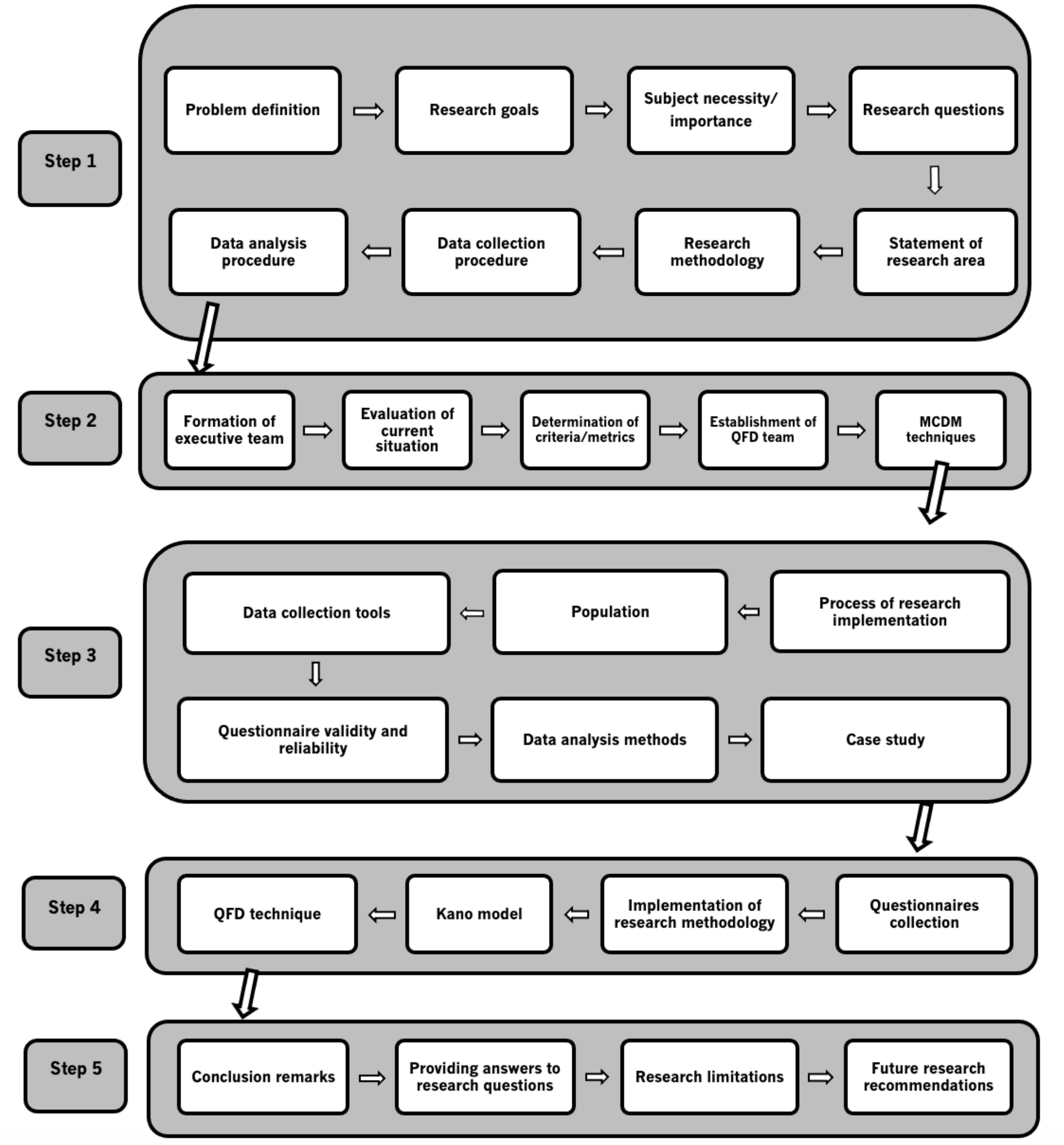

Figure 3-1 – Academic research methodology

3.4 Proposed Conceptual Methodology

As noted, the supplier selection problem seeks to evaluate the possible suppliers to increase the customer satisfaction by improving the product quality, reducing the manufacturer' cost, and controlling the time. In this section, the proposed customer-oriented supplier selection method based on the integration of the QFD and MCDM methods is presented. The proposed method takes to account the CRs to select the best supplier. The proposed case-focused model provides a systematic analysis of the interdependencies existing among the customer variables and technical criteria. To accomplish that, first considering the related literature and the opinions from the company's experts, the author extract the relevant factors/criteria assigned to customers and the manufacturing process. Then, the criteria are classified and weighted by the refined Kano model and validated with SWARA. Next, the COPRAS is combined with the QFD approach to calculate the weights of all the SAs. The proposed easy-to-implement hybrid method can be divided into a set of steps as below (Hariri et al., 2023a):

Step 1. Identifying the relevant CRs.

In this step, CRs are identified based on the existing literature and the experts' opinions. The CRs are the customer variables and considered as WHATs in HoQ matrix.

Step 2. Classify and rank the CRs with refined Kano model and SWARA.

In this step, the CRs from the last step are classified into different Kano categories, and the rank of the CRs is obtained considering the refined Kano model and the SWARA method to validate the model.

Step 3. Identifying the SAs.

In this step, the SAs as the supplier selection criteria are selected based on the existing literature and the company's features under analysis. For this purpose, brainstorming is employed using experts' opinions. These criteria are HOWs in HoQ.

Step 4: Identifying the alternative suppliers.

The alternative suppliers denoted by vector $S = (S_1, S_2, \dots, S_m)$ are listed in the upper, afterward will be presented in Table 4-11, and S is supplier indicator.

Step 5. Calculation of SA's weights.

The process of calculating the SA's weight is developed by the fuzzy-QFD which the inputs of the technique are CRs, and the output of the matrix are the weights of the SAs.

Step 6: Calculating the score of the alternative suppliers and ranking them with COPRAS.

In this step, the score of the suppliers is obtained from the COPRAS method. Then, the suppliers' indexes ranking obtain considering related SAs.

3.5 Statistical Sample

A population is a group of people or things which share at least one characteristic. The population under study in any research project is typically a statistical population the researcher wants to investigate regarding fixed or variable attributes of its units. The term "statistical population" needs to be defined in its entirety. This definition should be written in a way when viewed from the perspective of time and place, it encompasses all the studied units while also considering how to avoid including any units that should not be studied (Malterud et al., 2016).

A statistical sample is also a set of signs selected from a part, group, or larger society so that this set represents the characteristics of that part, group, or larger population. Sampling is the process of selecting a sample.

The purpose of all samplings in scientific research is to prepare accurate and meaningful statements about a group based on the study of a subset of that group. This group may be a collection of people or things. Access to the characteristics of the general group under research is possible if it has repeatedly tested various states or cases of the phenomenon under study (through observation or experience) (Malterud et al., 2016).

First, the categories of the product attributes were achieved by studying the literature and the related recent papers around this research. For example, there are many studies in the companies that value to sustainable characteristics of their products. Therefore, the main frame of the categories is extracted from previous literature and the dimensions of the current organization. The main categories of requirements that are significant and necessary in the manufacturing process are the technical, quality, and delivery categories, which directly affect customer satisfaction and the final product. Then, these three categories should always consider as customer needs.

The cost category is one of the critical categories that impact customer satisfaction and classification of the requirements.

In the first step, the categories discussed above were obtained from literature and interview with experts of the organization. The empirical results, lessons learned from the project, and technical data were assessed to specify the CRs.

The tools for data gathering include observation, expert interviews, literature reviews, questionnaires, and a significant number of meetings with experts. The observation tool is used as the production line screening for data gathering and better understanding to identify the deviations caused by supplier delivery to the organization. Table 3-1 shows the experts' distribution in the survey:

Table 3-1 – The expert's distribution in different CR categories

Area	***Max (Person)***	***Min (Person)***	***Number of Samples***
Technical	17	13	9
Quality	13	9	9
Cost	13	11	9
Delivery	13	9	9
Sustainability	20	15	9

Considering that the number of experts varies in each category in the table above, the maximum number of experts in the desired category was determined according to the surveys around the company's hierarchy chart. The minimum number of experts for that category was determined, because the several experts did not have enough knowledge in the field of the DMCS product, proper understanding of the problem, familiarity with the desired product, and response. Finally, there were nine people who become the minimum number of experts in all categories who were able to participate in the survey and fill out the questionnaire with accurate answers. This minimum number of experts was taken into account (in every category the nine samples have been selected) to be able to easier to collect the results of sampling. Meanwhile, sustainability has the highest number of experts (20 people), and quality and delivery have the lowest number of experts (9 people).

The experts participating in this study were technical (simultaneous engineers, process specialists, mechanical developers, hardware engineers, product line responsible, manufacturing production responsible, optics and mechanics), quality (quality managers, testing specialists, production test engineer, supplier quality engineer, process failure mode and effects analysis (PFMEA) moderator, display developer, supplier quality engineer, purchasing quality assurance, customer claim analysis), cost (project managers, program manager, process managers, project manager purchasing) delivery (logistic engineers), and sustainability (various proficient above, sustainability experts).

As mentioned previously, among the experts, nine people with high experience were willing to participate and answer the questionnaire chosen considering the limitation. The survey was carried out over two weeks, and 45 questionnaires were collected.

3.6 Data Gathering Through a Questionnaire

The quantitative investigation was based on a questionnaire. The questionnaire was utilized to gather information to examine the experts' discernment of the importance of CRs from the customers' point of view to calculate the weights of CRs and classify the requirements based on the Kano model. The reliability and validity of the questionnaire are the necessary scales and measures to determine the accuracy and consistency of a survey. Before a questionnaire is distributed among the statistical population, the reliability and validity of the questionnaire needs to be checked and measured by various methods and tools. The reliability and validity of the questionnaire are two related but separate subjects. Hence, It is necessary to identify and solve the weak points of the questionnaire by measurement tools of reliability and validity.

3.6.1 Validity and Reliability

Validity clarifies how well the collected information covers the actual range of examination. Validity essentially implies "measure what is expected to be measured". Which means whether the measurement tool can measure the characteristics and features for which the tool is designed? The validity content is important because measurements unrelated to the discussion can value and invalidate any scientific research (Fornell and Larcker, 1981). There are several ways to determine the validity of a measuring instrument. In this research, the "Face validity" method was used for the validity test, and the questionnaire is to be approved or modified with the opinion of professors and experts. The determination of face validity involves a personalized evaluation of the degree to which a construct has been adequately operationalized. The concept of face validity pertains to the level of association that a measurement possesses with a particular construct. This level is determined by non-experts who include individuals taking the test as well as representatives from the legal sector. To ascertain face validity, the contents of a test must appear relevant to the individual undergoing the testing process. This study assesses the questionnaire's visual presentation, especially analyzing its feasibility, readability, consistency in style and formatting, and the lucidity of language employed (Taherdoost, 2016).

Regarding the questionnaire considered in this part of the research, validity means whether the set of quality criteria presented in this questionnaire are those criteria that can be used to determine the importance of CRs in the DMCS according to their impact on BU or not.

Reliability is another concept to evaluate the accuracy of the measurement tool (questionnaire or interview) in field research. Unlike the validity tool, whose purpose is to ensure that the content of the measurement tool is related to the research objectives, the purpose of the reliability assessment is to answer the question of how much the measurement tool in question gives the same results under the same conditions. The term "Reliability" pertains to the level at which a collection of indicators representing a latent construct demonstrates internal consistency, based on the degree of correlation among the indicators. It signifies the extent to which these indicators accurately assess the same entity (Hair et al., 2017). Various methods are used to calculate the reliability of the measuring instrument, among which it can refers to the test re-execution method, the parallel method, the composition method, Cronbach's alpha method and other methods (Gilan-Deh and Chamanzamin, 2016).

The evaluation for reliability may be conducted utilizing Cronbach's alpha criteria, whereby values equal to or exceeding 0.7 are deemed favorable. These criteria have been established by Fornell and Larcker (1981). The method to calculate Cronbach's alpha is demonstrated through formulas (Eq. 3-1), (Eq. 3-2), and (Eq. 3-3) (Gilan-Deh and Chamanzamin, 2016):

$$X = \sum_j \underset{i}{Var}\,(a_{ij}) \tag{3-1}$$

$$Y = \underset{i}{Var}\left(\sum_j a_{ij}\right) \tag{3-2}$$

$$\alpha = \left(\frac{N}{N-1}\right)\left(1 - \frac{X}{Y}\right) \tag{3-3}$$

Where i is the index related to (here experts) fixed elements, j is the index related to variable elements (here questions), a_{ij} is the data value related to row i and column j of the data table (here, expert i's answer to j's question), N number of variable elements (here the total number of questions) and (Var also represents the sample variance formula).

3.6.2 Development of Questionnaire

112 CRs were collected for this thesis and were classified into technical, quality, cost, sustainability, and delivery dimensions. After identifying the CRs, the questionnaire included five sections, with each section corresponding to one of the previously mentioned dimensions. Each section provided sentences used to categorize requirements according to the model. The distribution of CRs for each category is shown in Table 3-2. Consequently, if applicable, the CRs were asked in both negative and positive spectrums, which means asking two parallel questions, one with a negative aspect and another with a positive aspect. Firstly, the positive question asks how a person feels if a particular quality attribute exists. Secondly, the parallel negative question asks about a person’s feelings in absence of that attribute. As a result, each section of the questionnaire consists of sentences that describe the requirements positively and

negatively, which shows the functional and non-functional forms of the needs in general. The scale used was a five-dimension scale proposed by Berger et al. (1993) that included:

- 1 = Like it
- 2 = Expect it
- 3 = Indifferent
- 4 = Tolerate it
- 5 = Unhappy.

Table 3.2 (below) illustrates the structure of CRs and the corresponding number of survey questions.

Table 3-2 – The structure of CRs and the number of questions in the survey

Row		***Category***	***Number of CRs (Number of Questions)***
1	Technical	Mechanical	23
		Electrical	8
		Optical	6
2	Quality	Definition of standard conditions	7
		Measurements conditions	7
		Customer rejection rate	2
3	Cost		12
4	Sustainability	Globalization	3
		Pollution production	5
		Urbanization and Eco-design Energy	7
		Health and Safety	3
		Water	2
5	Delivery		27
6	Total		112

Numerous consultations were conducted with subject matter specialists over a period of three months, including the five main categories mentioned previously, as well as the requirements and sub-categories derived from the discussions. Technical (Mechanical, electrical, optical) 45 items, cost (14 items), quality (Definition of standard conditions, measurement conditions, customer's rejection rate) 21 items, delivery (30 items), and sustainability (Globalization, pollution production, urbanization and eco-design energy, health and safety, water) 22 items comprise the total number of CRs. The final requirements to form the questionnaire were derived from their opinions, with some irrelevant items being removed from the list. The questionnaire is shown in Appendix 1. The five experts, consisting of 3 employees from the company, and 2 consultants from outside the company, participated in more than 5 hours of meetings. The following subcriteria are the final CRs for 112 obtained during this phase: Technical (Mechanical, electrical, optical) 37 items, cost (12 items), quality (Definition of standard conditions, measurements conditions, customer's rejection rate) 16 items, delivery (27 items) and sustainability (Globalization, pollution production, urbanization and eco-design energy, health and safety, water) 20 items. Then a pre-test survey was conducted among 5 expert participants in one week.

The outcomes of data collection from experts and all relevant authorities who documented customer needs, wishes, and complaints regarding the DMCS to enhance the BU, are organized into five categories based on the findings from earlier studies. Table 3-3 shows detailed information on 112 CRs in five categories, which will create the basis for further investigation.

Table 3-3 – The detail of extracted CRs in different categories

Category		***CR Indicator***	***CRs***
Technical	Mechanical	**CR1**	*Double side foam which connects the LCD to backlight frame*
		CR2	*Enough Dam space*
		CR3	*Rigidity of backlight unit housing*
		CR4	*Optical alignment features definition*
		CR5	*De-coupling of backlight unit and panel*
		CR6	*Sealant double side tape design*
		CR7	*Propensity to leakage of foam tape*
		CR8	*Dimension of the backlight frame*
		CR9	*Gap between rear glass and black housing*
		CR10	*Formation of air bubbles on LCD panel*
		CR11	*Alignment features on back housing of LCD to align center frame*
		CR12	*Height difference between the display frame and bonding surface*
		CR13	*Parallelism of display polarizer to support elements on the KIT*
		CR14	*Gap between backlight frame and LCD*
		CR15	*Light leakage due to mechanical lay out on the frame and back light*
		CR16	*Thickness of the inner glass*
		CR17	*Thickness of the polarizer*
		CR18	*Type of polarizer*
		CR19	*Backlight reflection sheet shape*
		CR20	*Shield film shape*
		CR21	*Flatness of backlight housing*
		CR22	*Contamination of the display*
		CR23	*Thickness of TFT-/color filter glass*

Table 3-3 – Continued on the next page

Table 3-3 – Continued from the previous page

Category		***CR Indicator***	
Technical	Electrical	**CR24**	*Foil banding material of the side of the display*
		CR25	*Foil banding width*
		CR26	*Position of the LEDs*
		CR27	*Thickness of the Driver IC*
		CR28	*Softness of flexible printed circuit (FPC) material*
		CR29	*Chip on Glass (CoG)/Foil on Glass (FoG) bonding-Chip /Anisotropic Conductive Film (ACF)*
		CR30	*Resistance of the track material*
		CR31	*LED power consumption*
Technical	Optical	**CR32**	*Stability regarding the contrast at higher temperatures*
		CR33	*Thermal reliability*
		CR34	*Dark Dot rate*
		CR35	*BU percentage*
		CR36	*Type of LED material*
		CR37	*Nit of brightness of screen*
Quality	Definition of standard conditions	**CR38**	*Digital pulse width modulation (PWM) rate*
		CR39	*Repeatability due to sensitivity of the display*
		CR40	*Parameter settings of equipment (e.g., printscreen of equipment graphical user interface (GUI) with settings)*
		CR41	*Touch Mura evaluation*
		CR42	*Respect to process rules for engineering (PRE)*
		CR43	*Stability of the measurement system analysis (MSA)*
		CR44	*Register active display area measurement*
Quality	Measurements conditions	**CR45**	*Water absorption rate*
		CR46	*Definition of the defects scale*
		CR47	*Difference between measurements LMK and TOPcon*
		CR48	*Reaching temperature for glass NTC during the measurement*
		CR49	*Measurement method regarding the part status (Free or on the Jig)*
		CR50	*High temperature/high humidity storage condition*
		CR51	*Position of tracks on FPCs*
Quality	Customer's rejection rate	**CR52**	*Sample size for measurement*
		CR53	*Material of the metal frame*
Cost		**CR54**	*Consignment contract*
		CR55	*Cost Breakdown Sheet (CBDS) for tooling*

Table 3-3 – Continued on the next page

Table 3-3 – Continued from the previous page

Category		CR Indicator	CRs
Cost		**CR56**	*Packaging cost*
		CR57	*Equipment set up requirements*
		CR58	*Tool strategy*
		CR59	*The optical measurement report*
		CR60	*Timeline to sourcing decision*
		CR61	*The amount of volume scenario*
		CR62	*Availability of the whole component*
		CR63	*Sampling agreement*
		CR64	*Raw material definition*
		CR65	*Target price*
Sustainability	Globalization	**CR66**	*Safe and sustainable transport systems*
		CR67	*Commitment to health and safety of employees*
		CR68	*Take responsibility of sustainability and create transparency*
Sustainability	Pollution production	**CR69**	*CO_2 emissions*
		CR70	*Product environmental performance footprint*
		CR71	*Potential toxicity to human*
		CR72	*Climate pledge friendly products*
		CR73	*Quality of water discharges*
Sustainability	Urbanization and Eco-design Energy	**CR74**	*Reduce operational water & energy consumption*
		CR75	*New sustainable materials implementation*
		CR76	*Reduce material through eco-design*
		CR77	*Water consumption*
		CR78	*Waste avoidance (Zero waste to landfill)*
		CR79	*Strengthen the circular economy strategy*
		CR80	*The energy supply from renewable sources*
Sustainability	Health and Safety	**CR81**	*Amount of emission of hazardous material (RoHS compliance)*

Table 3-3 – Continued on the next page

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Category		***CR Indicator***	***CRs***
Sustainability	Health and Safety	**CR82**	*Road safety*
		CR83	*Accident rate per hours of the work*
Sustainability	Water	**CR84**	*Water quality*
		CR85	*Water scarcity*
Delivery		**CR86**	*Order lead-time*
		CR87	*Better delivery flexibility*
		CR88	*Communication, Cooperation*
		CR89	*Standard cut-off time for release of the Transport Order (TO)*
		CR90	*Special transports*
		CR91	*Minimum order quantity*
		CR92	*Information transmission between the supplier and OEM*
		CR93	*Kanban call offs (Just in Time (JIT) calls)*
		CR94	*Start-up and phase-out control*
		CR95	*The delivery of sub-suppliers to the supplier*
		CR96	*Maximum storage time*
		CR97	*Transportation time*
		CR98	*Production progress information*
		CR99	*Number of parts in package*
		CR100	*Easy handling packaging*
		CR101	*Stack ability of the package*
		CR102	*Traceability of the product*
		CR103	*Corrosion prevention and moisture control*
		CR104	*Security in goods transportation*
		CR105	*Risk and crisis management*
		CR106	*Logistics failures*

Table 3-3 – Continued on the next page

Table 3-3 – Continued from the previous page

Category	CR Indicator	CRs
Delivery	**CR107**	*Digitalization of the supply chain*
	CR108	*The LCD bag material*
	CR109	*Maximum handling weight of the box*
	CR110	*Pallet size*
	CR111	*Clean returnable packaging*
	CR112	*Intermediate layers or nesting elements*

After collecting the CRs, the process moves to considering the importance of the CRs. This begins, another step of data gathering to translate the CRs into SAs used to develop the product. Table 3-4 extracts the SAs in terms of experts' opinions.

Table 3-4 – Supplier attributes (SAs)

Indicator	Supplier Attribute
SA1	R*emove the step between polarizer and TFT glass, increase Dam dispensing space.*
SA2	*Change the sealing tape material and close gaps on edges*
SA3	*Change the gaps to 0.35mm (0.2mm increase) by reducing the frame thickness*
SA4	*To reduce stress when bending, make FPC softer by changing cover lay to resist material*
SA5	*Make FPC softer by changing cover lay to resist material.*
SA6	*Polarizer of TFT side to be changed from NAZ to NSPZ*
SA7	*Put reflection tape to side edge of light guide plate*
SA8	*Use thinner LCD glass (1.4mm to 1.0mm)*
SA9	*Display bezel-less and fiducial marks on the surface with positional tolerance to the center of display active area of ±0.01mm*
SA10	*Decrease backlight unit flatness 0,4mm*
SA11	*More samples with clear peel-off design of expriments (DOE)strategy*
SA12	*Diecast aluminium ADC12*
SA13	*Defining the calculation methods to solve the defects range*
SA14	*Position of tracks on FPCs/tip of tracks: 0,3mm +-0,1mm from cutting edge*
SA15	*Provide only Pb-free components and solutions.*
SA16	*Electrostatic discharge (ESD) bag must be with a special orientation*
SA17	*Sea/ Air freight pallet 1175x750x....[mm]*
SA18	*An intermediate layer to avoid releasing particles (like paper or cardboard)*
SA19	*Empties Management System web platform (SupplyOn)*
SA20	*The responsibilty to clean returnable packaging*

Table 3-4 – Continued on the next page

Table 3-4 – Continued from the previous page

Indicator	***Supplier Attribute***
SA21	*During 3 days stock at the supplier*
SA22	*The weight of a single box should not exceed 7 kg*
SA23	*8pcs/Box*
SA24	*The solution for light lickage can be fill with a tape in cut corners of the back light*
SA25	*To improve the Gap between rear glass and black housing it needs to have good sealing properties*
SA26	*3 Months*
SA27	*500 PCs*
SA28	*Size and weight reduction and replacement of material mix and switch package size*
SA29	*Products need to have specific certifications to appear in this category*
SA30	*Eco-design guidelines applied in specific percentage of product development and processes*
SA31	*Double side tape/foam layout definition in the corners, to avoid leakage – according PRE*
SA32	*Decoupled LCD from backlight to avoid further stresses in the LCD panel, as plastic parts are assembled until final assembly*
SA33	*Agree with supplier a gap of 10% between supplier and customer spec. values*
SA34	*Use screw domes or other features (examples from existing products), to facilitate the alignment with the centre frame*
SA35	*Sample measurement report (Optical ISIR), 3-5 pcs, contrast, luminance, colors, etc.*
SA36	*Use PRE specifications, which define the height for this feature, to facilitate the bonding process*
SA37	*BHP's approach to carbon offsetting is to prioritise emission reduction*
SA38	*LCA/LCC for all products available, recycling content for Alu 40 %, Steel 25 %, plastics 25%*
SA39	*Increasing own renewable generation at our sites to 400 GWh and significantly expanding purchase of green electricity from new plants by 2030*
SA40	*Use central IT system – MaCS (Material Data Management for Compliance and Sustainability)*
SA41	*Training concept and define sustainability culture index*
SA42	*Risk minimization process for high-risk raw materials*
SA43	*Standard for LCA/LCC with focus CO2 Footprint Scope 3 (ESP 9 and NBS: IPB2.0 DPB, IBooster 2/3, ESP GEN10)*
SA44	*OSS and VDS: WSS 50/52 and AB, GEN 12*
SA45	*Water policy deployment non scarcity*
SA46	*Dynamic stacking factor at least 2 (1+1)*
SA47	*Desiccant bags, volatile corrosion inhibitor (VCI) paper and corrosion protection using intercept technology*
SA48	*Electronic data interchange (EDI) to exchange standardized messages in various formats and via different communication paths*
SA49	*K.I.S.S. (Keep, Improve, Start, Stop) method is used and, update at least twice a year*
SA50	*Set up "Near miss process" and quarterly reporting of number of near misses to corporate compliance (CC)/HSE*
SA51	*Packaging must be labeled with Mat-Label*
SA52	*Increasing dam material quantitiy on the ESD tape area (CW42)*
SA53	*Use three-dimension conservation method: Reuse the water consumed, use rainwater instead of fresh water, improve processes so that less water is needed*
SA54	*Circular economy: Materials efficiency (Microelectromechanical systems (MEMS)), Second life, Recycled materials*
SA55	*Master plan consists of measurement mismatch root cause: 125 samples production vs lab - supplier incoming inspection-measurement repeatability - protection foil (peel-off) follow-up in respective points.*

Table 3-4 – Continued on the next page

Table 3-4 – Continued from the previous page

Indicator	***Supplier Attribute***
SA56	*According the standard, must defocus until no Moiré due to high camera resolution.*
SA57	*About 36 to 40 degC*
SA58	*Standard PRE definition in all the aspects of technical*
SA59	*Overall volume (Scenario): 307,2 Kpc from 2018-2022*
SA60	*Parallel to short side (Vertical straight area)*
SA61	*Sub-suppliers management system standards*
SA62	*Vendor managed inventory (VMI)*
SA63	*Using control concepts (Call-off)*

After implementing the refined Kano approach, the data of the fuzzy-QFD method have been collected using two tables to complete the matrix of the HoQ. One table contains the experts' opinions regarding the importance of technical requirements in each of the CRs (relationship matrix). The second table relates to measuring the mutual impact of technical requirements on each other (roof of the house).

3.7 Data Analysis Method

To carry out the research, the CRs, ECs, and a list of suppliers were determined. The input data for the Kano model was collected using expert opinions and interviews with statistical samples (experts in 5 categories of CRs). Using the refined Kano model, CRs were categorized and weighted based on the results obtained from distributed questionnaires. In the next step, the weight of the CRs was used as the input of the integrated fuzzy-QFD approach to obtain the importance of ECs. Finally, the COPRAS technique based on the weight of the ECs of the previous step has been applied to rank the suppliers. The proposed model’s framework is illustrated in Figure 3-2.

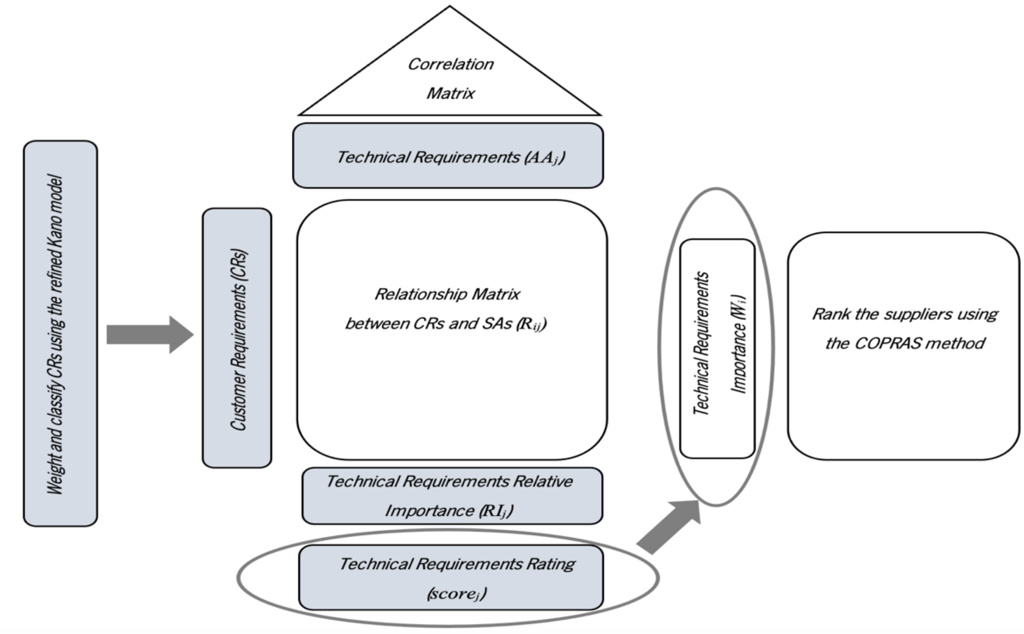

Figure 3-2 – The steps of model framework of the proposed approach

3.7.1 Refined Kano Model

This method was described in the second chapter of the present thesis. In this research, firstly, the CRs are categorized using the Kano approach, and then the categories are reviewed based on the refined Kano model.

In this study, the refined Kano approach is adopted to obtain the total satisfaction index (TSI) based on Kano responses (Timko, 1993). This method calculates better and worse values to understand the level of customer satisfaction and dissatisfaction with the features using the formulas (Eq. 3-5), (Eq. 3-5) (Go and Kim, 2018; Hariri et al., 2022; Shahin and Shahiverdi, 2015).

$$better = \frac{A+O}{A+O+I+M} \tag{3-4}$$

$$worse = \frac{M+O}{(A+O+I+M)\times(-1)} \tag{3-5}$$

The attributes, namely A, O, M, and I stand for the attributes of the attractive, one-dimensional, must-be, and indifferent quality, respectively.

The difference between better and worse values is known as the TSI. The CRs can be ranked based on the calculated values of the total satisfaction index. Negative values of the TSI indicate that the non-fulfilment of a certain requirement causes dissatisfaction, and positive values indicate that the fulfilment of a particular requirement causes satisfaction. In addition, higher values have more influence on the satisfaction rate. After calculating the weight and satisfaction index of the items, the average importance of the sub-criteria was obtained. Then, the refined Kano model classification was determined based on the average weight and classification of the simple Kano model.

3.7.2 Stepwise Weight Assessment Ratio Analysis (SWARA)

Keršuliene et al. (2010) introduced the SWARA method which is the MCDM that aims to calculate the weight of criteria and sub-criteria. The performance of this method is similar to the BWM, Shannon's entropy, and the linear programming technique for multidimensional analysis of preference (LINMAP), which weigh the criteria. SWARA expresses the analysis of the gradual weighting ratio. In this method, the criteria are ranked based on value and the most important criterion is given the first rank and the least important criterion is given the last rank. The steps of this method are as follows (Alinezhad and Khalili, 2019):

Step 1: The first step of SWARA aims to identify the criteria and sub-criteria, and the dependent criteria should be eliminated (all should be independent).

Step 2: This step provides the final criteria to the experts to rank in order of importance, and then those rankings are merged.

Step 3: This step aims to determine the relative importance weight (s_j) of each criterion which should be compared with its higher hierarchy (s_j is the importance of the criterion j than the criterion $j-1$, which is obtained from the values of the previous step). The value of the coefficient k_j is calculated as equation (Eq. 3-6):

$$k_j = \begin{cases} 1 & j = 1 \\ s_j + 1 & j > 1 \end{cases} \tag{3-6}$$

Step 4: Calculating the weight of criteria using the s_j through formula (Eq. 3-7):

$$q_j = \begin{cases} 1 & j = 1 \\ \frac{q_{j-1}}{k_j} & j > 1 \end{cases} \tag{3-7}$$

Step 5: Calculating the final weight of criteria (w_j), then, equation (Eq. 3-8) can be written as:

$$w_j = \frac{q_j}{\sum q_j} \quad (3\text{-}8)$$

For determining the weights of the n criteria where k of an attribute for each DM and s_{j-1} has a value 0 if criterion $j-1$ has the same importance as the criterion j, $sj \in [0,1]$, and the lower value of s_{j-1} denotes a greater degree of criterion j concerning criterion $j-1$. Figure 3-3 depicts a schematic representation of the procedural steps involved in the SWARA method.

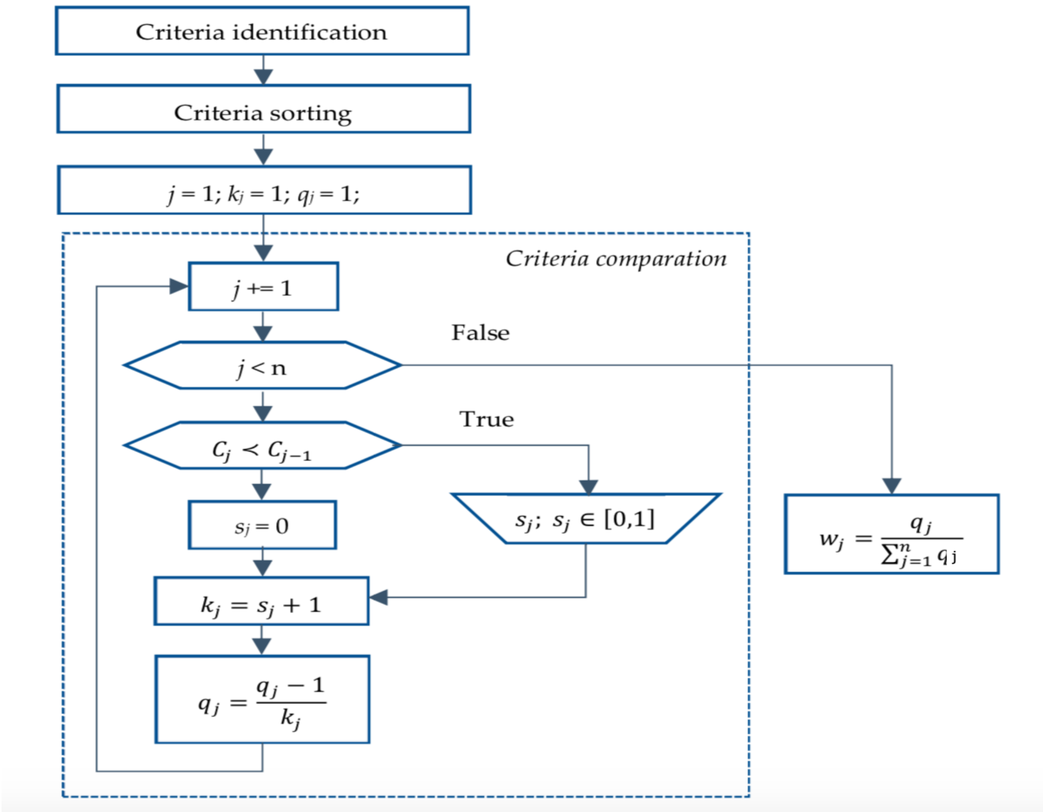

Figure 3-3 – Steps of the SWARA method (Keršuliene et al., 2010)

3.7.3 The Fuzzy-QFD Method

Since fuzzy logic is used in this thesis to deal with verbal judgments, the graphic symbols expressing the degree of relationship are also converted to triangular fuzzy numbers. Bottani and Rizzi (2006) converted the mentioned graphic symbols into fuzzy numbers as presented in Table 3-5.

Table 3-5 – Relation matrix symbols in QFD and their compatibility with fuzzy numbers (Bottani and Rizzi, 2006)

Relationship definition	***Graphical symbol***	***Fuzzy number***
Strong (S)	●	(0.7, 1, 1)
Medium (M)	○	(0.3, 0.5, 0.7)
Weak (W)	Δ	(0, 0, 3)

Considering that the values in this thesis are fuzzy, operations on fuzzy numbers are presented below:
If M_1 and M_2 are two triangular fuzzy numbers and their membership functions are respectively (l_1, m_1, u_1) and (l_2, m_2, u_2), also γ is an integer, then the calculation of fuzzy numbers obtains by formulas (Eq. 3-9 – Eq. 3-13):

$$M_1 \pm M_2 = (l_1 \pm l_2, m_1 \pm m_2, u_1 \pm u_2) \tag{3-9}$$

$$M_1 \times M_2 = \big(min(l_1 \times l_2, u_1 \times u_2), m_1 \times m_2, max(l_1 \times l_2, u_1 \times u_2)\big) \tag{3-10}$$

$$\frac{M_1}{M_2} = \big(min(l_1/u_2, u_1/l_2), m_1/m_2, max(u_1/l_2, l_1/u_2)\big) \tag{3-11}$$

$$\gamma \times M_1 = (\gamma l_1, \gamma m_1, \gamma u_1) \tag{3-12}$$

$$1/M_1 = \big(min(1/l_1, 1/u_1), 1/m_1, max(1/l_1, 1/u_1)\big) \tag{3-13}$$

Where, a triangular fuzzy number (M) can be represented by three consecutive numbers (l, m, u), where l and u denote the lower and upper bounds, respectively, while m is the middle value.
As mentioned before, since verbal judgments are addressed with fuzzy logic in this thesis, the graphic symbols for the degree of relationship are also converted back to triangular fuzzy number (TFN), shown in Table 3-5.
In the current research, the proposed approach requires the construction of HoQ, whose structure is shown in Figure 2-6. The HoQ intends to identify those technical requirements ($\mathrm{AA_j}$) that are created due to the CRs, as a result, CRs are placed in the "WHATs" rows in HoQ matrix. Afterwards, the technical requirements ($\mathrm{AA_j}$) are placed in the "HOWs" columns of the HoQ. The relationship matrix ($\mathrm{R_{ij}}$) in the HoQ is a matrix whose terms (j, i) show the impact of the $\mathrm{j^{th}}$ technical requirement on the i^{th} CR.
According to the QFD method, after the relationship between SAs and CRs is established, the relative importance ($\mathrm{RI_j}$) of the $\mathrm{j^{th}}$ technical requirement can be calculated using the equation (Eq. 3-14) as a fuzzy weighted average (Guh et al., 2008):

$RI_j = \sum_{i=1}^{n} w_i \times R_{ij} \quad \forall j = 1,2, \dots, m$ *(3-14)*

Where, w_i is the weight of the j^{th} CRs, and R_{ij} is a fuzzy number indicating the degree of connection between the j^{th} technical requirement and the i^{th} CR.

The inputs of the ceiling of the HoQ denoted by $T_{jj'}$ which represent the level of correlation between the j^{th} and the j'^{th} ($j \neq j'; j, j' = 1, \dots, m$) of the technical requirement (correlation between the $j^{th}$and the $j'^{th}$of the agile attributes). The weight of CRs is also defined using fuzzy numbers, the amount of which is assigned to each according to Table 3-6.

Table 3-6 – Adaptation the weight of CRs with fuzzy numbers (Vinodh et al., 2010)

Weight	Very high	High	Low	Very low
Fuzzy number	(0.7,1,1)	(0.5,0.7,1)	(0,0.3,0.5)	(0,0,0.3)

Correlation is usually measured by graphical symbols on a 4-level scale that starts from a strong negative and continues to a strong positive. The Table 3-7 shows the discussed relationships above:

Table 3-7 – Correlation level of graphic symbols and their compatibility with fuzzy numbers (Bottani and Rizzi, 2006)

Correlation level	***Graphic symbols***	***Fuzzy number***
Strong positive (sp)	●	(0.3,0.5,0.7)
Positive (p)	○	(0,0.3,0.5)
Negative (n)	□	(-0.5, -0.3,0)
Strong negative (sn)	▪	(-0.7, -0.5, -0.3)

Vinodh et al. (2010) Proposed an analytical method to quantitatively measure the existing correlation in the HoQ for the final ranking. According to this method, the final score of j^{th} of the technical requirement, i.e., $score_j$, can be calculated using the equation (Eq. 3-15):

$score_j = RI_j + \sum_{j \neq j'} T_{jj'} \times RI_{j'}$ *(3-15)*

In formula (Eq. 3-15), RI_j is the relative importance of each technical requirements obtained from the previous equation. It should be noted that the above formula describes the calculations between fuzzy numbers, so the score of each technical requirement ($score_j$) is also a fuzzy number.

3.7.4 COmplex PRoportional ASsessment (COPRAS) Method

Zavadskas, Kaklauskas, and Sarka developed the COmplex PRoportional ASsessment (COPRAS) method in 1994. The method applied to evaluate the value of the maximizing and minimizing indexes. The study aims to examine the distinct impacts of the maximizing and minimizing indexes of attributes on the assessment of outcomes (Alinezhad et al., 2019).

In recent years, the use of the COPRAS method as one of the MCDM methods has increased, and the reason for that is the simplicity of the calculation, the complete ranking of options, and the consideration of positive and negative criteria. In MCDM models, the goal is either to weight the criteria or to rank the options. This method also pursues the second goal, that is, ranking the options (Valipour et al., 2017). The steps of the COPRAS method are as follows:

1. *Developing the COPRAS decision matrix:* The COPRAS decision matrix is the same as the TOPSIS, VIKOR, or ÉLECTRE (ÉLimination Et Choix Traduisant la REalité) decision matrix and is called a criterion-alternative matrix. The decision matrix is obtained by distributing questionnaires among experts.
2. *Calculating the weight of the criteria:* In this step, the weight of the criteria should be obtained with one of the weight calculation methods.
3. *Determining positive and negative indexes:* Positive indexes are criteria whose increase made the situation better, and the negative indexes are whose reduction is more economical and turns the conditions better.
4. *Normalizing the decision matrix:* In this step, the decision matrix of the COPRAS method should be normalized.

The normalized decision matrix can be calculated by the formula (Eq. 3-16):

$$D = \frac{A}{max_i \sum_{j=1}^{n} a_{ij}} \, q_i \qquad (3\text{-}16)$$

Where: D is the normalized decision matrix and a_{ij} is the element of decision matrix for i^{th} alternative in j^{th} attribute.

5. *Developing a balanced normal decision matrix:* After determining the weight of criteria in advance, the created matrix in the previous step should be balanced. For this purpose, the importance of each criterion is multiplied by all the elements under the same criterion.

6. *Calculating the sum of normalized values:* In this step, the sum of the normal values of the positive (Sj_+), and the negative (Sj_-) indexes should be calculated separately for each option.

The calculation of the sum of normalized values obtains by equations (Eq. 3-17) and (3-18):

$$Sj_+ = \sum_{j+=1}^{k} d_{ij} \qquad \forall j = 1,2,\dots,k \qquad (3\text{-}17)$$

$$Sj_- = \sum_{j-=k+1}^{n} d_{ij} \; \forall j = k+1, k+2, \dots, n \qquad (3\text{-}18)$$

Where Sj_+ is the maximizing index and Sj_- is the minimizing indexe of $\mathrm{j^{th}}$attribute, and k identified as the number of positive attributes and $n-k$ represents the number of negative attributes.

7. *Final ranking of alternatives (options):* This step ranks the options according to the following relationship, which is the calculation of the COPRAS index. The larger the value of $\mathrm{Q_j}$ indicates the better rank of that alternative in prioritization. The alternative with the highest value is the ideal alternative.

The calculation of the Final ranking of alternatives obtains by equation (Eq. 3-19):

$$Q_j = Sj_+ + \frac{s_{min}^{-} \sum_{j=1}^{n} Sj_-}{Sj_- (\sum_{j=1}^{n} s_{min}^{-}/Sj_-)} \qquad (3\text{-}19)$$

Where: $\mathrm{Q_j}$ is the relative significance value of the alternative j, is ranked in descending order, and the highest value is the highest rank.

The final step is to specify the alternative that has the best status among the criteria. Since the rank of each alternative increases or decreases, its importance also increases or decreases. The alternatives that have the best situation in terms of criteria are identified with the highest degree of importance, N_j, which is equal to 100%. Each criterion's overall importance is calculated on a scale of 0 to 100 percent. In this domain, the best and the worst alternatives are determined. The degree of importance of each N_j of the alternatives A_j is calculated based on the formula (Eq. 3-20):

$$N_j = \frac{Q_j}{Q_{max}} \times 100 \qquad (3\text{-}20)$$

Where: the N_j is the performance index value, and the ranking of alternatives is from large to small and the Q_{max} is the maximum relative significance value of the alternatives.

3.8 Case Study

The DMCS display is a raw display of the final product which is outsourced for a heavy vehicle manufactured by an OEM company in Portugal [The exploded view of the DMCS product is depicted in Figure 3-4 in which the focus of the study is the second part as the LCD].

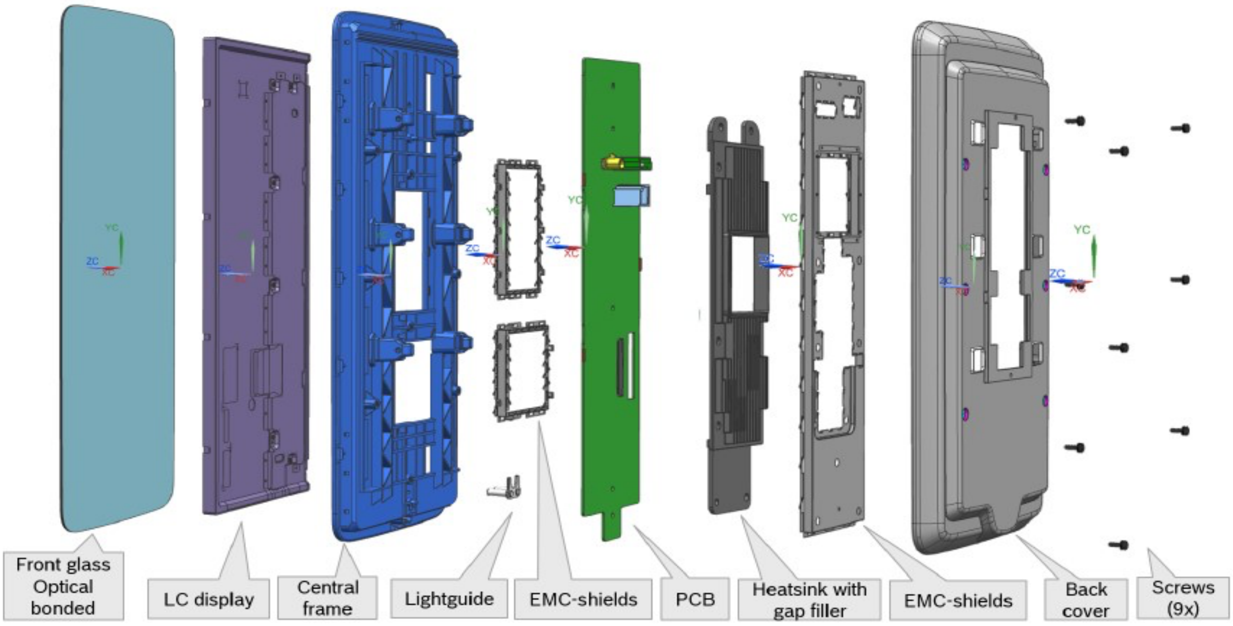

Figure 3-4 – The exploded view of the display DMCS (Bosch, 2018f).

The production phases show how to satisfy CRs in each step and which gaps might be covered by the supplier during the processes. This product goes through various steps in the production process, which include the following:

Step 1: The display components are received from the supplier; the main part is the DMCS single display which is the focus of this study. Figure 3-5 depicts the DMCS display.

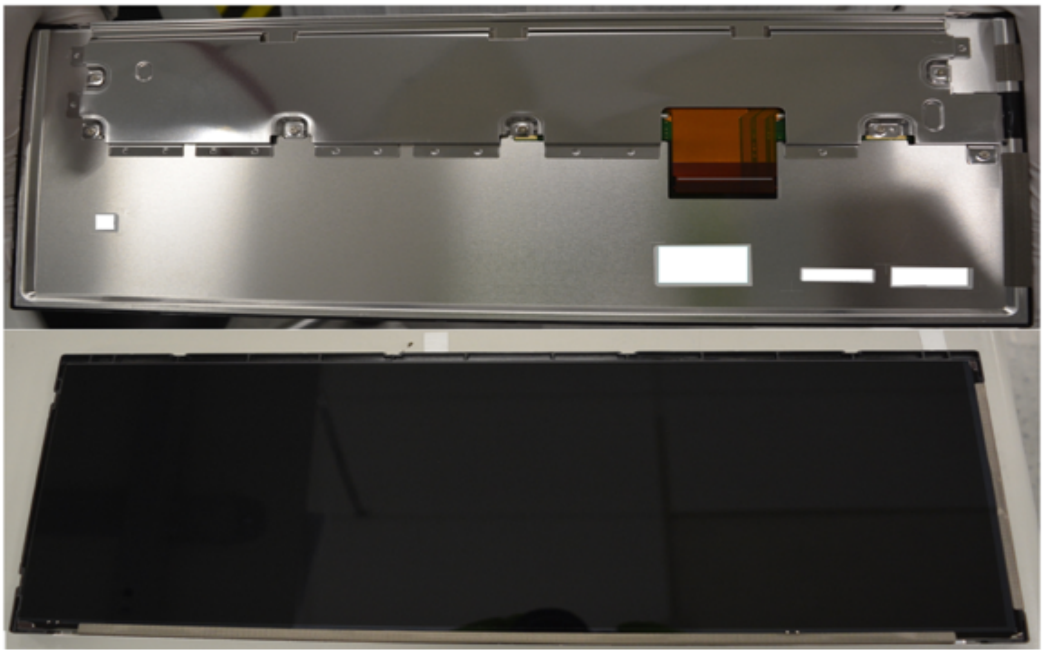

Figure 3-5 – The two-side view of the display DMCS (Burdack, 2020).

Also, Figure 3-6 shows details of the exploded view of the DMCS raw display and components of the DMCS.

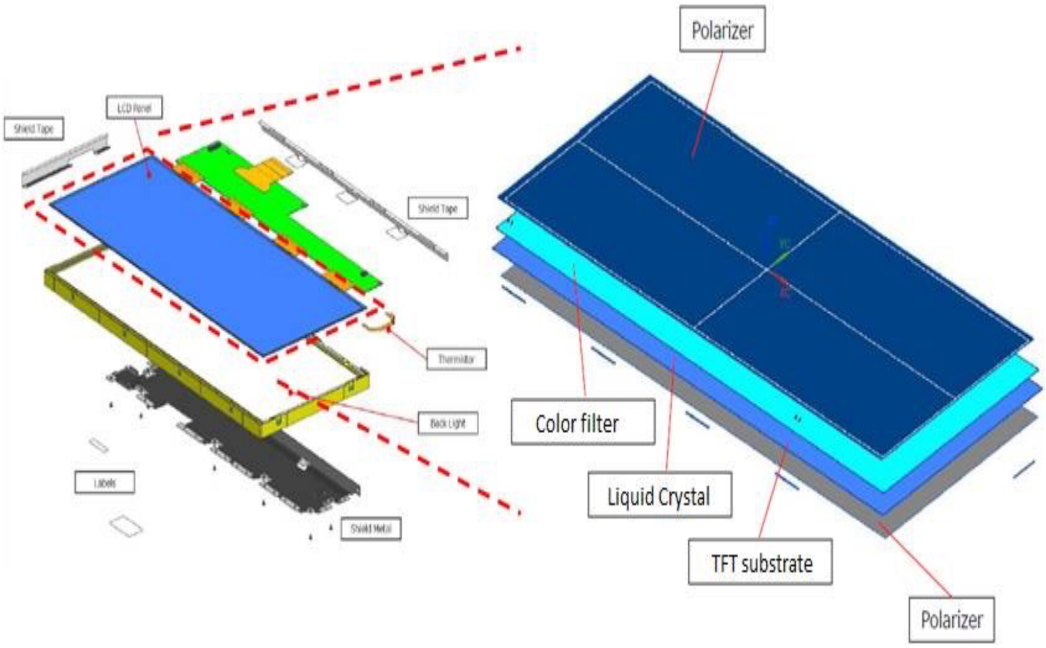

Figure 3-6 – The raw display DMCS exploded view (Burdack, 2020).

Step2: The bonding process is performed on a single display to bind a single display and another part called cover glass.

Step3: In the gluing step, the main frame is glued with special glues. Also, the plasma process and several tests are done to check if the materials are applied properly and aligned with the patterns. All these sequences are briefly mentioned as the gluing step.

Step 4: The screwing process is performed on the electronic chip called a Printed Circuit Board (PCB) attached to the product by different types of screws.

Step 5: The supplier provides the rear cover behind the display and assembles the whole product in the last step.

The LCD technology is based on the principle that certain organic molecules can be reoriented by an electric field. This technology has been used on a large scale since the 1970s and is the most common technology in FPDs (Flat Panel Displays). These molecules are called liquid crystals. As these materials are optically active, their natural braided structure can serve as a 'window' that closes or opens to block, to a varying degree, the passage of light. This blocking or partial blocking occurs perpendicularly to the passage of light when an electric current flows through the liquid crystal solution.

An LCD is made up of a series of layers of sandwiched composites, with the layer of liquid crystals in the middle of all the others as represented in Figure 3-7. At the bottom of the LCD there is the backlight, a white light responsible for illuminating the display (Indiana University Bloomington, 2023).

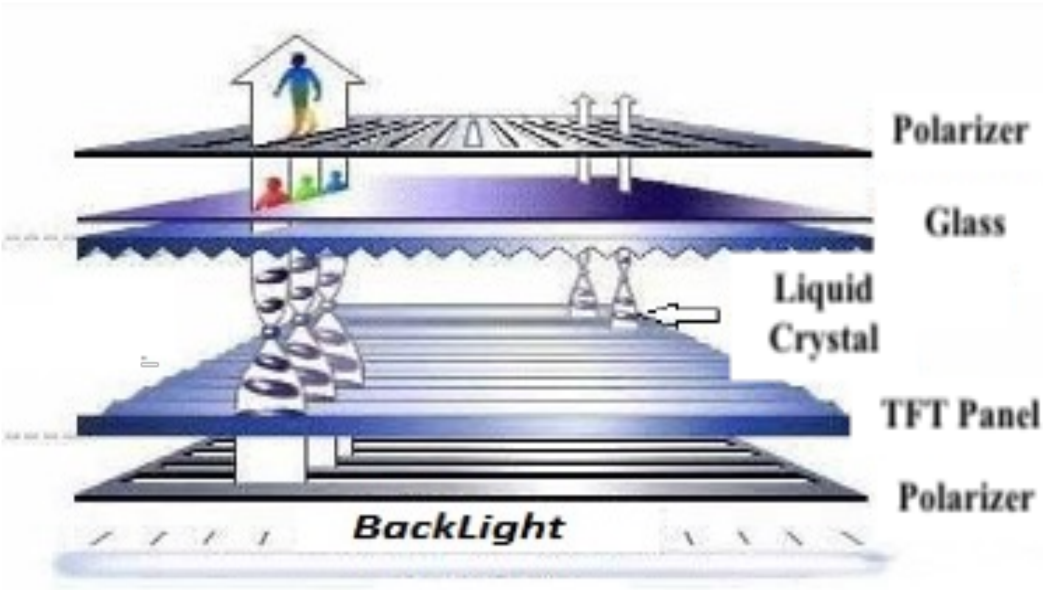

Figure 3-7 – The scheme of the composition of an LCD (Indiana University Bloomington, 2023).

The black uniformity (BU) feature represents the ability of a display to have a solid black appearance across the entire screen. This characteristic refers to luminance differences on the surface of a display. A display with perfect BU does not produce white spots or clouding areas that represent defects on the screen and that in extreme cases can affect the transmission of information from the display to the user (Rotscholl and Krüger, 2021).

The BU is one of the image features that is significant for the customer of the desired product and many defects has been caused by rejection due to not considering the desired BU rate. It is worth mentioning that the acceptable BU index for product acceptance by the customer is 50%. According to Figure 3-8, the rate of BU index shows a significant deviation in the BU. This deviation is due to the large gap observed in the display DMCS from the supplier in the tests performed in the display delivered to the OEM company. This reduction in the rate of BU led to customer dissatisfaction. Also, the rate of BU decreased as well in the subsequent steps, including bonding, gluing, screwing, and rear cover assembly. The product line has been activated continuously for the last two years; thereupon, some problems have been solved simultaneously by experts in the internal processes of the OEM, and some defects have improved. Therefore, the focus of the study is on the needs of OEM, automakers' requirements, and final customers' latent needs from the display DMCS delivered from the supplier. Since the scope was limited to semi-product delivered by the supplier, several tests and inspections were performed to validate the processes in each step, which are not mentioned in detail. The needs of the steps after display DMCS delivery, such as the bonding process (the first step of manufacturing the final product) addressed by experts as principal requirements to perform the operations and meet the technical needs.

To obtain the CRs, the main categories of these needs have been extracted from the literature review. To explore the sub-categories, the specifications list, and the manufacturing requirement documents needed to be investigated. Many tickets opened for claims, and comments have been sent to suppliers by various experts to improve product specifications. The customer's voice is adapted to study the feedback and reactions of suppliers to translate them to the ECs of the product.

Due to the implementation of Kano model, all CRs from DMCS display, including critical and basic requirements as well as indifferent and delighted ones from the supplier and the customer, must be considered for classification. Figure 3-8 presents the level of BU percentage provided by the supplier in DMCS samples, and the red line shows the minimum BU level accepted by the OEM (50%).

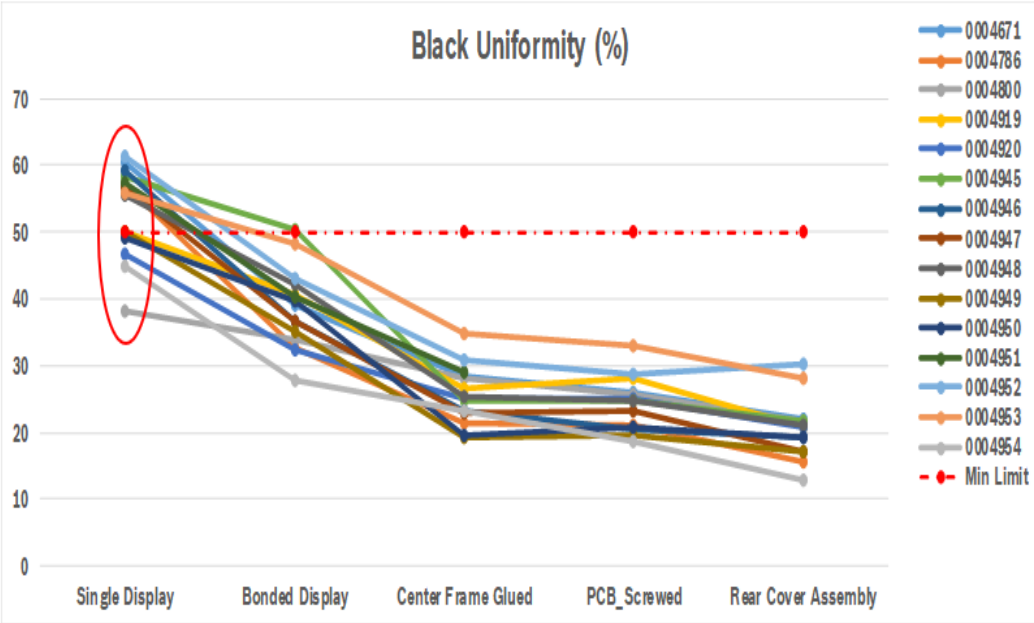

Figure 3-8 – The rate of BU index in different stages of DMCS production (Bosch, 2019).

The right column demonstrates the distribution of different samples identified by various codes. The diagram depicted how the rate of BU dropped during the process and before the OEM received the single display for various sample units.

Example of determining the CRs:

In the case of identifying the CRs, the research tried to find the VoC. For instance, the CR "Height difference between display frame and Bonding surface" is considered a technical requirement in the category of the mechanical requirements extracted from process rules for engineering (PRE). On the display, the top surface must guarantee that no materials (tape, pins, etc.) are laying on the surface without gluing properly to any surface, thin-film-transistor (TFT) glass, or polarizer with no air gaps. The minimum distance between the display housing/frame and the bounding surface should be 0.2mm. Figure 3-9 presents the following CR.

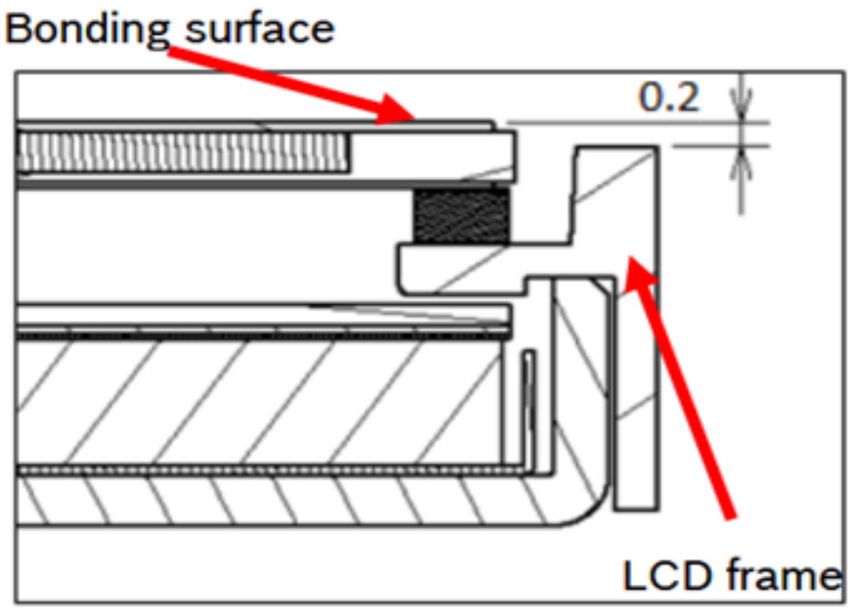

Figure 3-9 – Bonding surface requirement for the height (Bosch, 2018f).

3.9 Summary of the Chapter

In this chapter, the research methodology has been discussed. In this regard, the method used in this research has been explained and dissected, and the theoretical framework of the research method, then the statistical sample, sample size, sampling method, information collection tool, and data analysis approach have been described. In this chapter, after the preliminary introduction about scientific research and the necessity of conducting it, explanations were given regarding the type of investigation leading in this research.

The applied research method can be summarized into three steps:

- First, after surveying the literature, observing the manufacturing process, and brainstorming among the experts, the criteria are screened with the help of a survey of the organization's experts, and the most significant ones are selected.
- Second, the framework of the SWARA method, and the Kano model are adopted to determine the weight of CRs.

Finally, by establishing the HoQ considering fuzzy theory, the author will identify the SAs to develop appropriate implementation plans to satisfy the CRs and rank the suppliers.

CHAPTER 4

COMPUTATIONAL RESULTS

To conduct this study, after identifying relevant CRs, using experts' opinions and interviews with statistical samples the CRs determined. The validity and reliability of the questionnaire are evaluated and the required data to establish the Kano model collected (will be discussed in sub-section 4.1). Then, The CRs are classified using the simple Kano and the refined Kano model. Then, the CRs weighted using the SWARA approach in each category (will be discussed in sub-sections 4.2, 4.3, and 4.4). To translate the CRs to SAs, the significant SAs has identified by the experts in each requirement category. After that, the alternatives for supplying the DMCS determined (the potential suppliers presented in Table 4-11). Considering the integrated fuzzy-QFD, the final weights of the SAs obtain in sub-section 4.6. Finally, the suppliers rank according to SAs weight and supplier indicators using the COPRAS method (will be discussed in sub-section 4.6 and sub-section 4.7). Figure 4-1 presents the steps of the computational model considered for the study.

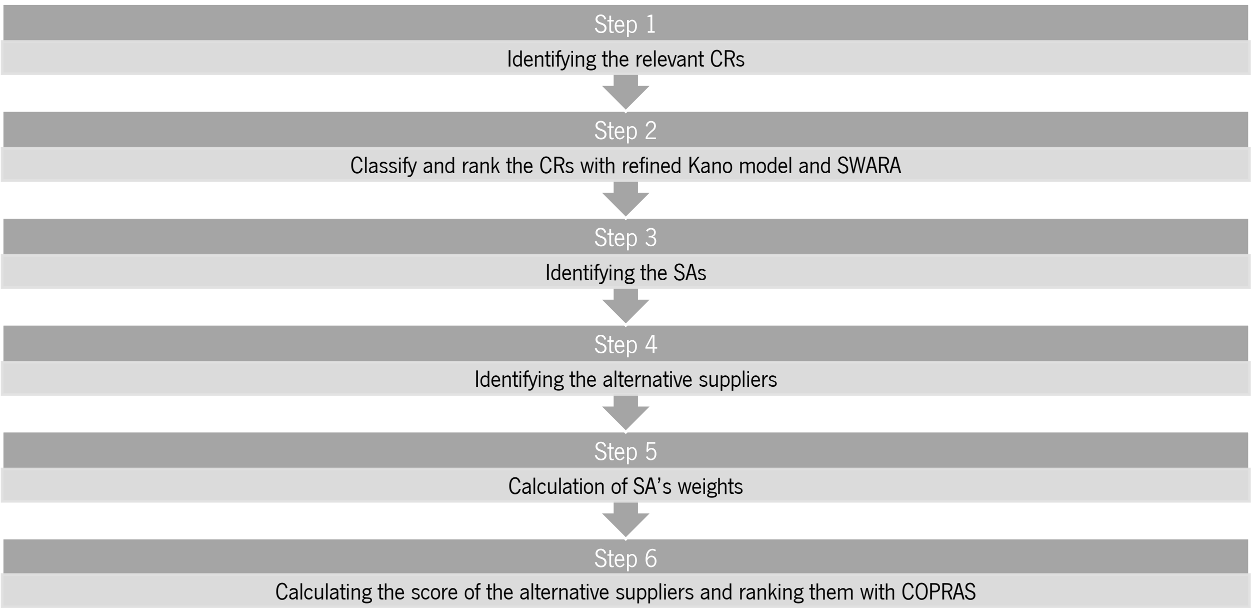

Figure 4-1– The steps of the computational model considered for the study

4.1 Data Gathering Results

First, the main categories of the product attributes were determined by reviewing the relevant literature and the related recent papers around this research. For example, numerous recent studies have focused on companies that place a high value on the sustainable attributes of their products. In this fashion, the determination of the main categories was extracted from literature review, empirical results, lessons learned from the project, and product technical information data assessed to specify the customer needs. There was also a review of the documents and the company's internal resources regarding the DMCS various shortcomings. In this way, the cause of defects was recognized and the CRs related to BU extracted in different main categories. In sustainable category, several meetings were held in main plant of the enterprise to propose novel approaches considering the benchmarking from other similar industries. The Cost category is one of the critical categories that impact on customer satisfaction and classification of the requirements.

The charts developed by queries were transferred directly to Microsoft Excel, and some were implemented using the internal form systems of the company. The tools for data gathering include observation, expert interviews, literature review, questionnaires, multiple meetings with experts, and multiple emails to relevant specialists.

This observation is applied as the production line screening for gathering the CRs and to better understand and identify the deviations in process and influence of the BU percentage in the supplier delivery stage and how it drops in the rest of the manufacturing processes (bonding, gluing, screwing, and cover glass assembly). The CRs and SAs obtained through this process are presented in Table 3-3 and 3-4.Throughout three months, several meetings were held with experts in each specific area including the five main categories discussed previously and the requirements and sub-categories extracted through the discussions. The number of requirements includes:

- Technical (mechanical, electrical, and optical)—45 items
- Cost—14 items
- Quality (definition of standard conditions, measurements conditions, customer's rejection rate)—21 items
- Delivery—30 items
- Sustainability (globalization, pollution production, urbanization and eco-design energy, health and safety, and water)—22 items

Using the ”Face Validity” method discussed in sub-section 3.6.1, this study assesses the questionnaire's visual presentation and analyzes its feasibility, readability, consistency in style and formatting, and the lucidity of language employed. The study considered the opinions of five experts (three employees from the company and two consultants from outside the company) who cooperated with the study and who participated in more than five hours of meetings.

By adopting the standard forms that exist as questionnaires to standardize the questionnaire and aggregation and evaluation of the expert's opinions, the final requirements to develop the questionnaire were obtained from their opinions (with some irrelevant requirements having been eliminated from the list). In this phase, the 112 final CRs were obtained as follow:

- Technical (mechanical, electrical, optical)—37 items
- Cost—12 items
- Quality (definition of standard conditions, measurements conditions, customer’s rejection rate)—16 items,
- Delivery—27 items
- Sustainability (globalization, pollution production, urbanization, and eco-design energy, health, and safety, water)—20 items.

Then, a pre-test survey was carried out for five expert participants throughout one week.

In this thesis, due to the simplicity of application and the mathematical approach of Cronbach's alpha method, this method has been used to determine the reliability of the questionnaire in Appendix 1. With the aid of this statistical metric, it is possible to ascertain whether the analyzed data sets exhibit requisite coherence and compatibility, thereby determining their reliability and trustworthiness. Cronbach's alpha can be calculated with SPSS software from the formulas presented in part 3-6. In the SPSS software, after entering the data and running the "Analyze/Scale/Reliability Analysis" path, you can get the Cronbach's alpha of the desired data set. Another feature of this software is the ability to view Cronbach's alpha values after removing variables. For this purpose, you can use this possibility after opening the "Reliability Analysis" menu and going to the "Statistics" tab and selecting the "Scale if Item Deleted" option. This method calculates the reliability of a set of data that consists of two dimensions. One dimension of the data represents the fixed dimension (cannot increase or decrease) of the problem and the other dimension represents the variable dimension (can increase or decrease) of the problem. In this method, you can reach the desired Cronbach's alpha by increasing and decreasing the elements of the variable dimension. Here, the experts (45 experts) are the constant elements, and the questions (112 questions) represent the variable dimension, so when entering the data in the SPSS software, you must be careful that the variable dimension elements must enter as columns, and each question represents a Var in the software. The Cronbach's alpha coefficient of the questionnaire is reported at 0.94, indicating a favorable level of reliability.

4.2 Kano Results

At this stage, the Table 4-1 presents the frequency of the CRs in five categories and their classification based on Kano model.

Table 4-1 – The frequency of CRs and their classifications based on Kano model

Category		***CRs***	***M***	***O***	***A***	***I***	***R***	***Q***	***Classification Kano model***
Technical	Mechanical	*Double side foam which connects the LCD to backlight frame*	2	3	2	2	0	0	O
		Enough Dam space	4	3	2	0	0	0	M
		Rigidity of backlight unit housing	0	2	4	2	1	0	A
		Optical alignment features definition	2	2	3	2	0	0	A
		De-coupling of backlight unit and panel	0	0	8	1	0	0	A
		Sealant double side tape design	2	3	2	2	0	0	O
		Propensity to leakage of foam tape	5	3	1	0	0	0	M
		Dimension of the backlight frame	3	2	2	2	0	0	M
		Gap between rear glass and black housing	0	0	8	1	0	0	A
		Formation of air bubbles on LCD panel	5	4	0	0	0	0	M
		Alignment features on back housing of LCD to align center frame	2	2	3	2	0	0	A
		Height difference between the display frame and bonding surface	4	1	1	3	0	0	M
		Parallelism of display polarizer to support elements on the KIT	2	2	0	5	0	0	I
		Gap between backlight frame and LCD	0	2	0	7	0	0	I
		Light leakage due to mechanical lay out on the frame and back light	5	2	0	2	0	0	M
		Thickness of the inner glass	0	1	1	6	0	1	I

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Table 4-1 – Continued from the previous page

Category		CRs	M	O	A	I	R	Q	Classification Kano model
Technical	Mechanical	*Thickness of the polarizer*	*0*	*0*	*3*	*5*	*1*	*0*	*I*
		Type of polarizer	*4*	*3*	*1*	*1*	*0*	*0*	*M*
		Backlight reflection sheet shape	*4*	*3*	*0*	*2*	*0*	*0*	*M*
		Shield film shape	*2*	*0*	*0*	*6*	*1*	*0*	*I*
		Flatness of backlight housing	*2*	*3*	*2*	*2*	*0*	*0*	*O*
		Contamination of the display	*4*	*5*	*0*	*0*	*0*	*0*	*O*
		Thickness of TFT-/color filter glass	*2*	*1*	*1*	*5*	*0*	*0*	*I*
	Electrical	*Foil banding material of the side of the display*	*4*	*2*	*1*	*2*	*0*	*0*	*M*
		Foil banding width	*0*	*1*	*0*	*7*	*0*	*1*	*I*
		Position of the LEDs	*4*	*2*	*0*	*3*	*0*	*0*	*M*
		Thickness of the Driver IC	*1*	*1*	*1*	*6*	*0*	*0*	*I*
		Softness of flexible printed circuit (FPC) material	*2*	*1*	*4*	*2*	*0*	*0*	*A*
		Chip on Glass (CoG)/Foil on Glass (FoG) bonding-Chip /Anisotropic Conductive Film (ACF)	*1*	*0*	*1*	*7*	*0*	*0*	*I*
		Resistance of the track material	*1*	*2*	*0*	*6*	*0*	*0*	*I*
		LED power consumption	*1*	*1*	*2*	*5*	*0*	*0*	*I*
	Optical	*Stability regarding the contrast at higher temperatures*	*2*	*2*	*2*	*3*	*0*	*0*	*I*
		Thermal reliability	*3*	*2*	*0*	*4*	*0*	*0*	*I*
		Dark Dot rate	*2*	*1*	*2*	*4*	*0*	*0*	*I*
		BU percentage	*2*	*5*	*1*	*1*	*0*	*0*	*O*
		Type of LED material	*2*	*2*	*1*	*4*	*0*	*0*	*I*
		Nit of brightness of screen	*0*	*3*	*2*	*4*	*0*	*0*	*I*
Quality	Definition of standard conditions	*Digital pulse width modulation (PWM) rate*	*3*	*2*	*0*	*4*	*0*	*0*	*I*

Table 4-1 – Continued on the next page

Table 4-1 – Continued from the previous page

Category		***CRs***	***M***	***O***	***A***	***I***	***R***	***Q***	***Classification Kano model***
Quality	Definition of standard conditions	*Repeatability due to sensitivity of the display*	*4*	*2*	*1*	*2*	*0*	*0*	*M*
		Parameter settings of equipment (e.g., printscreen of equipment GUI with settings)	*2*	*1*	*1*	*5*	*0*	*0*	*I*
		Touch Mura evaluation	*2*	*4*	*2*	*1*	*0*	*0*	*O*
		Respect to process rules for engineering (PRE)	*5*	*2*	*1*	*1*	*0*	*0*	*M*
		Stability of the measurement system analysis (MSA)	*3*	*0*	*1*	*4*	*1*	*0*	*I*
		Register active display area measurement	*3*	*1*	*1*	*4*	*0*	*0*	*I*
	Measurements conditions	*Water absorption rate*	*1*	*1*	*1*	*4*	*2*	*0*	*I*
		Definition of the defects scale	*3*	*4*	*0*	*2*	*0*	*0*	*O*
		Difference between measurements LMK and TOPcon	*2*	*2*	*1*	*4*	*0*	*0*	*I*
		Reaching temperature for glass NTC during the measurement	*4*	*2*	*0*	*3*	*0*	*0*	*M*
		Measurement method regarding the part status (Free or on the Jig)	*3*	*1*	*0*	*5*	*0*	*0*	*I*
		High temperature/high humidity storage condition	*3*	*0*	*2*	*4*	*0*	*0*	*I*
		Position of tracks on FPCs	*4*	*2*	*0*	*3*	*0*	*0*	*M*
	Customer's rejection rate	*Sample size for measurement*	*3*	*2*	*2*	*2*	*0*	*0*	*M*
		Material of the metal frame	*3*	*5*	*1*	*0*	*0*	*0*	*O*
Cost		*Consignment contract*	*0*	*0*	*1*	*6*	*2*	*0*	*I*
		Cost Breakdown Sheet (CBDS) for tooling	*0*	*1*	*1*	*4*	*3*	*0*	*I*
		Packaging cost	*0*	*2*	*2*	*4*	*1*	*0*	*I*
		Equipment set up requirements	*0*	*2*	*0*	*4*	*3*	*0*	*I*
		Tool strategy	*1*	*2*	*4*	*2*	*0*	*0*	*A*
		The optical measurement report	*4*	*2*	*1*	*2*	*0*	*0*	*M*
		Timeline to sourcing decision	*2*	*1*	*1*	*5*	*0*	*0*	*I*
		The amount of volume scenario	*2*	*4*	*2*	*1*	*0*	*0*	*O*

Table 4-1 – Continued on the next page

Table 4-1 – Continued from the previous page

Category		***CRs***	***M***	***O***	***A***	***I***	***R***	***Q***	***Classification Kano model***
Cost		*Availability of the whole component*	*0*	*1*	*3*	*4*	*1*	*0*	*I*
		Sampling agreement	*1*	*1*	*0*	*7*	*0*	*0*	*I*
		Raw material definition	*0*	*1*	*1*	*7*	*0*	*0*	*I*
		Target price	*1*	*0*	*2*	*5*	*1*	*0*	*I*
Sustainability	Globalization	*Safe and sustainable transport systems*	*0*	*8*	*1*	*0*	*0*	*0*	*O*
		Commitment to health and safety of employees	*2*	*6*	*1*	*0*	*0*	*0*	*O*
		Take responsibility of sustainability and create transparency	*2*	*5*	*1*	*1*	*0*	*0*	*O*
	Pollution production	*CO_2 emissions*	*0*	*6*	*2*	*1*	*0*	*0*	*O*
		Product environmental performance footprint	*2*	*5*	*1*	*1*	*0*	*0*	*O*
		Potential toxicity to human	*2*	*6*	*1*	*0*	*0*	*0*	*O*
		Climate pledge friendly products	*0*	*5*	*2*	*2*	*0*	*0*	*O*
		Quality of water discharges	*2*	*5*	*1*	*1*	*0*	*0*	*O*
	Urbanization and Eco-design Energy	*Reduce operational water & energy consumption*	*0*	*6*	*3*	*0*	*0*	*0*	*O*
		New sustainable materials implementation	*0*	*5*	*4*	*0*	*0*	*0*	*O*
		Reduce material through eco-design	*0*	*5*	*3*	*1*	*0*	*0*	*O*
		Water consumption	*1*	*6*	*2*	*0*	*0*	*0*	*O*
		Waste avoidance (Zero waste to landfill)	*0*	*5*	*3*	*1*	*0*	*0*	*O*
		Strengthen the circular economy strategy	*1*	*5*	*1*	*2*	*0*	*0*	*O*
		The energy supply from renewable sources	*0*	*5*	*2*	*2*	*0*	*0*	*O*
	Health and Safety	*Amount of emission of hazardous material (RoHS compliance)*	*2*	*5*	*2*	*0*	*0*	*0*	*O*
		Road safety	*1*	*4*	*1*	*3*	*0*	*0*	*O*
		Accident rate per hours of the work	*2*	*6*	*0*	*1*	*0*	*0*	*O*
	Water	*Water quality*	*2*	*6*	*1*	*0*	*0*	*0*	*O*

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Category		CRs	M	O	A	I	R	Q	Classification Kano model
Sustainability	Water	*Water scarcity*	*1*	*6*	*2*	*0*	*0*	*0*	*O*
Delivery		*Order lead-time*	*2*	*5*	*2*	*0*	*0*	*0*	*O*
		Better delivery flexibility	*0*	*1*	*8*	*0*	*0*	*0*	*A*
		Communication, Cooperation	*4*	*1*	*2*	*2*	*0*	*0*	*M*
		Standard cut-off time for release of the Transport Order (TO)	*2*	*0*	*4*	*3*	*0*	*0*	*A*
		Special transports	*2*	*1*	*4*	*1*	*1*	*0*	*A*
		Minimum order quantity	*2*	*6*	*1*	*0*	*0*	*0*	*O*
		Information transmission between the supplier and OEM	*6*	*0*	*2*	*1*	*0*	*0*	*M*
		Kanban call offs (Just in Time (JIT) calls)	*2*	*0*	*6*	*1*	*0*	*0*	*A*
		Start-up and phase-out control	*0*	*0*	*5*	*4*	*0*	*0*	*A*
		The delivery of sub-suppliers to the supplier	*4*	*3*	*0*	*2*	*0*	*0*	*M*
		Maximum storage time	*4*	*0*	*1*	*4*	*0*	*0*	*M*
		Transportation time	*4*	*0*	*3*	*2*	*0*	*0*	*M*
		Production progress information	*6*	*0*	*0*	*3*	*0*	*0*	*M*
		Number of parts in package	*4*	*3*	*2*	*0*	*0*	*0*	*M*
		Easy handling packaging	*0*	*7*	*0*	*2*	*0*	*0*	*O*
		Stack ability of the package	*2*	*5*	*0*	*2*	*0*	*0*	*O*
		Traceability of the product	*2*	*5*	*0*	*2*	*0*	*0*	*O*
		Corrosion prevention and moisture control	*4*	*1*	*0*	*4*	*0*	*0*	*M*
		Security in goods transportation	*2*	*3*	*0*	*4*	*0*	*0*	*I*
		Risk and crisis management	*0*	*2*	*0*	*7*	*0*	*0*	*I*
		Logistics failures	*2*	*1*	*2*	*4*	*0*	*0*	*I*
		Digitalization of the supply chain	*0*	*0*	*3*	*6*	*0*	*0*	*I*

Table 4-1 – Continued on the next page

Table 4-1 – Continued from the previous page

Category	***CRs***	***M***	***O***	***A***	***I***	***R***	***Q***	***Classification Kano model***
Delivery	*The LCD bag material*	*2*	*3*	*0*	*4*	*0*	*0*	*I*
	Maximum handling weight of the box	*3*	*0*	*0*	*5*	*1*	*0*	*I*
	Pallet size	*5*	*1*	*0*	*3*	*0*	*0*	*M*
	Clean returnable packaging	*0*	*6*	*0*	*2*	*1*	*0*	*O*
	Intermediate layers or nesting elements	*6*	*2*	*0*	*0*	*0*	*1*	*M*

In this dissertation, the author applied a refined Kano approach which uses the TSI based on Kano responses (Timko, 1993). This method calculates better and worse values to understand the rate of customer satisfaction and dissatisfaction with the features using the formulas (Eq. 3-4) and (Eq. 3-5) discussed in Chapter 3 (Shahin and Shahiverdi, 2015; Go and Kim, 2018).

In the next step, after calculating the Kano classifications, the Kano group of the CRs is obtained in Table 4-1. Then, the details of the refined Kano model classifications were obtained, and the CRs classified into eight categories of the refined Kano model based on the average weight and simple Kano model classifications.

First, based on Kano responses obtained from questionnaires according to equations 3-1 and 3-2, the better and worse values were calculated and presented in Table 4-2. Then, the TSI and weights of each CR in the main categories were calculated and obtained at the final step, presented in Table 4-2.

Table 4-2 – The classification of the refined Kano model and TSI and weights of CRs for DMCS.

	Category	CRs	better	worse	Weight of Attribute	TSI	Kano group	Refined kano group
Technical	Mechanical	*Double side foam which connects the LCD to backlight frame*	*0.56*	*-0.56*	*0.56*	*0*	*O*	*Low Value-Added*
		Enough Dam space	*0.78*	*-0.56*	*0.78*	*0.22*	*M*	*Critical*
		Rigidity of backlight unit housing	*0.25*	*-0.75*	*0.75*	*-0.50*	*A*	*Low Attractive*
		Optical alignment features definition	*0.44*	*-0.56*	*0.56*	*-0.1*	*A*	*Low Attractive*
		De-coupling of backlight unit and panel	*0*	*-0.89*	*0.89*	*-0.89*	*A*	*Low Attractive*
		Sealant double side tape design	*0.56*	*-0.56*	*0.56*	*0*	*O*	*Low Value-Added*
		Propensity to leakage of foam tape	*0.89*	*-0.44*	*0.89*	*0.45*	*M*	*Critical*
		Dimension of the backlight frame	*0.56*	*-0.44*	*0.56*	*0.12*	*M*	*Necessary*
		Gap between rear glass and black housing	*0*	*-0.89*	*0.89*	*-0.89*	*A*	*High Attractive*
		Formation of air bubbles on LCD panel	*1*	*-0.44*	*1*	*0.56*	*M*	*Necessary*
		Alignment features on back housing of LCD to align center frame	*0.44*	*-0.56*	*0.56*	*-0.12*	*A*	*Low Attractive*
		Height difference between the display frame and bonding surface	*0.56*	*-0.22*	*0.56*	*0.34*	*M*	*Necessary*
		Parallelism of display polarizer to support elements on the KIT	*0.44*	*-0.22*	*0.44*	*0.22*	*I*	*Care-free*
		Gap between backlight frame and LCD	*0.22*	*-0.22*	*0.22*	*0*	*I*	*Care-free*
		Light leakage due to mechanical lay out on the frame and back light	*0.78*	*-0.22*	*0.78*	*0.56*	*M*	*Critical*
		Thickness of the inner glass	*0.13*	*-0.25*	*0.25*	*-0.12*	*I*	*Care-free*
		Thickness of the polarizer	*0*	*-0.38*	*0.38*	*-0.38*	*I*	*Care-free*
		Type of polarizer	*0.78*	*-0.44*	*0.78*	*0.34*	*M*	*Critical*
		Backlight reflection sheet shape	*0.78*	*-0.33*	*0.78*	*0.45*	*M*	*Critical*
		Shield film shape	*0.25*	*0*	*0.25*	*0.25*	*I*	*Care-free*

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Category		CRs	better	worse	Weight of Attribute	TSI	Kano group	Refined kano group
Technical	Mechanical	*Flatness of backlight housing*	*0.56*	*-0.56*	*0.56*	*0*	*O*	*Low Value-Added*
		Contamination of the display	*1*	*-0.56*	*1*	*0.44*	*O*	*High Value-Added*
		Thickness of TFT-/color filter glass	*0.33*	*-0.22*	*0.33*	*0.11*	*I*	*Care-free*
	Electrical	*Foil banding material of the side of the display*	*0.67*	*-0.33*	*0.67*	*0.34*	*M*	*Critical*
		Foil banding width	*0.13*	*-0.13*	*0.13*	*0*	*I*	*Care-free*
		Position of the LEDs	*0.67*	*-0.22*	*0.67*	*0.45*	*M*	*Critical*
		Thickness of the Driver IC	*0.22*	*-0.22*	*0.22*	*0*	*I*	*Care-free*
		Softness of flexible printed circuit (FPC) material	*0.33*	*-0.56*	*0.56*	*-0.23*	*A*	*High Attractive*
		Chip on Glass (CoG)/Foil on Glass (FoG) bonding-Chip /Anisotropic Conductive Film (ACF)	*0.11*	*-0.11*	*0.11*	*0*	*I*	*Care-free*
		Resistance of the track material	*0.33*	*-0.22*	*0.33*	*0.11*	*I*	*Care-free*
		LED power consumption	*0.22*	*-0.33*	*0.33*	*-0.11*	*I*	*Care-free*
	Optical	*Stability regarding the contrast at higher temperatures*	*0.44*	*-0.44*	*0.44*	*0*	*I*	*Care-free*
		Thermal reliability	*0.56*	*-0.22*	*0.56*	*0.34*	*I*	*Potential*
		Dark Dot rate	*0.33*	*-0.33*	*0.33*	*0*	*I*	*Care-free*
		BU percentage	*0.78*	*-0.67*	*0.78*	*0.11*	*O*	*High Value-Added*
		Type of LED material	*0.44*	*-0.33*	*0.44*	*0.11*	*I*	*Care-free*
		Nit of brightness of screen	*0.33*	*0.56*	*0.56*	*0.89*	*I*	*Potential*
Quality	Definition of standard conditions	*Digital pulse width modulation (PWM) rate*	*0.56*	*-0.22*	*0.56*	*0.34*	*I*	*Potential*
		Repeatability due to sensitivity of the display	*0.67*	*-0.33*	*0.67*	*0.34*	*M*	*Critical*
		Parameter settings of equipment (e.g., printscreen of equipment GUI with settings)	*0.33*	*-0.22*	*0.33*	*0.11*	*I*	*Care-free*

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	Category	CRs	better	worse	Weight of Attribute	TSI	Kano group	Refined kano group
Quality	Definition of standard conditions	Touch Mura evaluation	0.67	-0.67	0.67	0	O	Low Value-Added
		Respect to process rules for engineering (PRE)	0.78	-0.33	0.78	0.45	M	Critical
		Stability of the measurement system analysis (MSA)	0.38	-0.13	0.38	0.25	I	Care-free
		Register active display area measurement	0.44	-0.22	0.44	0.22	I	Care-free
	Measurements conditions	Water absorption rate	0.29	-0.29	0.29	0	I	Care-free
		Definition of the defects scale	0.78	-0.44	0.78	0.34	O	High Value-Added
		Difference between measurements LMK and TOPcon	0.44	-0.33	0.44	0.11	I	Care-free
		Reaching temperature for glass NTC during the measurement	0.67	-0.22	0.67	0.45	M	Critical
		Measurement method regarding the part status (Free or on the Jig)	0.44	-0.11	0.44	0.33	I	Care-free
		High temperature/high humidity storage condition	0.33	-0.22	0.33	0.11	I	Care-free
		Position of tracks on FPCs	0.67	-0.22	0.67	0.45	M	Critical
	Customer's rejection rate	Sample size for measurement	0.56	-0.44	0.56	0.12	M	Necessary
		Material of the metal frame	0.89	-0.67	0.89	0.22	O	High Value-Added
Cost		Consignment contract	0	-0.14	0.14	-0.14	I	Care-free
		Cost Breakdown Sheet (CBDS) for tooling	0.17	-0.33	0.33	-0.16	I	Care-free
		Packaging cost	0.25	-0.50	0.50	-0.25	I	Care-free
		Equipment set up requirements	0.33	-0.33	0.33	0	I	Care-free
		Tool strategy	0.33	-0.67	0.67	-0.34	A	High Attractive
		The optical measurement report	0.67	-0.33	0.67	0.34	M	Critical
		Timeline to sourcing decision	0.33	-0.22	0.33	0.11	I	Care-free
		The amount of volume scenario	0.67	-0.67	0.67	0	O	High Value-Added
		Availability of the whole component	0.13	-0.50	0.50	-0.37	I	Care-free

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Category		CRs	better	worse	Weight of Attribute	TSI	Kano group	Refined kano group
Cost		Sampling agreement	0.22	-0.11	0.22	0.11	I	Care-free
		Raw material definition	0.11	-0.22	0.22	-0.11	I	Care-free
		Target price	0.13	-0.25	0.25	-0.12	I	Care-free
Sustainability	Globalization	Safe and sustainable transport systems	0.89	-1	1	-0.11	O	Low Value-Added
		Commitment to health and safety of employees	0.89	-0.78	0.89	0.11	O	High Value-Added
		Take responsibility of sustainability and create transparency	0.78	-0.67	0.78	0.11	O	High Value-Added
	Pollution production	CO_2 emissions	0.67	-0.89	0.89	-0.22	O	Low Value-Added
		Product environmental performance footprint	0.78	-0.67	0.78	0.11	O	High Value-Added
		Potential toxicity to human	0.89	-0.78	0.89	0.11	O	High Value-Added
		Climate pledge friendly products	0.56	-0.78	0.78	-0.22	O	Low Value-Added
		Quality of water discharges	0.78	-0.67	0.78	0.11	O	High Value-Added
	Urbanization and Eco-design Energy	Reduce operational water & energy consumption	0.67	-1	1	-0.33	O	Low Value-Added
		New sustainable materials implementation	0.56	-1	1	-0.44	O	Low Value-Added
		Reduce material through eco-design	0.56	-0.89	0.89	-0.33	O	Low Value-Added
		Water consumption	0.78	-0.89	0.89	-0.11	O	Low Value-Added
		Waste avoidance (Zero waste to landfill)	0.56	-0.89	0.89	-0.33	O	Low Value-Added
		Strengthen the circular economy strategy	0.67	-0.67	0.67	0	O	High Value-Added
		The energy supply from renewable sources	0.56	-0.78	0.78	-0.22	O	Low Value-Added
	Health and Safety	Amount of emission of hazardous material (RoHS compliance)	0.78	-0.78	0.78	0	O	High Value-Added
		Road safety	0.56	-0.56	0.56	0	O	Low Value-Added
		Accident rate per hours of the work	0.89	-0.67	0.89	0.22	O	High Value-Added
	Water	Water quality	0.89	-0.78	0.89	0.11	O	High Value-Added

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Category		CRs	better	worse	Weight of Attribute	TSI	Kano group	Refined kano group
Sustainability	Water	Water scarcity	0.78	-0.89	0.89	-0.11	O	Low Value-Added
Delivery		Order lead-time	0.78	-0.78	0.78	0	O	High Value-Added
		Better delivery flexibility	0.11	-1	1	-0.89	A	High Attractive
		Communication, Cooperation	0.56	-0.33	0.56	0.23	M	Necessary
		Standard cut-off time for release of the Transport Order (TO)	0.22	-0.44	0.44	-0.22	A	Low Attractive
		Special transports	0.38	-0.63	0.63	-0.25	A	High Attractive
		Minimum order quantity	0.89	-0.78	0.89	0.11	O	High Value-Added
		Information transmission between the supplier and OEM	0.67	-0.22	0.67	0.45	M	Critical
		Kanban call offs (Just in Time (JIT) calls)	0.22	-0.67	0.67	-0.45	A	High Attractive
		Start-up and phase-out control	0	-0.56	0.56	-0.56	A	Low Attractive
		The delivery of sub-suppliers to the supplier	0.78	-0.33	0.78	0.45	M	Critical
		Maximum storage time	0.44	-0.11	0.44	0.33	M	Necessary
		Transportation time	0.44	-0.33	0.44	0.11	M	Necessary
		Production progress information	0.67	0	0.67	0.67	M	Critical
		Number of parts in package	0.78	-0.56	0.78	0.22	M	Critical
		Easy handling packaging	0.78	-0.78	0.78	0	O	High Value-Added
		Stack ability of the package	0.78	-0.56	0.78	0.22	O	High Value-Added
		Traceability of the product	0.78	-0.56	0.78	0.22	O	High Value-Added
		Corrosion prevention and moisture control	0.56	-0.11	0.56	0.45	M	Necessary
		Security in goods transportation	0.56	-0.33	0.56	0.23	I	Care-free
		Risk and crisis management	0.22	-0.22	0.22	0	I	Care-free
		Logistics failures	0.33	-0.33	0.33	0	I	Care-free
		Digitalization of the supply chain	0	-0.33	0.33	-0.33	I	Care-free

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Table 4-2 – Continued from the previous page

Category	CRs	better	worse	Weight of Attribute	TSI	Kano group	Refined kano group
Delivery	*The LCD bag material*	*0.56*	*-0.33*	*0.56*	*0.23*	*I*	*Care-free*
	Maximum handling weight of the box	*0.38*	*0*	*0.38*	*0.38*	*I*	*Care-free*
	Pallet size	*0.67*	*-0.11*	*0.67*	*0.56*	*M*	*Critical*
	Clean returnable packaging	*0.75*	*-0.75*	*0.75*	*0*	*O*	*High Value-Added*
	Intermediate layers or nesting elements	*1*	*-0.25*	*1*	*0.75*	*M*	*Critical*

Table 4-3 presenting the refined Kano classification and weights of the categories of the CRs. It is important to understand the main categories that in general, have which quality attribute classification. As presented in Table 4-3, the highest weights belong to the "Globalization", and "Water" categories (sustainability) by 0.89, are in one- dimensional Kano group, and the "Electrical" (technical) with 0.378 is the lowest among categories which are indifferent Kano group.

Table 4-3 – The classification of the main categories in the refined Kano model of case study

Category		Weight	Kano Classification	Refined Kano Classification
Technical	Mechanical	*0.623*	*M*	*Critical*
	Electrical	*0.378*	*I*	*Care-free*
	Optical	*0.518*	*I*	*Care-free*
Quality	Definition of standard conditions	*0.547*	*I*	*Care-free*
	Measurements conditions	*0.517*	*I*	*Care-free*
	Customer's rejection rate	*0.725*	*M or O*	*High value-added or necessary*
Cost		*0.403*	*I*	*Care-free*
Sustainability	Globalization	*0.89*	*O*	*Low value-added*

Table 4-3 – Continued on the next page

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Category		**Weight**	**Kano Classification**	**Refined Kano Classification**
Sustainability	Pollution production	*0.824*	*O*	*High value-added*
	Urbanization and Eco-design Energy	*0.874*	*O*	*Low value-added*
	Health and Safety	*0.743*	*O*	*High value-added*
	Water	*0.89*	*O*	*High value-added*
Delivery		*0.63*	*M*	*Critical*

The reliability and validity for five categories of the product were fulfilled. In terms of compatibility of the CRs in the five main categories, the CRs were verified correspondingly. The negative queries within the Kano questionnaire were negated not only through the application of negative prefixes but also through the framing of the questions in a manner that conveys negative connotations. The Kano classification is then given for each category as shown in Table 4-2, and subsequently for each CR. In Table 4-3, the CRs classified by the refined Kano model according to the classification shown in Table 2-2. According to the refined Kano model, high value-added attributes cause a high level of customer satisfaction and thus reduce defective products and increase production efficiency. Among the sub-criteria, 20 CRs follow this feature. The 15 items of CRs are low value-added attributes. Although this feature does not play a significant role in satisfying customer demands, still the absence of it causes dissatisfaction, so it should be considered in the product. The high attractive attributes include seven items. This feature is the best tool to attract customers to improve customer satisfaction, therefore, it recommends fulfilling that kind of CRs. The Indifferent attribute is divided into two, which are significantly classified as potential. The potential attributes' CRs become an attractive quality attribute, and suppliers should consider the Potential needs of the product to attract the customer. In this study, three CRs are in this category. The care-free features are scattered into four categories except for sustainability. Meeting the care-free requirements in the DMCS requires significant costs. Therefore, it is better not to apply these features to the product or simplify or superficially apply them. Even in some performance needs of the DMCS, care-free features can make improvements at a high cost which in the absence of these features does not disrupt the product's performance.

Almost in every category, there are must-be attributes divided into two dimensions. Critical quality is the basis for the manufacturer to meet customer expectations and these CRs are significant. In the five categories of the CRs, some critical attributes are needed to be considered in the product to satisfy the consumer. Despite critical features, there are Necessary items in each category except for sustainability. The necessary items must be provided from the customer's point of view, and if it does not satisfy these features, the level of BU drops which means customer dissatisfaction. Table 4-3 shows the main dimensions of CRs, mechanical, and delivery in the critical category; electrical, optical, definition of standard conditions, measurements conditions, and cost are in the care-free category. Customer rejection rate, pollution production, health and safety, and water are classified in the high value-added category. On the other hand, items of globalization and urbanization and eco-design energy are in the low value-added group.

Finally, after weighting and ranking the expectations of customers using the refined Kano approach based on the opinion of experts, some CRs with low importance weight were removed. After their removal, 66 items remained as CRs.

Table 4-4 shows the final list of the CRs which ranked as nominated CRs:

Table 4-4 – The final list of CRs.

Category		***CRs***	***Weight***	***Refined Kano***
Technical	Mechanical	Double side foam which connects the LCD to backlight frame	0.56	Low Value-Added
		Enough Dam space	0.78	Critical
		Rigidity of backlight unit housing	0.75	Low Attractive
		Optical alignment features definition	0.56	Low Attractive
		De-coupling of backlight unit and panel	0.89	High Attractive
		Sealant double side tape design	0.56	Low Value-Added
		Propensity to leakage of foam tape	0.89	Critical
		Dimension of the backlight frame	0.56	Necessary
		Gap between rear glass and black housing	0.89	High Attractive
		Formation of air bubbles on LCD panel	1	Necessary
		Alignment features on back housing of LCD to align center frame	0.56	Low Attractive
		Height difference between the display frame and bonding surface	0.56	Necessary
		Light leakage due to mechanical lay out on the frame and back light	0.78	Critical
		Type of polarizer	0.78	Critical
		Backlight reflection sheet shape	0.78	Critical
		Flatness of backlight housing	0.56	Low Value-Added
		Contamination of the display	1	High Value-Added
	Electrical	Foil banding material of the side of the display	0.67	Critical
		Position of the LEDs	0.67	Critical
		Softness of flexible printed circuit (FPC) material	0.56	High Attractive
	Optical	BU percentage	0.78	High Value-Added
Quality	Definition of standard conditions	Repeatability due to sensitivity of the display	0.67	Critical
		Respect to process rules for engineering (PRE)	0.78	Critical
	Measurements conditions	Definition of the defects scale	0.78	High Value-Added
		Reaching temperature for glass NTC during the measurement	0.67	Critical
		Position of tracks on FPCs	0.67	Critical
	Customer rejection rate	Sample size for measurement	0.56	Necessary
		Material of the metal frame	0.89	High Value-Added
Cost		The optical measurement report	0.67	Critical
		The amount of volume scenario	0.67	High Value-Added
Sustainability	Globalization	Safe and sustainable transport systems	1	Low Value-Added

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Category		CRs	Weight	Refined Kano
Sustainability	Globalization	Commitment to health and safety of employees	0.89	High Value-Added
		Take responsibility of sustainability and create transparency	0.78	High Value-Added
	Pollution production	CO_2 emissions	0.89	Low Value-Added
		Product environmental performance footprint	0.78	High Value-Added
		Potential toxicity to human	0.89	High Value-Added
		Climate pledge friendly products	0.78	Low Value-Added
		Quality of water discharges	0.78	High Value-Added
	Urbanization and	Reduce operational water & energy consumption	1	Low Value-Added
	Eco-design Energy	New sustainable materials implementation	1	Low Value-Added
		Reduce material through eco-design	0.89	Low Value-Added
		Water consumption	0.89	Low Value-Added
		Waste avoidance (Zero waste to landfill)	0.89	Low Value-Added
		The energy supply from renewable sources	0.78	Low Value-Added
	Health and Safety	Amount of emission of hazardous material (RoHS compliance)	0.78	High Value-Added
		Accident rate per hours of the work	0.89	High Value-Added
	Water	Water quality	0.89	High Value-Added
		Water scarcity	0.89	Low Value-Added
Delivery		Order lead-time	0.78	High Value-Added
		Better delivery flexibility	1	High Attractive
		Communication, cooperation	0.56	Necessary
		Minimum order quantity	0.89	High Value-Added
		Information transmission between the supplier and OEM	0.67	Critical
		Kanban call offs (Just in Time (JIT) calls)	0.67	High Attractive
		The delivery of sub-suppliers to the supplier	0.78	Critical
		Maximum storage time	0.44	Necessary
		Transportation time	0.44	Necessary
		Production progress information	0.67	Critical
		Number of parts in package	0.78	Critical
		Easy handling packaging	0.78	High Value-Added
		Stack ability of the package	0.78	High Value-Added
		Traceability of the product	0.78	High Value-Added
		Corrosion prevention and moisture control	0.56	Necessary
		Pallet size	0.67	Critical
		Clean returnable packaging	0.75	High Value-Added
		Intermediate layers or nesting elements	1	Critical

4.3 The SWARA Approach Results

In this stage, the SWARA approach is discussed to weight the sub-criteria for each main criteria separately, and the results of this approach are presented in the following tables. For example, the calculation of. the "Optical" sub-criteria weight is shown in Table 4-5. The "Optical" sub-criteria consist of six items first provided to the experts. The experts were asked to arrange the criteria according to their importance. Table 4-5 shows the coding of the requirements and the rankings of the sub-criteria based on the experts' opinions.

Table 4-5 – The coding of the optical requirements.

Requirement Name	***Code***	***Item Ranking***
Stability regarding the contrast at higher temperatures	C1	2
Thermal reliability	C2	1
Dark Dot rate	C3	5
BU percentage	C4	4
Type of LED material	C5	3
Nit of brightness of screen	C6	6

Afterward, it is necessary to calculate the S_j, k_j, and criteria's importance weight, respectively (Table 4-6).

Table 4-6 – The weighting of optical requirements.

Requirement Name	***Code***	S_j	k_j	$q_j = \frac{q_{j-1}}{k_j}$	$w_j = \frac{q_j}{\sum q_j}$
Stability regarding the contrast at higher temperatures	C1	0.1	1.1	0.909	0.203
Thermal reliability	C2	1	1	1	0.224
Dark Dot rate	C3	0.168	1.168	0.575	0.129
BU percentage	C4	0.179	1.179	0.672	0.150
Type of LED material	C5	0.148	1.148	0.792	0.177
Nit of brightness of screen	C6	0.102	1.102	0.522	0.117

The calculation programming code of the SWARA is shown in Figure 4-2 and is implemented to generalize the method to use for big data.

```
b=[6   2   3   5   4   1   7
   6   7   3   1   2   5   4
   7   5   6   3   4   1   2
   6   4   7   1   3   2   5
   5   6   4   1   2   3   7
   7   2   6   3   4   5   1
   3   4   5   7   6   2   1
   4   6   3   1   5   2   7
   7   6   5   4   1   3   2
   7   6   2   1   5   4   3];
b1=sum(b);
b1=b1/sum(b1);
b2(2,7)=0;
b3=sort(b1);
for j=1:7
    for i=1:7
        if b3(j)==b1(i)
            b2(1,i)=b1(i);
            b2(2,i)=7-j+1;
        end
    end
end
k(7)=0;
s(7)=0;
q(7)=0;
for i=1:7
    kk=b2(2,i);
    if kk==1
        k(i)=1;
        s(i)=1;
        q(i)=1;
    end
    if kk>1
        for j=1:7
            if j~=i
              kk1=b2(2,j);
              if kk1==kk-1
                  k(i)=abs((b2(1,i)-b2(1,j)))/b2(1,i);
                  s(i)=k(i)+1;
                  break;
              end
            end
        end
    end
end
for j=2:7
```

Figure 4-2 – The code of SWARA for implementing the data

According to the calculation of the SWARA method in section 3.7.2, the model formulated as shown above in MATLAB software and the data developed by the program.

Table 4-7 shows the weights of all criteria related to CRs considering the SWARA approach.

Table 4-7 – The weights of CRs considering the SWARA approach

Category		***CRs***	***Weight of Attribute***	***Item ranking***
Technical	Mechanical	*Double side foam which connects the LCD to backlight frame*	*0.0567*	*9*
		Enough Dam space	*0.0630*	*7*
		Rigidity of backlight unit housing	*0.0088*	*20*
		Optical alignment features definition	*0.0635*	*6*
		De-coupling of backlight unit and panel	*0.0440*	*13*
		Sealant double side tape design	*0.0675*	*1*
		Propensity to leakage of foam tape	*0.0194*	*17*
		Dimension of the backlight frame	*0.0380*	*14*
		Gap between rear glass and black housing	*0.0666*	*4*
		Formation of air bubbles on LCD panel	*0.0671*	*2*
		Alignment features on back housing of LCD to align center frame	*0.0110*	*18*
		Height difference between the display frame and bonding surface	*0.0068*	*21*
		Parallelism of display polarizer to support elements on the KIT	*0.0666*	*4*
		Gap between backlight frame and LCD	*0.0338*	*15*
		Light leakage due to mechanical lay out on the frame and back light	*0.0556*	*10*
		Thickness of the inner glass	*0.0099*	*19*
		Thickness of the polarizer	*0.0293*	*16*
		Type of polarizer	*0.0637*	*5*
		Backlight reflection sheet shape	*0.0551*	*11*
		Shield film shape	*0.0667*	*3*

Table 4-7 – Continued on the next page

Table 4-7 – Continued from the previous page

Category		***CRs***	***Weight of Attribute***	***Item ranking***
Technical	Mechanical	*Flatness of backlight housing*	*0.0456*	*12*
		Contamination of the display	*0.0025*	*22*
		Thickness of TFT-/color filter glass	*0.0590*	*8*
	Electrical	*Foil banding material of the side of the display*	*0.1810*	*1*
		Foil banding width	*0.1315*	*6*
		Position of the LEDs	*0.1468*	*3*
		Thickness of the Driver IC	*0.1440*	*4*
		Softness of flexible printed circuit (FPC) material	*0.0760*	*7*
		Chip on Glass (CoG)/Foil on Glass (FoG) bonding-Chip /Anisotropic Conductive Film (ACF)	*0.0332*	*8*
		Resistance of the track material	*0.1507*	*2*
		LED power consumption	*0.1368*	*5*
	Optical	*Stability regarding the contrast at higher temperatures*	*0.203*	*2*
		Thermal reliability	*0.224*	*1*
		Dark Dot rate	*0.129*	*5*
		BU percentage	*0.150*	*4*
		Type of LED material	*0.177*	*3*
		Nit of brightness of screen	*0.117*	*6*
Quality	Definition of standard conditions	*Digital pulse width modulation (PWM) rate*	*0.0893*	*5*
		Repeatability due to sensitivity of the display	*0.0172*	*7*
		Parameter settings of equipment (e.g., printscreen of equipment GUI with settings)	*0.2038*	*3*
		Touch Mura evaluation	*0.2585*	*2*
		Respect to process rules for engineering (PRE)	*0.3063*	*1*

Table 4-7 – Continued on the next page

Table 4-7 – Continued from the previous page

Category		CRs	Weight of Attribute	Item ranking
Quality	Definition of standard conditions	*Stability of the measurement system analysis (MSA)*	*0.0289*	*6*
		Register active display area measurement	*0.0960*	*4*
	Measurements conditions	*Water absorption rate*	*0.0387*	*4*
		Definition of the defects scale	*0.2896*	*2*
		Difference between measurements LMK and TOPcon	*0.2784*	*3*
		Reaching temperature for glass NTC during the measurement	*0.0133*	*7*
		Measurement method regarding the part status (Free or on the Jig)	*0.0339*	*6*
		High temperature/high humidity storage condition	*0.0386*	*5*
		Position of tracks on FPCs	*0.3075*	*1*
	Customer's rejection rate	*Sample size for measurement*	*0.49*	*2*
		Material of the metal frame	*0.51*	*1*
Cost		*Consignment contract*	*0.0401*	*9*
		Cost Breakdown Sheet (CBDS) for tooling	*0.3365*	*1*
		Packaging cost	*0.0504*	*8*
		Equipment set up requirements	*0.0546*	*5*
		Tool strategy	*0.0576*	*4*
		The optical measurement report	*0.0259*	*10*
		Timeline to sourcing decision	*0.0526*	*6*
		The amount of volume scenario	*0.0510*	*7*
		Availability of the whole component	*0.0184*	*11*
		Sampling agreement	*0.0155*	*12*
		Raw material definition	*0.2261*	*2*
		Target price	*0.0712*	*3*

Table 4-7 – Continued on the next page

Table 4-7 – Continued from the previous page

	Category	CRs	Weight of Attribute	Item ranking
Sustainability	Globalization	*Safe and sustainable transport systems*	*0.5286*	*1*
		Commitment to health and safety of employees	*0.3504*	*2*
		Take responsibility of sustainability and create transparency	*0.1210*	*3*
	Pollution production	*CO_2 emissions*	*0.2218*	*3*
		Product environmental performance footprint	*0.0753*	*5*
		Potential toxicity to human	*0.2334*	*2*
		Climate pledge friendly products	*0.2064*	*4*
		Quality of water discharges	*0.2631*	*1*
	Urbanization and Eco-design Energy	*Reduce operational water & energy consumption*	*0.0287*	*7*
		New sustainable materials implementation	*0.0324*	*5*
		Reduce material through eco-design	*0.2196*	*3*
		Water consumption	*0.2506*	*1*
		Waste avoidance (Zero waste to landfill)	*0.2341*	*2*
		Strengthen the circular economy strategy	*0.0308*	*6*
		The energy supply from renewable sources	*0.2038*	*4*
	Health and Safety	*Amount of emission of hazardous material (RoHS compliance)*	*0.4419*	*2*
		Road safety	*0.0717*	*3*
		Accident rate per hours of the work	*0.4864*	*1*
	Water	*Water quality*	*0.1200*	*2*
		Water scarcity	*0.8800*	*1*
Delivery		*Order lead-time*	*0.0864*	*2*
		Better delivery flexibility	*0.0649*	*9*
		Communication, Cooperation	*0.0103*	*22*

Table 4-7 – Continued on the next page

Table 4-7 – Continued from the previous page

Category	***CRs***	***Weight of Attribute***	***Item ranking***
Delivery	*Standard cut-off time for release of the Transport Order (TO)*	*0.0132*	*19*
	Special transports	*0.0089*	*26*
	Minimum order quantity	*0.0652*	*8*
	Information transmission between the supplier and OEM	*0.0095*	*23*
	Kanban call offs (Just in Time (JIT) calls)	*0.0735*	*6*
	Start-up and phase-out control	*0.0132*	*19*
	The delivery of sub-suppliers to the supplier	*0.0142*	*18*
	Maximum storage time	*0.0778*	*3*
	Transportation time	*0.0764*	*5*
	Production progress information	*0.0123*	*20*
	Number of parts in package	*0.0665*	*7*
	Easy handling packaging	*0.0208*	*15*
	Stack ability of the package	*0.0236*	*12*
	Traceability of the product	*0.0170*	*17*
	Corrosion prevention and moisture control	*0.0189*	*16*
	Security in goods transportation	*0.0092*	*25*
	Risk and crisis management	*0.0094*	*24*
	Logistics failures	*0.0245*	*11*
	Digitalization of the supply chain	*0.0217*	*14*
	The LCD bag material	*0.0909*	*1*
	Maximum handling weight of the box	*0.0606*	*10*
	Pallet size	*0.0772*	*4*
	Clean returnable packaging	*0.0226*	*13*
	Intermediate layers or nesting elements	*0.0113*	*21*

4.4 Discussion on Kano and SWARA Results

The outcome of the thesis is presented for an automotive company to use to improve the attributes of the display DMCS based on sustainable requirements acquired by final customers and OEM companies. Hence, the CRs with high importance weight for an automotive product can be outlined as a benchmark to improve other products or services in the future. The study results for managers of the OEM Company offers a model to recognise and rank the CRs and gives an insight for an efficient management competence to identify the customers' concerns regarding the product.

The proposed method easily can be developed in practice concerning MCDM tools. The executive managers can take proper strategies to apply the Kano model and MCDM tools to obtain the relative weight of the CRs. The proposed method can help the OEMs to receive semi-products from the suppliers according to the emphasised customer parameters to deliver better service or products to the customer.

The current discussion shows two approaches of Kano and SWARA to address a real problem involving the CRs to recognise and evaluate their significant parameters to improve the products.

There are some reasons why the SWARA method have been selected. First, because of the large number of criteria, the SWARA method is simpler to compute the data compared to the other tools like AHP. Even though other methods like ANP are based on pairwise comparison, it is difficult to obtain a high consistency rate and the process of calculation is time-consuming. Also, the SWARA method is a policy-based tool that is applied in various areas and a vital tool to evaluate the importance weight of criteria depending on their priority. Meanwhile, the Kano model supports another idea to classify and rank the CRs based on Kano theory which is different from MCDM methods. According to the experts' perspective, the survey is deemed to align more closely with the refined Kano classification which the outcomes obtained using the refined Kano model will be utilized for subsequent analysis, while the SWARA approach will be employed as an additional method to evaluate the importance of CRs that has not to adopt as input into the QFD.

The calculation details of the criteria weights obtained based on the Kano model are presented in Table 4-2, while the importance weights of CRs based on the SWARA method are shown in Table 4-7. In competitive market manufacturing, a product that is not aligned with customer preference can be a tremendously huge cost for the company; therefore, it makes sense to follow the customer's desires. The result shown in each category of the CRs has different values in the Kano model and the SWARA method. For instance, in the refined Kano model, the highest weight attained for the "Technical" category pertains to the "Sealant double side tape design" which falls under the "low value-added" group, with a value of 0.56. On the other hand, the highest rating for the "Technical" category is attributed to "De-coupling of backlight unit and panel", "Propensity to leakage of foam tape", and "Gap between rear glass and black housing", with a value of 0.89.

Here one of the advantages of this comparison, which has been done in this research, is that the weights of the sub-criteria are obtained from the comparison between the sub-criteria within a cluster of the category, so the sub-criteria that of one class are compared with each other and not with other sub-criteria in another category. For example, the "Better delivery flexibility" from the "Delivery" cannot be compared with the "Contamination of the display" from the "Technical" because they are not of the same type of requirements, and the experts that evaluate them are different in the two categories. However, the value of both CRs is 1.

This thesis aimed to apply the refined Kano approach and SWARA to categorise and prioritise CRs. First, 112 CRs of the DMCS display were identified in five different categories: technical, cost, delivery, sustainability, and quality. Then, CRs were categorised and ranked using the refined Kano model. Afterwards, the SWARA was developed to obtain importance weights. According to the results from the refined Kano model, the mechanical and delivery categories are in the critical group. Hence, the supplier must accord greater importance to these aforementioned requirements to eliminate the possibility of customers perceiving lack of these requirements. Furthermore, it is noteworthy that these requirements hold immense significance from the customers' standpoint, and any failure to meet them could potentially result in an erosion of their confidence and loyalty. This failure can consequently leading to a decline in market share.

The carefree category consists of electrical, optical, definition of standard conditions, measurement conditions, and cost. The supplier can spend the budget and time on other needs if necessary. The customer's rejection rate, pollution production, health and safety, and water are in high value-added classification. Not only do these requirements increase satisfaction, but they also increase profitability and the competitiveness of the organisation. As it requires efforts to improve these requirements, it is important to understand the emphasis that customers place on them, and the direct impact they have on customer satisfaction. Therefore, the supplier must improve these needs that are the most significant CRs in the point of view of OEM, which ultimately reduces the defects and increases the BU, or at least decreases the deviation range. On the other hand, globalization, urbanization, and eco-design energy should be considered by the supplier, although it does not have a significant impact on customer satisfaction to prevent dissatisfaction and produce a consistent product.

As can be seen, the needs of ''pollution production'', ''health and safety'', and ''water'' are among the sustainability needs and are in the high value-added group. It shows that in addition to the economic and profit, the company must pay attention to the sustainable development category in terms of people's familiarity with sustainability concepts and green products. Today, everyone is aware of the importance of social, humanitarian, and environmental goals. All worldwide industries, including the automotive industry must maintain sustainable customers and attract new customers to create sustainable development. A company can create value when the management method includes various characteristics to integrate the economic, environmental, and social dimensions. Sustainability is the performance of the enterprise in all aspects of the company's sustainability drivers that go beyond the traditional organisational boundaries and from the upstream performance of the value chain (suppliers) to the downstream (customers).

4.5 Results of Fuzzy-QFD Method

To develop the HoQ, first, the weights of the CRs were adapted with the fuzzy numbers according to Table 3-6. The difference between the lowest and highest weight in Table 4-4 is calculated and divided by 4. Then, compliance is determined as 4 spectrums from very low to very high as fuzzy numbers in Table 3-6.

After nominating the 66 items of CRs (Table 4-4) based on the experts' opinion considering the weight, refined Kano group classification, and technical considerations, the experts in each category gathered the related SAs which can improve the CRs (basically Table 4-8 presenting the HoQ relationship matrix between CRs and SAs). Table 4-8 presents the nominated CRs by the experts indexed from CR1 to CR66, and the related SAs (SA1-SA63) (linked to CRs in the last column).

Table 4-8 – The nominated CRs and relationship with SAs in HoQ.

	Category	CRs	CR Index	Weight	Refined Kano	Related SAs
Technical	Mechanical	*Double side foam which connects the LCD to backlight frame*	*CR1*	*0.56*	*Low Value-Added*	*SA2*
		Enough Dam space	*CR2*	*0.78*	*Critical*	*SA1*
		Rigidity of backlight unit housing	*CR3*	*0.75*	*Low Attractive*	*SA12*
		Optical alignment features definition	*CR4*	*0.56*	*Low Attractive*	*SA9*
		De-coupling of backlight unit and panel	*CR5*	*0.89*	*Low Attractive*	*SA32*
		Sealant double side tape design	*CR6*	*0.56*	*Low Value-Added*	*SA31*
		Propensity to leakage of foam tape	*CR7*	*0.89*	*Critical*	*SA31*
		Dimension of the backlight frame	*CR8*	*0.56*	*Necessary*	*SA10, SA3*
		Gap between rear glass and black housing	*CR9*	*0.89*	*High Attractive*	*SA25*
		Formation of air bubbles on LCD panel	*CR10*	*1*	*Necessary*	*SA52*
		Alignment features on back housing of LCD to align center frame	*CR11*	*0.56*	*Low Attractive*	*SA34*
		Height difference between the display frame and bonding surface	*CR12*	*0.56*	*Necessary*	*SA36*
		Light leakage due to mechanical lay out on the frame and back light	*CR13*	*0.78*	*Critical*	*SA24*
		Type of polarizer	*CR14*	*0.78*	*Critical*	*SA6*
		Backlight reflection sheet shape	*CR15*	*0.78*	*Critical*	*SA7*
		Flatness of backlight housing	*CR16*	*0.56*	*Low Value-Added*	*SA10*
		Contamination of the display	*CR17*	*1*	*High Value-Added*	*SA18*
	Electrical	*Foil banding material of the side of the display*	*CR18*	*0.67*	*Critical*	*SA4, SA14*
		Position of the LEDs	*CR19*	*0.67*	*Critical*	*SA60*
		Softness of flexible printed circuit (FPC) material	*CR20*	*0.56*	*High Attractive*	*SA4, SA14*
	Optical	*BU percentage*	*CR21*	*0.78*	*High Value-Added*	*SA8, SA33, SA56*

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	Category	CRs	CR Index	Weight	Refined Kano	Related SAs
Quality	Definition of standard conditions	*Repeatability due to sensitivity of the display*	*CR22*	*0.67*	*Critical*	*SA55*
		Respect to process rules for engineering (PRE)	*CR23*	*0.78*	*Critical*	*SA31, SA36, SA58*
	Measurements conditions	*Definition of the defects scale*	*CR24*	*0.78*	*High Value-Added*	*SA13*
		Reaching temperature for glass NTC during the measurement	*CR25*	*0.67*	*Critical*	*SA57*
		Position of tracks on FPCs	*CR26*	*0.67*	*Critical*	*SA4, SA14*
	Customer's rejection rate	*Sample size for measurement*	*CR27*	*0.56*	*Necessary*	*SA11, SA35*
		Material of the metal frame	*CR28*	*0.89*	*High Value-Added*	*SA12*
Cost		*The optical measurement report*	*CR29*	*0.67*	*Critical*	*SA11, SA35*
		The amount of volume scenario	*CR30*	*0.67*	*High Value-Added*	*SA59*
Sustainability	Globalization	*Safe and sustainable transport systems*	*CR31*	*1*	*Low Value-Added*	*SA49, SA50*
		Commitment to health and safety of employees	*CR32*	*0.89*	*High Value-Added*	*SA41, SA42, SA49, SA50*
		Take responsibility of sustainability and create transparency	*CR33*	*0.78*	*High Value-Added*	*SA41, SA42, SA49*
	Pollution production	*CO_2 emissions*	*CR34*	*0.89*	*Low Value-Added*	*SA28, SA30, SA43*
		Product environmental performance footprint	*CR35*	*0.78*	*High Value-Added*	*SA39, SA42, SA43*
		Potential toxicity to human	*CR36*	*0.89*	*High Value-Added*	*SA15, SA16, SA42, SA50*
		Climate pledge friendly products	*CR37*	*0.78*	*Low Value-Added*	*SA29, SA39, SA43*
		Quality of water discharges	*CR38*	*0.78*	*High Value-Added*	*SA39, SA45*
	Urbanization and Eco-design Energy	*Reduce operational water & energy consumption*	*CR39*	*1*	*Low Value-Added*	*SA37, SA38, SA39, SA45*
		New sustainable materials implementation	*CR40*	*1*	*Low Value-Added*	*SA15, SA16, SA40*

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Category		CRs	CR Index	Weight	Refined Kano	Related SAs
Sustainability	Urbanization and Eco-design Energy	*Reduce material through eco-design*	*CR41*	*0.89*	*Low Value-Added*	*SA28, SA30, SA38, SA44*
		Water consumption	*CR42*	*0.89*	*Low Value-Added*	*SA30, SA53, SA54*
		Waste avoidance (Zero waste to landfill)	*CR43*	*0.89*	*Low Value-Added*	*SA37, SA38, SA54*
		The energy supply from renewable sources	*CR44*	*0.78*	*Low Value-Added*	*SA39, SA40, SA44*
	Health and Safety	*Amount of emission of hazardous material (RoHS compliance)*	*CR45*	*0.78*	*High Value-Added*	*SA15, SA42, SA43*
		Accident rate per hours of the work	*CR46*	*0.89*	*High Value-Added*	*SA41, SA49, SA50*
	Water	*Water quality*	*CR47*	*0.89*	*High Value-Added*	*SA53, SA54*
		Water scarcity	*CR48*	*0.89*	*Low Value-Added*	*SA45, SA53*
Delivery		*Order lead-time*	*CR49*	*0.78*	*High Value-Added*	*SA26*
		Better delivery flexibility	*CR50*	*1*	*High Attractive*	*SA63*
		Communication, Cooperation	*CR51*	*0.56*	*Necessary*	*SA19, SA48*
		Minimum order quantity	*CR52*	*0.89*	*High Value-Added*	*SA27*
		Information transmission between the supplier and OEM	*CR53*	*0.67*	*Critical*	*SA48*
		Kanban call offs (Just in Time (JIT) calls)	*CR54*	*0.67*	*High Attractive*	*SA48*
		The delivery of sub-suppliers to the supplier	*CR55*	*0.78*	*Critical*	*SA61, SA63*
		Maximum storage time	*CR56*	*0.44*	*Necessary*	*SA21, SA48*
		Transportation time	*CR57*	*0.44*	*Necessary*	*SA62, SA63*
		Production progress information	*CR58*	*0.67*	*Critical*	*SA63*
		Number of parts in package	*CR59*	*0.78*	*Critical*	*SA23*
		Easy handling packaging	*CR60*	*0.78*	*High Value-Added*	*SA22, SA28*
		Stack ability of the package	*CR61*	*0.78*	*High Value-Added*	*SA46*
		Traceability of the product	*CR62*	*0.78*	*High Value-Added*	*SA51*

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Table 4-8 – Continued from the previous page

Category	***CRs***	***CR Index***	***Weight***	***Refined Kano***	***Related SAs***
Delivery	*Corrosion prevention and moisture control*	*CR63*	*0.56*	*Necessary*	*SA47, SA5*
	Pallet size	*CR64*	*0.67*	*Critical*	*SA17, SA28*
	Clean returnable packaging	*CR65*	*0.75*	*High Value-Added*	*SA20, SA21, SA19*
	Intermediate layers or nesting elements	*CR66*	*1*	*Critical*	*SA18*

In the next step, the questionnaires of the HoQ include two questionnaires. First, "the degree of influence of technical requirements (SAs) on CRs" is presented in Appendix 2. The range of the values in the relationship matrix is according to Table 3-5. Symbolically, for the comfort of calculation, the relationship considered between integer numbers 1, 2, and 3, as weak, medium, and strong, and for no relationship, a blank cell is assigned. Second, "the degree of correlation between technical requirements (SAs)" were collected among distribution experts and their opinions. Then, the definite score of opinions was replaced with equivalent fuzzy numbers, and the fuzzy average of answers was calculated. After calculating the fuzzy average of experts' opinions, it is time to calculate the relative importance of technical requirements (RI_j) which is shown in Table 4-9.

Table 4-9 – Fuzzy values of the relative importance of the SAs ($RI_j = (l, m, u)$)

SA indicator	***Supplier Attribute***	$(\boldsymbol{l}, \boldsymbol{m}, \boldsymbol{u})$
SA1	R*emove the step between polarizer and TFT glass, increase Dam dispensing space.*	$(0.35, 0.7, 1.504)$
SA2	*Change the Sealing tape material and close gaps on edges*	$(0, 0, 0.811)$
SA3	*Change the gaps to 0.35mm (0.2mm increase) by reducing the frame thickness*	$(0, 0, 0.811)$
SA4	*To reduce stress when bending, make FPC softer by changing cover lay to resist material*	$(0, 0.3, 1.451)$
SA5	*Make FPC softer by changing cover lay to resist material.*	$(0, 0, 0.811)$
SA6	*Polarizer of TFT side to be changed from NAZ to NSPZ*	$(0.35, 0.7, 1.504)$
SA7	*Put reflection tape to side edge of light guide plate*	$(0.35, 0.7, 1.504)$
SA8	*Use thinner LCD glass (1.4mm to 1.0mm)*	$(0.15, 0.35, 1.204)$
SA9	*Display bezel-less and fiducial marks on the surface with positional tolerance to the center of display active area of ±0.01mm*	$(0, 0, 0.811)$
SA10	*Decrease backlight unit flatness 0,4mm*	$(0, 0, 1.108)$
SA11	*More samples with clear peel-off design of expriments (DOE) strategy*	$(0, 0, 0.956)$
SA12	*Diecast aluminium ADC12*	$(0.84, 1.7, 2.494)$
SA13	*Defining the calculation methods to solve the defects range*	$(0.35, 0.7, 1.504)$
SA14	*Position of tracks on FPCs/tip of tracks: 0,3mm +-0,1mm from cutting edge*	$(0, 0.45, 1.441)$
SA15	*Provide only Pb-free components and solutions.*	$(1.05, 2.2, 3.184)$
SA16	*ESD bag must be with a special orientation*	$(0.7, 1.5, 2.194)$
SA17	*Sea/ Air freight pallet 1175x750x....[mm]*	$(0, 0.3, 1.009)$
SA18	*An intermediate layer to avoid releasing particles (like paper or cardboard)*	$(0.98, 2, 2.494)$
SA19	*Empties Management System web platform (SupplyOn)*	$(0.35, 1, 2.296)$
SA20	*The responsibilty to clean returnable packaging*	$(0, 0.3, 1.299)$
SA21	*During 3 days stock at the supplier*	$(0.7, 1.4, 2.936)$
SA22	*The weight of a single box should not exceed 7 kg*	$(0.35, 0.7, 1.504)$
SA23	*8pcs/Box*	$(0.35, 0.7, 1.504)$

Table 4-9 – Continued on the next page

Table 4-9 – Continued from the previous page

SA indicator	**Supplier Attribute**	(l, m, u)
SA24	*The solution for light lickage can be fill with a tape in cut corners of the back light*	$(0.35, 0.7, 1.504)$
SA25	*To improve the Gap between rear glass and black housing it needs to have good sealing properties*	$(0.49, 1, 1.504)$
SA26	*3 Months*	$(0.35, 0.7, 1.504)$
SA27	*500 PCs*	$(0.49, 1, 1.504)$
SA28	*Size and weight reduction and replacement of material mix and switch package size*	$(0.77, 2, 3.379)$
SA29	*Products need to have specific certifications to appear in this category*	$(0.35, 0.7, 1.504)$
SA30	*Eco-design guidelines applied in specific percentage of product development and processes*	$(0.63, 1.5, 2.584)$
SA31	*Double side tape/foam layout definition in the corners, to avoid leakage – according PRE*	$(0.64, 1.35, 2.491)$
SA32	*Decoupled LCD from backlight to avoid further stresses in the LCD panel, as plastic parts are assembled until final assembly*	$(0.21, 0.5, 1.204)$
SA33	*Agree with supplier a gap of 10% between supplier and customer spec. values*	$(0.15, 0.35, 1.204)$
SA34	*Use screw domes or other features (examples from existing products), to facilitate the alignment with the centre frame*	$(0, 0, 0.811)$
SA35	*Sample measurement report (Optical ISIR), 3-5 pcs, contrast, luminance, colors, etc.*	$(0, 0, 0.721)$
SA36	*Use PRE specifications, which define the height for this feature, to facilitate the bonding process*	$(0.15, 0.35, 1.501)$
SA37	*BHP's approach to carbon offsetting is to prioritise emission reduction*	$(0.21, 0.5, 1.494)$
SA38	*LCA/LCC for all products available, Recycling content for Alu 40 %, Steel 25 % , plastics 25%*	$(0.63, 1.5, 2.584)$
SA39	*Increasing own renewable generation at our sites to 400 GWh and significantly expanding purchase of green electricity from new plants by 2030*	$(1.49, 3.1, 4.864)$
SA40	*Use central IT system – MaCS (Material Data Management for Compliance and Sustainability)*	$(0.49, 1, 1.794)$
SA41	*Training concept and define sustainability culture index*	$(1.13, 2.35, 3.184)$
SA42	*Risk minimization process for high-risk raw materials*	$(0.79, 1.7, 3.464)$
SA43	*Standard for LCA/LCC with focus carbon dioxide (CO2) Footprint Scope 3 (ESP 9 and NBS: IPB2.0 DPB, IBooster 2/3, ESP GEN10)*	$(0.99, 2.05, 3.474)$
SA44	*OSS and VDS: WSS 50/52 and AB, GEN 12*	$(0.36, 0.85, 1.894)$
SA45	*Water policy deployment non scarcity*	$(0.85, 1.85, 2.884)$
SA46	*Dynamic stacking factor at least 2 (1+1)*	$(0.35, 0.7, 1.504)$
SA47	*Desiccant bags, VCI paper and corrosion protection using intercept technology*	$(0, 0, 0.721)$
SA48	*Electronic data interchange (EDI) to exchange standardized messages in various formats and via different communication paths*	$(0, 0.6, 1.888)$
SA49	*K.I.S.S. (Keep, Improve, Start, Stop) method is used and, update at least twice a year*	$(1.62, 3.35, 4.174)$
SA50	*Set up "Near miss process" and quarterly reporting of number of near misses to CC/ Health, safety, and environment (HSE)*	$(0.91, 2, 3.174)$
SA51	*Packaging must be labeled with Mat-Label*	$(0.35, 0.7, 1.504)$

Table 4-9 – Continued on the next page

Table 4-9 – Continued from the previous page

SA indicator	***Supplier Attribute***	(l,m,u)
SA52	*Increasing Dam material quantitiy on the ESD tape area (CW42)*	$(0.7, 1.5, 2.194)$
SA53	*Use three-dimension conservation method: Reuse the water consumed, use rainwater instead of fresh water, improve processes so that less water is needed*	$(1.19, 2.5, 3.184)$
SA54	*Circular economy: Materials efficiency (Microelectromechanical systems (MEMS)), Second life, Recycled materials*	$(0.49, 1, 1.794)$
SA55	*Master plan consists of measurement mismatch root cause: 125 samples production vs lab - supplier incoming inspection- measurement repeatability - protection foil (peel-off) follow-up in respective points.*	$(0, 0.3, 1.009)$
SA56	*According the standard, must defocus until no Moiré due to high camera resolution.*	$(0.15, 0.35, 1.204)$
SA57	*About 36 to 40 degC*	$(0, 0.3, 1.009)$
SA58	*Standard PRE definition in all the aspects of technical*	$(0.35, 0.7, 1.504)$
SA59	*Overall volume (Scenario): 307,2 Kpc from 2018-2022*	$(0, 0.6, 1.504)$
SA60	*Parallel to short side (Vertical straight area)*	$(0, 0.3, 1.009)$
SA61	*Sub-suppliers management system standards*	$(0, 0, 0.811)$
SA62	*Vendor managed inventory (VMI)*	$(0.35, 0.7, 1.801)$
SA63	*Using control concepts (Call-off)*	$(0.64, 1.65, 2.986)$

It is then currently necessary to compute the ultimate weight of technical requirements, followed by the solicitation of expert evaluations regarding the interaction effects of technical requirements using a questionnaire, and to calculate the fuzzy average of the expert opinions. Finally, using equation 3-15, the weight of SAs was calculated. The final weights of SAs are presented in Table 4-10.

Table 4-10 – The final weight of SAs.

SA indicator	(l,m,u)	***Defuzzified Value***	***Normal weight***
SA1	$(-4.1,4.31,38.3)$	*10.71*	*0.170*
SA2	$(-1.202,11.91,49.67)$	*18.07*	*0.287*
SA3	$(-2.15,11.01,47.17)$	*16.76*	*0.266*
SA4	$(-1.49,10.38,45.6)$	*16.217*	*0.257*
SA5	$(-0.471,13.93,51.52)$	*19.73*	*0.313*
SA6	$(-0.573,12.38,49.65)$	*18.46*	*0.293*
SA7	$(0.081,14.22,50.77)$	*19.82*	*0.315*
SA8	$(-2.36,9.25,44.67)$	*15.20*	*0.241*
SA9	$(-2.27,7.86,45.17)$	*14.66*	*0.233*
SA10	$(-1.17,11.58,48.89)$	*17.72*	*0.281*
SA11	$(-0.941,10.77,48.58)$	*17.29*	*0.275*
SA12	$(-0.299,12.86,48.89)$	*18.58*	*0.295*
SA13	$(-1.17,12.22,48.63)$	*17.97*	*0.285*

Table 4-10 – Continued on the next page

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SA indicator	(l, m, u)	***Defuzzified Value***	***Normal weight***
SA14	(−3.89,4.24,37.46)	*10.51*	*0.167*
SA15	(−1.3,11.61,49.18)	*17.78*	*0.282*
SA16	(−1.41,10.71,46.67)	*16.67*	*0.265*
SA17	(−2.70,7.79,43.93)	*14.204*	*0.225*
SA18	(1.48,16.47,56.32)	*22.68*	*0.360*
SA19	(−4.88,2.56,36.42)	*9.17*	*0.145*
SA20	(−2.09,9.81,46.33)	*15.97*	*0.253*
SA21	(−1.55,11.03,47.23)	*16.94*	*0.269*
SA22	(−0.675,12.74,50.05)	*18.71*	*0.297*
SA23	(−0.026,14.13,52.77)	*20.25*	*0.321*
SA24	(−0.617,12.92,50.35)	*18.89*	*0.299*
SA25	(−3.44,7.04,44.46)	*13.77*	*0.219*
SA26	(−1.4,12.52,48.21)	*17.96*	*0.285*
SA27	(−1.3,10.38,46.4)	*16.46*	*0.261*
SA28	(0.063,14.61,54.3)	*20.89*	*0.332*
SA29	(1.55,17.05,57.92)	*23.39*	*0.371*
SA30	(−3.45,6.96,41.02)	*12.87*	*0.204*
SA31	(−0.795,11.62,47.76)	*17.55*	*0.279*
SA32	(−1.68,10.38,47.43)	*16.87*	*0.268*
SA33	(−0.71,12.38,47.15)	*17.80*	*0.283*
SA34	(−1.08,12.11,50.33)	*18.37*	*0.292*
SA35	(−2.02,10.53,48.46)	*16.88*	*0.268*
SA36	(−1.29,12.51,50.69)	*18.60*	*0.295*
SA37	(−0.436,12.98,51.7)	*19.31*	*0.306*
SA38	(−3.82,5.53,41.49)	*12.18*	*0.193*
SA39	(0.011,13.55,48.69)	*18.95*	*0.301*
SA40	(−1.13,11.72,50.39)	*18.17*	*0.288*
SA41	(−2.86,8.59,45.91)	*15.06*	*0.239*
SA42	(1.25,16.81,58.57)	*23.36*	*0.371*
SA43	(−1.04,12.23,50.28)	*18.42*	*0.292*
SA44	(−0.981,13.04,51.28)	*19.09*	*0.303*
SA45	(1.10,15.91,55.48)	*22.09*	*0.351*
SA46	(0.373,14.51,53.12)	*20.63*	*0.327*
SA47	(−3.22,7.17,42.06)	*13.29*	*0.211*
SA48	(−2.43,8.58,43.85)	*14.64*	*0.232*
SA49	(−0.866,12.89,50.38)	*18.82*	*0.299*
SA50	(−1.02,13.13,49.74)	*18.74*	*0.298*
SA51	(−2.47,10.64,47.81)	*16.65*	*0.264*
SA52	(−0.652,12.41,51.17)	*18.83*	*0.299*
SA53	(−2.4,8.58,47.73)	*15.62*	*0.248*

Table 4-10 – Continued on the next page

Table 4-10 – Continued from the previous page

SA indicator	(l,m,u)	Defuzzified Value	Normal weight
SA54	$(-0.839,11.92,48.51)$	17.88	0.284
SA55	$(-1.03,12.39,51.91)$	18.91	0.300
SA56	$(0.601,15.37,52.74)$	21.02	0.334
SA57	$(0.262,16,56.64)$	22.22	0.358
SA58	$(-3.08,8.51,44.58)$	14.63	0.232
SA59	$(-1.33,10.38,48.01)$	16.86	0.268
SA60	$(-1.4,11.69,48.69)$	17.67	0.280
SA61	$(-4.36,4.52,39.37)$	11.01	0.175
SA62	$(-2.74,7.65,41.33)$	13.47	0.214
SA63	$(-0.77,11.7,47.79)$	17.60	0.279

Note: the defuzzification value of a fuzzy number like (l,m,u) based on the defuzzification method of Jiménez (1996) is equal to $\frac{l+2m+u}{4}$.

4.6 Results of the COPRAS Method

In the previous step, the weight of the technical requirements, which in this study are the SAs, were determined. The COPRAS method was applied to rank the suppliers and to evaluate them based on technical requirements. Table 4-11 shows the list of suppliers for the DMCS product and the supplier indicators.

Table 4-11 – List of suppliers.

Potential Suppliers' indicators	Potential Suppliers' Name
S1	X (SHARP)
S2	Y (MDTI)
S3	Z (LGD)
S4	W (JDI)
S5	U (AUO)
S6	V (INX (CarUx))

To implement the COPRAS as an MCDM tool, a matrix with dimensions of 6*63 was developed (63 SAs and 6 suppliers) for ten experts. The experts were asked to give each supplier a score of 1 to 7 according to each SA. After data collection, actions were taken according to the steps of the COPRAS, and the importance and rank of the suppliers were determined and ascertained.

According to the steps of the COPRAS method, after development of the COPRAS matrix and normalizing the matrix, it is time to balance the normalized decision matrix. For this purpose, the weight of each criterion is multiplied by all the elements under the same sub-criterion. In the next step, positive and negative criteria should be specified. In this study, the criteria or technical requirements are all positive, which means their increase will improve the conditions. In the last step, the final ranking of the alternatives (options) is computed, then the best option is determined. Table 4-12 presents the importance rate of the suppliers and the final rank of the suppliers.

Table 4-12 – Determining the importance rate and ranking of suppliers.

Potential Suppliers' indicators	***Potential Suppliers' Name***	q_j	N_j	***Rank***
S1	*X(SHARP)*	*2.822*	*93.724*	*4*
S2	*Y(MDTI)*	*2.975*	*98.808*	*2*
S3	*Z(LGD)*	*2.729*	*90.618*	*5*
S4	*W(JDI)*	*2.918*	*96.919*	*3*
S5	*U(AUO)*	*2.427*	*80.592*	*6*
S6	*V (INX (CarUx))*	*3.011*	*100*	*1*

As can be seen, the best alternative is supplier number 6, and suppliers numbers 2, 4, 1, 3, and 5 are ranked second to sixth, respectively. The final rank of the DMCS suppliers ordered as relationship (Eq. 4-1):

$$S6 > S2 > S4 > S1 > S3 > S5 \qquad (4\text{-}1)$$

4.7 Discussion On Fuzzy-QFD and COPRAS Method

This thesis presents work in progress on customer expectations and desires from a semi-product (DMCS) that the OEM company received from suppliers. Then, the decisions made using supplier evaluation and selection decisions under the umbrella of the SSCM considering all aspects of "Technical", "Quality", "Cost", and "Delivery" requirements.

The novelty of this study is in the proposal of an integrated model to decide and evaluate the supplier's fulfilment level according to significant CRs. And, at the next step, use these requirements to determine the characteristics of the suppliers that align the efforts of all members of a part supply chain (QFD team) to create common value, setting the foundation for sustainable development. Thus, a review of the conventional sustainable product design process is obtained to use as a starting point of the actual "Voice of the Customer", leading to the ultimate goals of manufacturing quality, the satisfaction of both intermediate and final customers (consumers), and sustainability along the production system design.

Although QFD has various applications in the manufacturing industry, it has not been used previously for evaluating and choosing suppliers for OEMs (in general) or for screening semi-products (in particular). Moreover, it is uncommon to find references in the literature to the inclusion of sustainability factors, such as environmental and social responsibility criteria, in the evaluation and selection of suppliers. Nor has there been much research done on the function of sustainability and sustainable supply chain management in the automotive industry. This thesis presents a fuzzy-QFD methodology framework for the first time, linking production design decisions with supplier rating and selection choices.

This project concerns the implementation of the proposed fuzzy-QFD integrated with MCDM tools as a supply chain management tool to improve the quality and sustainability of services provided by a chosen OEM company, strengthening its competitive position. The Bosch company will apply the proposed methodological framework that is selected according to its attitude toward SSCM.

In this thesis, the evaluation and weighting of suppliers have been discussed using the refined Kano model, fuzzy-QFD and COPRAS method. First, the list of CRs, SAs, and display DMCS suppliers created. Then, the refined Kano approach was used to categorize and weight of the CRs. In the next step, the weight of the SAs and their relative importance are determined applying the fuzzy-QFD method. In the last step, DMCS suppliers have been ranked and evaluated according to the weight and importance of SAs, using the MCDM method (COPRAS approach).

Figure 4-3 displays the bar chart of the distribution of weight among the final CRs observed in this study, exhibiting a range extending from 0.56 to 1.

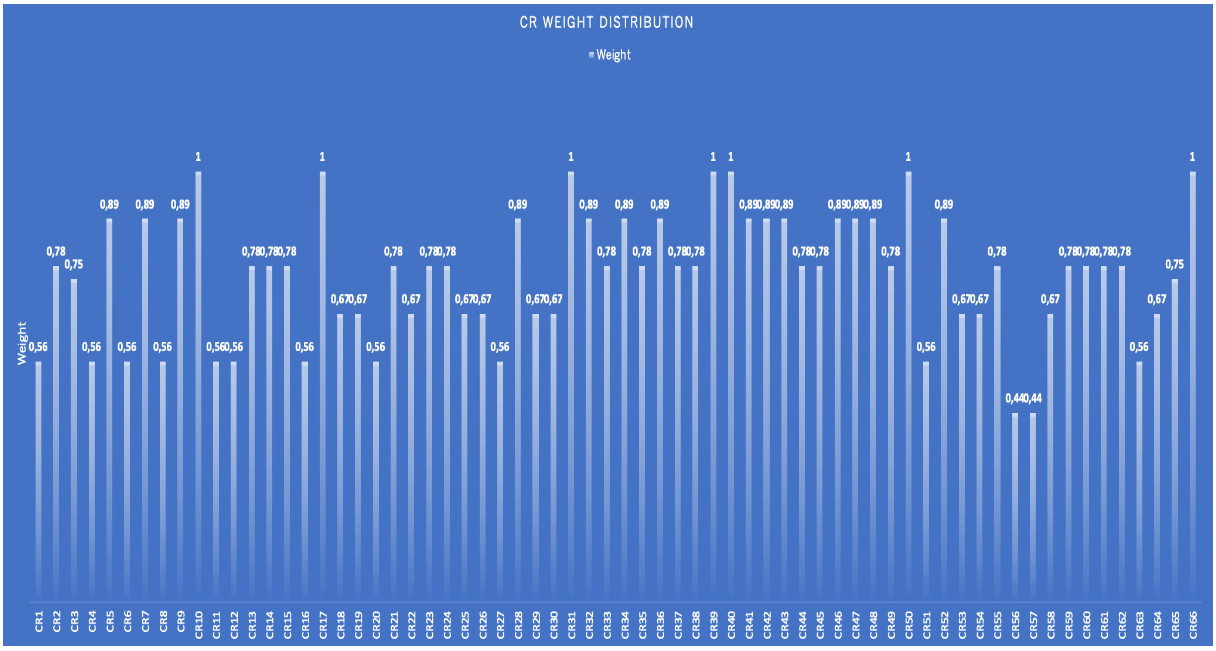

Figure 4-3 – The distribution of weight among the final CRs

The result from the fuzzy-QFD matrix shows that SA29 (Products need to have specific certifications to appear in this category) and SA42 (Risk minimization process for high-risk raw materials) are with the same importance weight (0.371) out of 63 SAs are the highest values. The SA29 is obtained by CR37 (Climate pledge friendly products) and belongs to the category of Sustainability (Pollution production). The SA42 has a relationship with CR32 (Commitment to health and safety of employees), CR33 (Take responsibility for sustainability and create transparency), CR35 (Product environmental performance footprint), CR36 (Potential toxicity to human), and CR45 (Amount of emission of hazardous material (RoHS compliance)) which CR32 and CR33 referring to sustainability (Globalization), CR35 and CR36 belong to sustainability (Pollution production), and CR45 belongs to sustainability (Health and Safety) sub-category, respectively.

Secondly, the SA18 (An intermediate layer cannot be made of the material can release particles like paper or cardboard) is the maximum value (0.360) between all the attributes that are affecting CR66 (Intermediate layers or nesting elements) and also CR17 (Contamination of the display). The SA18 that is nominated as one of the most critical items that affects supplier selection and satisfaction of CRs are Technical (Mechanical) and Delivery requirements.

The third position goes to SA57 (About 36 to 40 deg C) affects CR25 (Reaching temperature for glass negative temperature coefficient (NTC) during the measurement) which belongs to the quality (Measurements conditions) category.

The next high assigned values go to SA45, SA56, SA28, SA46, SA23, SA5, SA7, SA37, SA44 which translated the SAs from customers' expectations including CR38, CR39, CR48, CR21, CR34, CR41, CR43, CR44, CR60, CR64, CR61, CR59, CR63, CR15. These items are extracted from sustainability (Pollution production [1 item], urbanization and eco-design energy [6 items], water), technical (Mechanical [1 item], optical [1 item]), and delivery [5 items].

Figure 4-4 displays the bar chart of the final weights among the SAs after defuzzification observed in this study, exhibiting a range extending from 0.145 to 0.371.

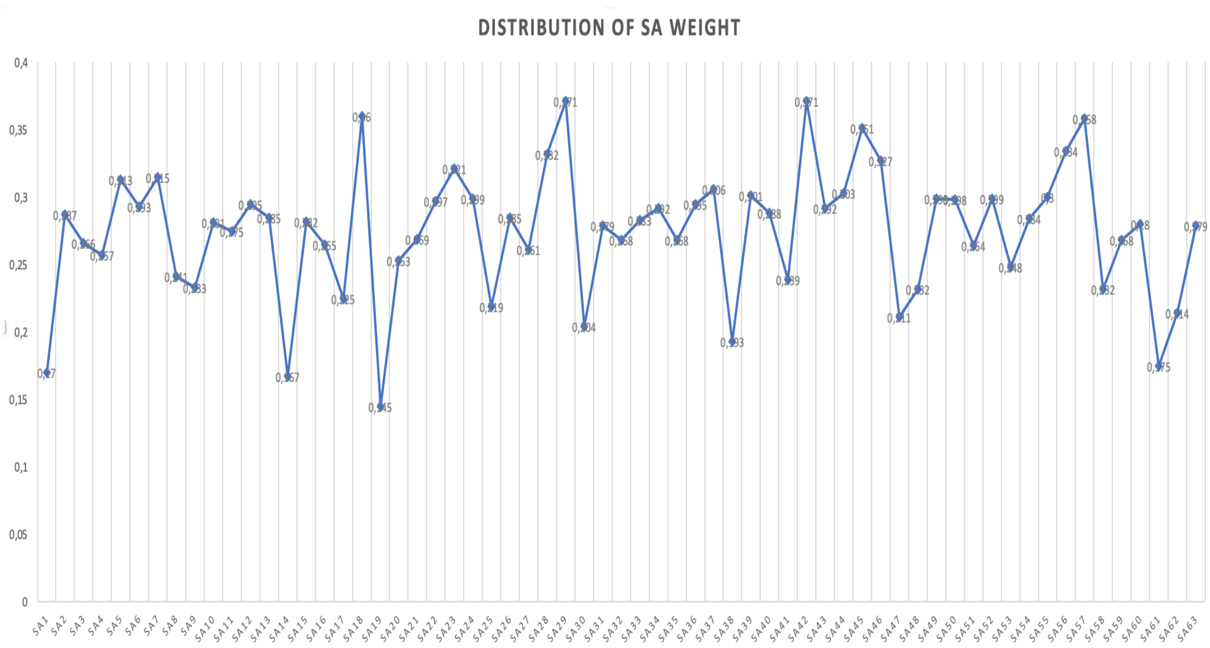

Figure 4-4 –The final weight of SAs

The present findings illustrate that nearly twenty percent of the surveyed SAs possess a weight exceeding 0.3, denoted above, and are categorized into four classes according to the degree of their significance concerning their impact on the supplier selection procedure. A significant number of CRs translated by QFD from SAs (20% of all the SAs with the highest weights) categorized as sustainability (Globalization [2 items], pollution production [5 items], health and safety [1 item], urbanization and eco-design energy [6 items], water [1 item], delivery [6 items]), technical (Mechanical [2 items], optical [1 item]), quality (Measurements conditions [1 item]). The sustainability has a frequency of 15 is the most rated. Then, the delivery (6 items), technical (3 items), and quality (1 item) ranked respectively. Regarding the results obtained from this study, the sustainable requirements are recently valued by final customers, and they transfer these attractive requirements considering today's environmental concerns many customers try to save energy, adding less harmful reactions to the environment and the rights of human force. The

Bosch also heard the VoC from 2021, and by benchmarking and many meetings try to implement the models prepared for sustainable design needs realization, and develop some lessons learned by pioneers. The other important category which must be considered as the priority need is delivery. Due to the type of product and sensitivity of the screens, is very critical how to transport and manage the delivery of DMCS because any kind of pressure or weather condition can affect the mechanical and optical characteristics of the screen. Also, there are various tiers of suppliers for this product and the assembly process itself has many transportation phases that make the delivery a critical process. Then the delivery CRs should consider as one of the important requirements. The technical category is one of the most important requirements which should be improved considering the proposed procedures and experts' opinions. As these requirements are not visible to the final customers, they may be expressed more by experts' opinions, and these requirements which are considered as necessary items must be in the product.

The quality requirements are the fourth item that obtained results which can be discussed in all the tiers of the suppliers. Some of the deviations are related to the manner of the measurement in different tiers of the suppliers.

Although the cost requirements are not considered in the final stage of the research, it does not mean that these requirements are not important. As most of the items in cost requirements are carefree and necessary needs, they were not passed to the last step.

The results of categorizing CRs showed that mechanical and delivery requirements are in the critical category; electrical, optical, definition of standard conditions, measurements conditions, and cost requirements are in the care-free category. Customer rejection rate, pollution production, health and safety, and water needs are categorized in the "High Value-Added". However, the requirements of globalization and urbanization and eco-design energy are in the "Low Value-Added" group. In addition, the fuzzy-QFD method showed two technical requirements, the risk minimization process for high-risk raw materials and products that need specific certifications to appear in this category, which have the highest importance, and their weight is equal to 0.371. On the other hand, according to the results of the COPRAS approach, it was observed that the most important supplier of the display DMCS is supplier number 6, and the least significant supplier is number five.

Overall, this study presents a scientific and engineering framework related to the features that may help manufacturing organizations, especially OEMs to re-evaluate their services and achieve efficient and new technological features in the automotive field.

4.8 Summary of the Chapter

In this section, the author analysed the data obtained from the case study and presented and discussed the main findings from the calculations and the survey according to research objectives and scheme of the proposed model:

- First, the data gathering concluded from the survey presented, and the main categories and CRs identified.
- Second, the Kano results were classified in detail, and expert opinions distribution was presented.
- Third, the refined Kano was adopted according to the basic Kano model and the TSI index, weight, and refined Kano group for each CR and the main categories calculated.
- Fourth, the SWARA method was implemented to calculate the importance value of the CRs.
- Fifth, the fuzzy-QFD approach developed on the output of the refined Kano model, and SAs rated and classified according to the CRs.
- Finally, the COPRAS method was applied to SAs related to the six different suppliers for DMCS product and the suppliers ranked respectively.

In the current thesis, a conceptual model was developed followed by the Kano model and fuzzy-QFD technique with MCDM tools to validate the data from DMCS and evaluate CRs and SAs. The results identified significant CRs and their importance value, and the related SAs concluded which are weighted by integrated model, finally, the suppliers are ranked by customer preferences.

CHAPTER 5

CONCLUSIONS AND DIRECTIONS FOR FUTURE AGENDA

The early chapters of this thesis outlined various research goals and questions that served as a guide for the research phases up until the results were presented, analysed, discussed, and dissected in the context of the relevant research fields in the computational results section. These results are compared to the research goals in this chapter and then used to address each research question. The overall conclusions of this work are then described with the contributions to the field highlighted. Finally, the study's limitations, future research agenda, and practical suggestions for future investigations are discussed.

5.1 Conclusion and Summary of Research Results

Generally, this study provides a scientific and engineered framework for features that may help manufacturing companies re-evaluate their services and reach efficient and new technological features in the automotive area.

In this dissertation, according to the broad search of articles in recent years, many studies have been followed in filling the research gap in the application of integrated quality management tools and decision-making model in various fields. To this end, a refined Kano model was applied to classify the CRs adapted to categorize latent and obvious VoCs as input of another quality tool (QFD). Due to the identified strengths and weaknesses of the QFD method, many articles, particularly in the last few years (since 2017) have adopted hybrid models to improve the traditional QFD model. The application of MCDM in the QFD model has improved the traditional methods used in the QFD and increased the precision and accuracy of the evaluation and ranking of the CRs. Afterward, implementing the integrated model and identifying DRs (output of the model) provided ameans to develop the DRs for manufacturing a product or service. The proposed hybrid model integrates the QFD with the fuzzy theory in which the inputs are CRs in a fuzzy manner (since the variables are fuzzy-verbal), customers' qualitative judgments, and experts have increased the flexibility and accuracy of the data.The management of imprecise data and the ingrained inference of human thought are two notable constraints of the fuzzy theory. If the system's information is inaccurate, a person cannot infer knowledge or a relationship. The application of fuzzy theory has been fulfilled by complex calculations due to the combination of fuzzy numbers with the decision method which requires fuzzification and defuzzification.

User-friendliness, sustainability, green manufacturing, and environmental concerns are some of the major current customers' needs currently compared to previous years. These topics have received a lot of attention in recent years. On one hand, these new specifications restricted producers while increasing customer pleasure. On the other hand, businesses and factories have run across issues (such as the complexity of the manufacturing process and the incompatibility in the interdependence of DRs), which have forced them to utilize various machinery and raised the final price of the products or services in the end. Thus, this dissertation has considered a new type of CRs as sustainable requirements that are basically important for the final customer, specifically in the investigated case study (DMCS) affect customer satisfaction which combined with another four categories and their importance has been rated and classed. There are standard sustainable requirements obtained from different studies that often seek to reduce fuel consumption, pollution, and increase productivity, and use new energy sources, such as the use of photovoltaic in automotive process design.

The refined Kano model has been used in research and is suitable as a tool to classify customer needs and has been combined with appropriate fuzzy and decision tools to achieve the desired results, which is also very useful in NPD project. The Kano model is used to show a better understanding of the most significant DMCS features from the customers' point of view. The Kano model divides customers' needs into five main categories: Must-be, Attractive, One-dimensional, Indifferent, or Reverse attribute for a product. Then, the CRs are entered into the HoQ matrix and made the required classifications on the left wall of the HoQ. Adopting this tool can also help the manufacturer to avoid wasting extra time and money to meet customer needs.

This study proposes mainly two steps: first, the identification and categorization of the CRs with a refined Kano model, and the second step is identification of SAs and their relationship with the FQFD technique and ranking of the potential suppliers with the COPRAS method. The specific product in the automotive industry was collected to address the proposed approach called a screen (DMCS) provided by a supplier to the OEM (Bosch). The objective of the OEM is to perform a series of processes by the assembly to produce the final product. Specifically, the focus of the study was the improvement of the quality rate in one of the displaying characteristics called BU. Then, the CRs identified and ranked based on the influence of the items directly and latently on the BU. Sustainable requirements increased as the global concerns raised in recent years. Most of the customers and, thereinafter, industries pay considerable attention to these requirements, which can change the future position of the companies in the market and cause a competitive advantage for the enterprises. Everyone is aware of the importance of social, humanitarian, and environmental goals. All worldwide industries for example, the automotive industry must maintain sustainable customers and attract new customers to create sustainable development. A company can create value when the management method includes various characteristics to integrate the economic, environmental, and social dimensions. Sustainability is the performance of the enterprise in all aspects of the company's sustainability drivers that go beyond the traditional organizational boundaries and the upstream performance of the value chain (suppliers) to the downstream (customers).

According to the results of the COPRAS approach, it was observed that the most important suppliers of the display DMCS are: $S6 > S2 > S4 > S1 > S3 > S5$.

Overall, this study presented a scientific and engineering framework related to the features that may help manufacturing organizations, especially OEMs to re-evaluate their services and achieve efficient and new technological features in the automotive field.

One of the benefits of the applied model was to consider the weight of the CRs in each category independently which means a CR in the technical category will not be classed with a CR in sustainable requirements.

5.2 Research Limitation

Regarding the limitation, as the current study encompassed validation of the empirical data, comparative analysis, and the frequency of the hybrid QFD-MCDM studies needed, future study needs to compare the results obtained from various hybrid models in detail to introduce more efficient models in terms of accuracy and precision of the results. Furthermore, different alternatives in various developed QFD models need to be addressed. However, as this dissertation does not address these limitations.The author intends contribute more in the future by presenting the novel QFD evolution results rather than traditional methods.

Although this study considered and ranked 112 CRs in different aspects, it is possible that not all relevant CRs were identified and included in the study. Also, the research compiled the ideas of various types of experts (with different skill sets) who are not professionals in other fields, making the studies separate. The third limitation is related to the content of the questionnaire, which could be more generic to the final customer rather than the experts. The final customer sometimes does not feel the invisible criteria sometimes that are significant to the experts.

In the current study, due to the restricted investigation time, a certain plan was apportioned for information collection. Moreover, to dispose few ambiguities, it was essential to inquire a few questions orally which caused collecting data troublesome and time-consuming.

Here, one of the shortcomings in collecting information was the non-participation of some experts in answering the survey. In addition, the complex organizational structure caused a broad search to find the target person to answer. Hence, due to the specific structure of the questionnaire, occasionally some people had misunderstandings and mistakes, which slowed down the project. In several items, there were limitations to recognize the target customers, and considering that the product produced in OEM has different levels of customers, this would increase the time of data collection. Some of the questions are qualitative, then caused some confusion among the respondents and required a clear explanation.

In this study, the refined Kano model integrated with QFD and two novel MCDM tools are implemented in the automotive industry which considered not only significant CRs but also included the wide range of customer needs as sustainability requirements, making the study innovative in terms of green supplier selection criteria. Integration of COPRAS with the Kano model and the QFD turned the model into an efficient model which can consider big data and at the same time convenient calculations, unlike the previous tools. Implementing two different methods to weigh and classify the CRs can help the automotive industries to understand better the priorities of the customers. As the case study is an OEM company, numerous CRs can extract from the different tiers of the suppliers. Among other innovations of this research, it is possible to mention the presentation of combined approaches of the Kano and MCDM along with fuzzy theory which helps the accuracy of measurements.

5.3 Future Research Agenda

The current study gives a scientific and designing system for highlights that aid fabricating organizations to re-evaluate their services and accomplish effective highlights within the automotive field. For future research, it is recommended to use other MCDM tools and compare their results with applied tools for big data. On the other hand, the combination of MCDM methods and the refined Kano model can help to improve the results, due to the managerial and mathematical aspects of the methods. For instance, in the service area due to uncertainty, it is possible to integrate the model with fuzzy theory as it has adopted in this study in the QFD stage. In addition, this method can be applied as a programming framework to use in other areas, including the various products, healthcare systems, education, and financial systems to identify significant criteria and classify and weigh these criteria to generalize and apply them as an organized method in different countries. Meanwhile, environmental concerns have become one of the main concerns in many countries today, so there is a need to highlight these requirements and consider a broad number of CRs in this category.

To implement hybrid models, it is necessary to consider the needs of customers and manufacturers properly. For example, in the health care case, if the target customers are defined as patients, the DRs should be determined differently from the physician and nurse's DRs as the final customers because their needs differ with the patients. Sometimes, however, the experts and physicians can be considered as representative of the patient needs because they have enough knowledge about the tools and treatment process (Neira-Rodado et al., 2020).

In many studies, there is no mention of studying the competitors' evaluation section. The integration of this section in the HoQ matrix can be significant and have a difference in the ranking of CRs. The competitor evaluation department can also act as a benchmarking tool in creating business process competition patterns and the best performance from other similar companies, which requires comparing a similar product or service with the desired product and service. The competitive conditions in the market make it necessary to consider some factors such as supplier selection, raw materials, and transportation preferable to overall customers' preferences, which should provide a model to consider having competitive advantages and faster customer satisfaction. In this case, the Kano model can also integrate into the hybrid model to classify and highlight the customer needs that are more basic and show the cause of customer dissatisfaction.

TRIZ can be used as a problem-solving tool to better introduce DRs (Chen et al., 2010). It can aid to engineers in product design, by improving the process to identify technical characteristics in the HoQ matrix. Studies have scarcely shown how to use questionnaires and techniques used to assess customer needs. It is recommended to determine the validity and reliability of the questionnaire and sample size determination tools because they have a great impact on the data collection results. Also, establishing a control verification matrix can be effective in prioritizing methods and process control parameters and can provide good support to the prioritized elements of the QFD process design stage by controlling the critical factors in the final stage. After determining the critical processes and operations in the matrix rows, the requirements for controlling them to prevent errors and failures in the matrix columns of the process control planning is determined.

Due to the correlation matrix (ECs correlation matrix) in the roof of the HoQ, many studies have not paid special attention to this sector, which may not cause attention to the impact of ECs interactions, causing inconsistencies in customer needs and conflict in the performance of some processes in the HoQ which affect the desirability of the ECs to satisfy the CRs, negatively. Therefore, adopting the MCDM tools such as DEMATEL can improve the calculation in the roof of the HoQ and obtain the weights of interrelationships of roof elements. Particularly, the DEMATEL accurately identifies the effect of the ECs on each other in the roof, and it helps to eliminate the contradictory effect on ECs.

According to the statistics of the related literature, the use of the hybrid QFD-MCDM methods including QFD, MCDM, and other applied tools is much more than individual QFD-MCDM. It shows the efficiency of hybrid QFD-MCDM in achieving the desired results which are mostly used in manufacturing products and industries, supplier selection, and services, respectively. According to recent studies (after 2018), there are hybrid methods for integrated product and process development, and integrated decision-support mechanisms for all product-related processes which improve the flexibility of the manufacturing system.

Due to not only changing customer demands over time, but also the advancement of technology, customers who are initially attracted to the new service characteristics take them for granted over time in most cases which caused some customer demands during the design process and even caused final product changes. Therefore, it is recommended using a dynamic QFD or other quality tools such as Kano Dynamic (an online platform to meet the updated needs of customers to update the CRs) or manufacturing the goods without considering customers' need (which leads to customer dissatisfaction and has an extra cost for the company). It is also possible to predict changes in customer demand or use the time series to update CRs.

Feature selection methods can efficiently reduce the number of functional requirements (FRs) and decrease the complexity of a new product/service design by reducing the number of FRs at the customer requirement definition phase. In this regard, unsupervised machine learning techniques in selection of functional requirements during customer requirement definition phase of QFD technique can be an attractive future research topic.

An optimal new product design needs high-dimensional information analysis at the early stage of the QFD technique. In this regard, neural network (NN) is a powerful tool for data analysis for product development purposes. Combining NNs with QFD technique for assessing the design alternatives during design phase is suggested as an important direction for future research.

5.4 Practical Suggestions for Future Agenda

Meanwhile, to improve the rank and prioritize CRs and determine the most significant SAs for obtaining the rank of the suppliers for the DMCS display at Bosch Multimedia, the following changes are recommended:

One of the main drawbacks of fuzzy logic is completely dependent on human intelligence and expertise. The efficiency of the system is another shortcoming that is not high because they majorly work on inaccurate inputs. If the data is imprecise in the system, a human being cannot infer the knowledge or relation. The application of fuzzy theory requires complex calculations because the combination of fuzzy theory is used with the decision method, which requires fuzzification and defuzzification. Therefore, creating appropriate software to facilitate the process can be effective in conducting case studies with extensive information. Depending on the type of CRs, the type of fuzzy numbers that may be used differs, but it can make the calculation difficult. For this reason, some research may remain theoretical, or the case study may not be fully implemented.

The study should point out that the numbers used in the project matrices are estimated from the QFD team observation results and investigations. However, all efforts made to be approximate the calculations with the actual values of the parameters. To implement this project in Bosch, it is necessary to review the numbers of the matrices by applying the opinions of technical experts (Simultaneous engineers, process specialists, mechanical developers, hardware engineers, product line responsible, manufacturing production responsible, optics and mechanics), quality experts (Quality managers, testing specialists, production test engineer, supplier quality engineer, PFMEA moderator, display developer, supplier quality engineer, purchasing quality assurance, customer claim analysis), cost experts (project managers, program manager, process managers, project manager purchasing), delivery experts (logistic engineers), and sustainability experts (various proficient experts, and sustainability experts). In any case, considering the existing problems, there is a long way to implement this project. It is hoped that this project will be the beginning of improving the supplier selection process of the products considering all the requirements.

The results of categorizing CRs showed that mechanical and delivery requirements are in the critical category; electrical, optical, definition of standard conditions, measurements conditions, and cost requirements are in the care-free category. Customer rejection rate, pollution production, health and safety, and water, needs are categorized in the "High Value-Added". On the other hand, the requirements of globalization and urbanization and eco-design energy are in the "Low Value-Added" group. For instance, the experience of PRE structure from the Braga plant, the mechanical team which provides the mechanical ECs to improve the mechanical CRs, can be extended to a wide scale of requirements to the other categories. This study proposes that small groups under the supervision of the QFD team make process rules in each category and then refer them to a higher level of the departments from those categories to generalize the rules to different products to help the decision-maker to implement the model on different types of products in the company.

The highest values of SAs which show the importance of the necessary attributes refer to "Technical", "Sustainability", "Delivery", "Quality", and "Cost" respectively. In this regard, the company should value to fulfil these items by considering the priority for the supplier selection process. Afterward, for "Technical" requirements, it is proposed to the engineering team, including operators, line responsible personnel, simultaneous engineers, and development engineers that they incorporate all the necessary ECs into a dynamic platform to refer the CRs to discuss. For example, the DMCS has already PRE instruction but is not dynamic which it is excluded from most of the issues already discussed in the BU subject. Then for each main category, a similar structure with related experts can be established. Finally, a working group of experts from each category joins the QFD team who is familiar with the product, then the team does the brainstorming and tries to rank the SAs and considers the strengths and weaknesses of each EC. If there are some contradictions between them, the experts decide and rate the elements coherently.

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BIOGRAPHY

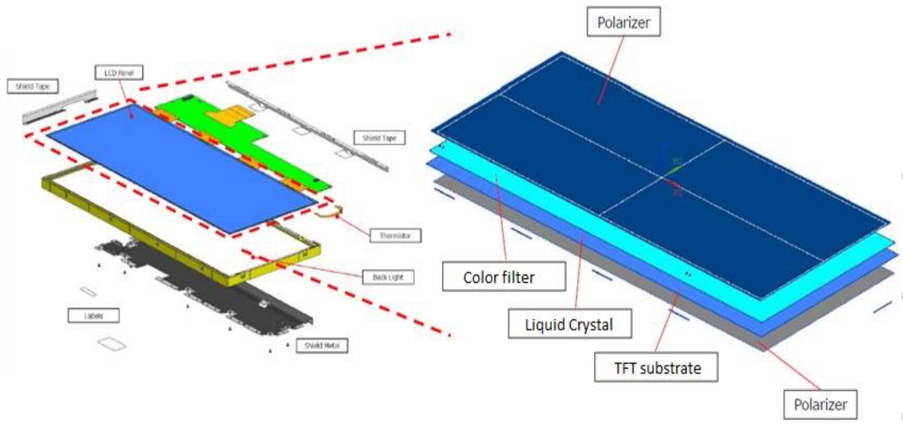
Ahmad Hariri was born in Bojnord, Iran in 1988. He received his bachelor's degree with honors in Industrial and Systems Engineering from Sadjad University of Mashhad in 2012. He continued his studies with a master's in industrial engineering – System Management Planning and Analysis from Islamic Azad University, Tehran, Iran, in 2017 with the highest honors. He started his Ph.D. in 2018 at the Department of Production and Systems (DPS) at the University of Minho in the Program in Advanced Engineering Systems for Industry (AESI). He started the partnership project between the University of Minho and Bosch in 2018. He joined to simultaneous engineering team (MFE 23) at the Bosch Multimedia Braga in 2020 as a quality management investigator with a focus on quality managmet and decision-making tools on supplier selection. His current focus is on developing the QFD approach integrated with the Kano model and using decision-making tools under an uncertain environment to optimize supplier selection problems.

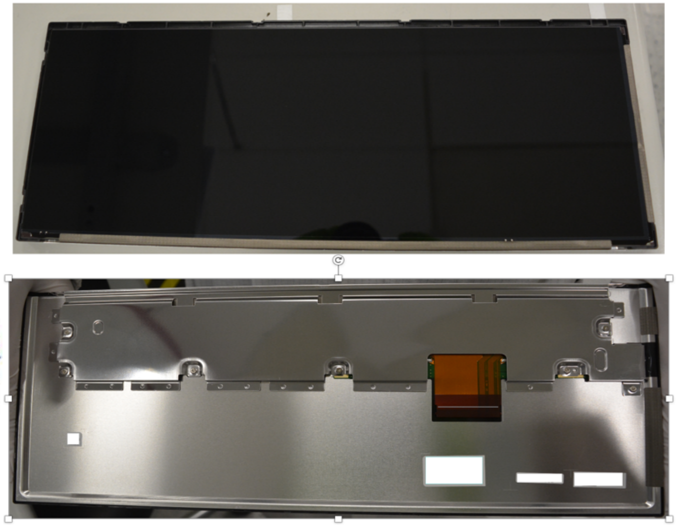
APPENDIX 1 – QUESTIONNAIRE

Welcome

Thank you for filling out this survey, we appreciate your response. Below is the list of requirements and their influence on the Black Uniformity. There are two questions regarding each requirement. Each question is divided into two to consider the two-aspect existence and non-existence of the feature in the product. Please read the description of each feature in the questions and then imagine how you'd feel if you had that feature available to the product "Daimler MCS Raw LCD (AA150AA01)" or if you did NOT have it available in the product.

This survey is about: The Black Uniformity of the raw display of Daimler MCS which BOSCH receives from the supplier and The picture below depicted the product:





Please take your time and be honest in your answers.

Thanks!!

		Technical		
		Mechanical		
Functional			Dysfunctional	
		Question 1		
How would you feel if Double side foam which connects the LCD to backlight frame was included in the product?	1. Like it ☐		How would you feel if Double side foam which connects the LCD to backlight frame was not included in the product?	1. Like it ☐
	2. Expect it ☐			2. Expect it ☐
	3. Indifferent ☐			3. Indifferent ☐
	4. Tolerate it ☐			4. Tolerate it ☐
	5. Unhappy ☐			5. Unhappy ☐
		Question 2		
How would you feel if the product had enough DAM space in part design?	1. Like it ☐		How would you feel if the product did not have enough DAM space in part design?	1. Like it ☐
	2. Expect it ☐			2. Expect it ☐
	3. Indifferent ☐			3. Indifferent ☐
	4. Tolerate it ☐			4. Tolerate it ☐
	5. Unhappy ☐			5. Unhappy ☐
		Question 3		
How would you feel if a rigid backlight Unit Housing was included in the product?	1. Like it ☐		How would you feel if a rigid backlight Unit Housing feature was not included in the product?	1. Like it ☐
	2. Expect it ☐			2. Expect it ☐
	3. Indifferent ☐			3. Indifferent ☐
	4. Tolerate it ☐			4. Tolerate it ☐
	5. Unhappy ☐			5. Unhappy ☐
		Question 4		
	1. Like it ☐			1. Like it ☐

How would you feel if optical alignment features were defined in the product?	2. Expect it ☐	How would you feel if optical alignment features were not defined in the product?	2. Expect it ☐
	3. Indifferent ☐		3. Indifferent ☐
	4. Tolerate it ☐		4. Tolerate it ☐
	5. Unhappy ☐		5. Unhappy ☐

Question 5

How would you feel if de-coupling of backlight unit and panel was considered in our product?	1. Like it ☐	How would you feel if de-coupling of backlight unit and panel was not considered in our product?	1. Like it ☐
	2. Expect it ☐		2. Expect it ☐
	3. Indifferent ☐		3. Indifferent ☐
	4. Tolerate it ☐		4. Tolerate it ☐
	5. Unhappy ☐		5. Unhappy ☐

Question 6

How would you feel if the sealant double side tape design was considered in the product?	1. Like it ☐	How would you feel if sealant double side tape design was not considered in the product?	1. Like it ☐
	2. Expect it ☐		2. Expect it ☐
	3. Indifferent ☐		3. Indifferent ☐
	4. Tolerate it ☐		4. Tolerate it ☐
	5. Unhappy ☐		5. Unhappy ☐

Question 7

How would you feel if foam tape was not leaked in the corners?	1. Like it ☐	How would you feel if foam tape was leaked in the corners?	1. Like it ☐
	2. Expect it ☐		2. Expect it ☐
	3. Indifferent ☐		3. Indifferent ☐
	4. Tolerate it ☐		4. Tolerate it ☐
	5. Unhappy ☐		5. Unhappy ☐

Question 8

	1. Like it ☐		1. Like it ☐

How would you feel if the dimension of the backlight frame was in spec?	2. Expect it ☐	How would you feel if the dimension of the backlight frame was out of spec?	2. Expect it ☐
	3. Indifferent ☐		3. Indifferent ☐
	4. Tolerate it ☐		4. Tolerate it ☐
	5. Unhappy ☐		5. Unhappy ☐
Question 9			
How would you feel if there was a GAP between Rear Glass and Black Housing?	1. Like it ☐	How would you feel if there was not a GAP between Rear Glass and Black Housing?	1. Like it ☐
	2. Expect it ☐		2. Expect it ☐
	3. Indifferent ☐		3. Indifferent ☐
	4. Tolerate it ☐		4. Tolerate it ☐
	5. Unhappy ☐		5. Unhappy ☐
Question 10			
How would you feel if air bubbles were not formed on LCD panel?	1. Like it ☐	How would you feel if air bubbles were formed on LCD panel?	1. Like it ☐
	2. Expect it ☐		2. Expect it ☐
	3. Indifferent ☐		3. Indifferent ☐
	4. Tolerate it ☐		4. Tolerate it ☐
	5. Unhappy ☐		5. Unhappy ☐
Question 11			
How would you feel if alignment features on back housing of LCD to align center frame was considered?	1. Like it ☐	How would you feel if alignment features on back housing of LCD to align center frame was not considered?	1. Like it ☐
	2. Expect it ☐		2. Expect it ☐
	3. Indifferent ☐		3. Indifferent ☐
	4. Tolerate it ☐		4. Tolerate it ☐
	5. Unhappy ☐		5. Unhappy ☐
Question 12			
	1. Like it ☐		1. Like it ☐

How would you feel if there was not a height difference between the display frame and bonding surface?	2. Expect it ☐	How would you feel if there was a height difference between the display frame and bonding surface?	2. Expect it ☐
	3. Indifferent ☐		3. Indifferent ☐
	4. Tolerate it ☐		4. Tolerate it ☐
	5. Unhappy ☐		5. Unhappy ☐
Question 13			
How would you feel if parallelism of display polarizer to support elements on the KIT was considered?	1. Like it ☐	How would you feel if parallelism of display polarizer to support elements on the KIT was not considered?	1. Like it ☐
	2. Expect it ☐		2. Expect it ☐
	3. Indifferent ☐		3. Indifferent ☐
	4. Tolerate it ☐		4. Tolerate it ☐
	5. Unhappy ☐		5. Unhappy ☐
Question 14			
How would you feel if more gap between the Backlight frame and LCD was included in the product?	1. Like it ☐	How would you feel if the less gap between the Backlight frame and LCD was included in the product?	1. Like it ☐
	2. Expect it ☐		2. Expect it ☐
	3. Indifferent ☐		3. Indifferent ☐
	4. Tolerate it ☐		4. Tolerate it ☐
	5. Unhappy ☐		5. Unhappy ☐
Question 15			
How would you feel if the light was not leaked due to the mechanical layout on the frame and backlight?	1. Like it ☐	How would you feel if the light was leaked due to the mechanical layout on the frame and backlight?	1. Like it ☐
	2. Expect it ☐		2. Expect it ☐
	3. Indifferent ☐		3. Indifferent ☐
	4. Tolerate it ☐		4. Tolerate it ☐
	5. Unhappy ☐		5. Unhappy ☐
Question 16			
	1. Like it ☐		1. Like it ☐

How would you feel if the thickness of the Inner glass was thinner?	2. Expect it ☐	How would you feel if the thickness of the Inner glass was thicker?	2. Expect it ☐
	3. Indifferent ☐		3. Indifferent ☐
	4. Tolerate it ☐		4. Tolerate it ☐
	5. Unhappy ☐		5. Unhappy ☐
Question 17			
How would you feel if a thinner polarizer was considered in the product?	1. Like it ☐	How would you feel if a thicker polarizer was considered in the product?	1. Like it ☐
	2. Expect it ☐		2. Expect it ☐
	3. Indifferent ☐		3. Indifferent ☐
	4. Tolerate it ☐		4. Tolerate it ☐
	5. Unhappy ☐		5. Unhappy ☐
Question 18			
How would you feel if a proper type of polarizer was used in the product?	1. Like it ☐	How would you feel if a non- proper type of polarizer was used in the product?	1. Like it ☐
	2. Expect it ☐		2. Expect it ☐
	3. Indifferent ☐		3. Indifferent ☐
	4. Tolerate it ☐		4. Tolerate it ☐
	5. Unhappy ☐		5. Unhappy ☐
Question 19			
How would you feel if the backlight reflection sheet shape was considered?	1. Like it ☐	How would you feel if the backlight reflection sheet shape was not considered?	1. Like it ☐
	2. Expect it ☐		2. Expect it ☐
	3. Indifferent ☐		3. Indifferent ☐
	4. Tolerate it ☐		4. Tolerate it ☐
	5. Unhappy ☐		5. Unhappy ☐
Question 20			
	1. Like it ☐		1. Like it ☐

How would you feel if the Shield film shape was changed and added some slits?	2. Expect it ☐	How would you feel if the Shield film shape was not changed and there were no slits?	2. Expect it ☐
	3. Indifferent ☐		3. Indifferent ☐
	4. Tolerate it ☐		4. Tolerate it ☐
	5. Unhappy ☐		5. Unhappy ☐
Question 21			
How would you feel if the Flatness of Backlight Housing was satisfied?	1. Like it ☐	How would you feel if the Flatness of Backlight Housing was not satisfied?	1. Like it ☐
	2. Expect it ☐		2. Expect it ☐
	3. Indifferent ☐		3. Indifferent ☐
	4. Tolerate it ☐		4. Tolerate it ☐
	5. Unhappy ☐		5. Unhappy ☐
Question 22			
How would you feel if the contamination of the display was according to a satisfactory level?	1. Like it ☐	How would you feel if the contamination of the display was under a satisfactory level?	1. Like it ☐
	2. Expect it ☐		2. Expect it ☐
	3. Indifferent ☐		3. Indifferent ☐
	4. Tolerate it ☐		4. Tolerate it ☐
	5. Unhappy ☐		5. Unhappy ☐
Question 23			
How would you feel if the thickness of TFT-/color filter glass was optimum?	1. Like it ☐	How would you feel if the thickness of TFT- /color filter glass was not optimum?	1. Like it ☐
	2. Expect it ☐		2. Expect it ☐
	3. Indifferent ☐		3. Indifferent ☐
	4. Tolerate it ☐		4. Tolerate it ☐
	5. Unhappy ☐		5. Unhappy ☐
Technical			

Electrical			
Functional		Dysfunctional	
Question 24			
How would you feel if foil banding material on the sides of the display were placed properly?	1. Like it ☐ 2. Expect it ☐ 3. Indifferent ☐ 4. Tolerate it ☐ 5. Unhappy ☐	How would you feel if foil banding material on the sides of the display were placed not properly?	1. Like it ☐ 2. Expect it ☐ 3. Indifferent ☐ 4. Tolerate it ☐ 5. Unhappy ☐
Question 25			
How would you feel if the Foil banding width was shorter?	1. Like it ☐ 2. Expect it ☐ 3. Indifferent ☐ 4. Tolerate it ☐ 5. Unhappy ☐	How would you feel if the Foil banding width was longer?	1. Like it ☐ 2. Expect it ☐ 3. Indifferent ☐ 4. Tolerate it ☐ 5. Unhappy ☐
Question 26			
How would you feel if the position of the LEDs was accurate?	1. Like it ☐ 2. Expect it ☐ 3. Indifferent ☐ 4. Tolerate it ☐ 5. Unhappy ☐	How would you feel if the position of the LEDs was inaccurate?	1. Like it ☐ 2. Expect it ☐ 3. Indifferent ☐ 4. Tolerate it ☐ 5. Unhappy ☐
Question 27			
How would you feel if a thinner driver IC was considered in the product?	1. Like it ☐ 2. Expect it ☐ 3. Indifferent ☐	How would you feel if a thinner driver IC was not considered in the product?	1. Like it ☐ 2. Expect it ☐ 3. Indifferent ☐

	4. Tolerate it ☐		4. Tolerate it ☐
	5. Unhappy ☐		5. Unhappy ☐
Question 28			
How would you feel if the product had a softer FPC material to avoid stress?	1. Like it ☐	How would you feel if the product did not have a softer FPC material to avoid stress?	1. Like it ☐
	2. Expect it ☐		2. Expect it ☐
	3. Indifferent ☐		3. Indifferent ☐
	4. Tolerate it ☐		4. Tolerate it ☐
	5. Unhappy ☐		5. Unhappy ☐
Question 29			
How would you feel if the product included Chip on Glass (COG)/Foil on Glass (FOG) bonding-Chip Bonding with Anisotropic Conductive Film (ACF)?	1. Like it ☐	How would you feel if the Chip on Glass (COG)/Foil on Glass (FOG) bonding-Chip Bonding with Anisotropic Conductive Film (ACF) was not used in the product?	1. Like it ☐
	2. Expect it ☐		2. Expect it ☐
	3. Indifferent ☐		3. Indifferent ☐
	4. Tolerate it ☐		4. Tolerate it ☐
	5. Unhappy ☐		5. Unhappy ☐
Question 30			
How would you feel if the resistance of the track material was high?	1. Like it ☐	How would you feel if the resistance of the track material was low?	1. Like it ☐
	2. Expect it ☐		2. Expect it ☐
	3. Indifferent ☐		3. Indifferent ☐
	4. Tolerate it ☐		4. Tolerate it ☐
	5. Unhappy ☐		5. Unhappy ☐
Question 31			
How would you feel if the LED power consumption was low?	1. Like it ☐	How would you feel if the LED power consumption was large?	1. Like it ☐
	2. Expect it ☐		2. Expect it ☐
	3. Indifferent ☐		3. Indifferent ☐

	4. Tolerate it ☐		4. Tolerate it ☐
	5. Unhappy ☐		5. Unhappy ☐

	Technical	
	Optical	
Functional		Dysfunctional

Question 32

How would you feel if the product was more stable regarding the contrast at higher temperatures?	1. Like it ☐	How would you feel if the product was not stable regarding the contrast at higher temperatures?	1. Like it ☐
	2. Expect it ☐		2. Expect it ☐
	3. Indifferent ☐		3. Indifferent ☐
	4. Tolerate it ☐		4. Tolerate it ☐
	5. Unhappy ☐		5. Unhappy ☐

Question 33

How would you feel if the product had desirable thermal reliability?	1. Like it ☐	How would you feel if the product had poor thermal reliability?	1. Like it ☐
	2. Expect it ☐		2. Expect it ☐
	3. Indifferent ☐		3. Indifferent ☐
	4. Tolerate it ☐		4. Tolerate it ☐
	5. Unhappy ☐		5. Unhappy ☐

Question 34

How would you feel if the product was provided a low DARK DOT rate?	1. Like it ☐	How would you feel if the product was provided a high DARK DOT rate?	1. Like it ☐
	2. Expect it ☐		2. Expect it ☐
	3. Indifferent ☐		3. Indifferent ☐
	4. Tolerate it ☐		4. Tolerate it ☐
	5. Unhappy ☐		5. Unhappy ☐

Question 35

How would you feel if the BU percentage was acceptable?	1. Like it ☐ 2. Expect it ☐ 3. Indifferent ☐ 4. Tolerate it ☐ 5. Unhappy ☐	How would you feel if the BU percentage was not enough high?	1. Like it ☐ 2. Expect it ☐ 3. Indifferent ☐ 4. Tolerate it ☐ 5. Unhappy ☐

Question 36

How would you feel if the product was designed with a suitable type of LED material?	1. Like it ☐ 2. Expect it ☐ 3. Indifferent ☐ 4. Tolerate it ☐ 5. Unhappy ☐	How would you feel if the product was not designed with a suitable type of LED material?	1. Like it ☐ 2. Expect it ☐ 3. Indifferent ☐ 4. Tolerate it ☐ 5. Unhappy ☐

Question 37

How would you feel if the nit of brightness level of the screen was high?	1. Like it ☐ 2. Expect it ☐ 3. Indifferent ☐ 4. Tolerate it ☐ 5. Unhappy ☐	How would you feel if the nit of brightness level of screen was low?	1. Like it ☐ 2. Expect it ☐ 3. Indifferent ☐ 4. Tolerate it ☐ 5. Unhappy ☐

<table>
<tr><td colspan="2"></td><td>Quality</td><td colspan="2"></td></tr>
<tr><td colspan="2"></td><td>Definition of standard conditions</td><td colspan="2"></td></tr>
<tr><td colspan="2">Functional</td><td></td><td colspan="2">Dysfunctional</td></tr>
<tr><td colspan="5" align="center">Question 1</td></tr>
<tr><td rowspan="5">How would you feel if the Digital PWM is in accordance with standard?</td><td>1. Like it ☐</td><td rowspan="5"></td><td rowspan="5">How would you feel if the percentage of Digital PWM is lower than standard?</td><td>1. Like it ☐</td></tr>
<tr><td>2. Expect it ☐</td><td>2. Expect it ☐</td></tr>
<tr><td>3. Indifferent ☐</td><td>3. Indifferent ☐</td></tr>
<tr><td>4. Tolerate it ☐</td><td>4. Tolerate it ☐</td></tr>
<tr><td>5. Unhappy ☐</td><td>5. Unhappy ☐</td></tr>
<tr><td colspan="5" align="center">Question 2</td></tr>
<tr><td rowspan="5">How would you feel if you did not face repeatability problem due to sensitivity of the Display?</td><td>1. Like it ☐</td><td rowspan="5"></td><td rowspan="5">How would you feel if you faced repeatability problem due to sensitivity of the Display?</td><td>1. Like it ☐</td></tr>
<tr><td>2. Expect it ☐</td><td>2. Expect it ☐</td></tr>
<tr><td>3. Indifferent ☐</td><td>3. Indifferent ☐</td></tr>
<tr><td>4. Tolerate it ☐</td><td>4. Tolerate it ☐</td></tr>
<tr><td>5. Unhappy ☐</td><td>5. Unhappy ☐</td></tr>
<tr><td colspan="5" align="center">Question 3</td></tr>
<tr><td rowspan="5">How would you feel if the product was designed according to the parameter settings of equipment (e.g., PrintScreen of equipment GUI)?</td><td>1. Like it ☐</td><td rowspan="5"></td><td rowspan="5">How would you feel if the product was not designed according to the parameter settings of equipment (e.g., PrintScreen of equipment GUI)?</td><td>1. Like it ☐</td></tr>
<tr><td>2. Expect it ☐</td><td>2. Expect it ☐</td></tr>
<tr><td>3. Indifferent ☐</td><td>3. Indifferent ☐</td></tr>
<tr><td>4. Tolerate it ☐</td><td>4. Tolerate it ☐</td></tr>
<tr><td>5. Unhappy ☐</td><td>5. Unhappy ☐</td></tr>
<tr><td colspan="5" align="center">Question 4</td></tr>
</table>

How would you feel if the Touch Mura effect was not found in LCDs?	1. Like it	☐
	2. Expect it	☐
	3. Indifferent	☐
	4. Tolerate it	☐
	5. Unhappy	☐

How would you feel if the Touch Mura effect was found in some LCDs?	1. Like it	☐
	2. Expect it	☐
	3. Indifferent	☐
	4. Tolerate it	☐
	5. Unhappy	☐

Question 5

How would you feel if the supplier was respecting PRE conditions?	1. Like it	☐
	2. Expect it	☐
	3. Indifferent	☐
	4. Tolerate it	☐
	5. Unhappy	☐

How would you feel if the supplier was not respecting PRE conditions?	1. Like it	☐
	2. Expect it	☐
	3. Indifferent	☐
	4. Tolerate it	☐
	5. Unhappy	☐

Question 6

How would you feel if a stable MSA was used to assess gauge precision?	1. Like it	☐
	2. Expect it	☐
	3. Indifferent	☐
	4. Tolerate it	☐
	5. Unhappy	☐

How would you feel if a stable MSA was not used to assess gauge precision?	1. Like it	☐
	2. Expect it	☐
	3. Indifferent	☐
	4. Tolerate it	☐
	5. Unhappy	☐

Question 7

How would you feel if the orientation of the measurement system was relative to the display (Register Active Display Area)?	1. Like it	☐
	2. Expect it	☐
	3. Indifferent	☐
	4. Tolerate it	☐
	5. Unhappy	☐

How would you feel if the orientation of the measurement system was not relative to the display?	1. Like it	☐
	2. Expect it	☐
	3. Indifferent	☐
	4. Tolerate it	☐
	5. Unhappy	☐

	Quality	
	Measurements conditions	
Functional		Dysfunctional
	Question 8	
How would you feel if the water absorption rate was defined in spec?	1. Like it ☐ 2. Expect it ☐ 3. Indifferent ☐ 4. Tolerate it ☐ 5. Unhappy ☐	How would you feel if the water absorption rate was not defined in spec?	1. Like it ☐ 2. Expect it ☐ 3. Indifferent ☐ 4. Tolerate it ☐ 5. Unhappy ☐
	Question 9	
How would you feel if defects scale or vastness of defects for the product were defined?	1. Like it ☐ 2. Expect it ☐ 3. Indifferent ☐ 4. Tolerate it ☐ 5. Unhappy ☐	How would you feel if defects scale or vastness of defects for the product were not determined?	1. Like it ☐ 2. Expect it ☐ 3. Indifferent ☐ 4. Tolerate it ☐ 5. Unhappy ☐
	Question 10	
How would you feel if the difference between measurements (LMK and TOPcon) were acceptable?	1. Like it ☐ 2. Expect it ☐ 3. Indifferent ☐ 4. Tolerate it ☐ 5. Unhappy ☐	How would you feel if the difference between measurements (LMK and TOPcon) were significant?	1. Like it ☐ 2. Expect it ☐ 3. Indifferent ☐ 4. Tolerate it ☐ 5. Unhappy ☐
	Question 11	

How would you feel if reaching temperature during measurement (e.g., for glass NTC) was defined?	1. Like it ☐ 2. Expect it ☐ 3. Indifferent ☐ 4. Tolerate it ☐ 5. Unhappy ☐		How would you feel if reaching temperature during measurement (e.g., for glass NTC) was not clearly defined?	1. Like it ☐ 2. Expect it ☐ 3. Indifferent ☐ 4. Tolerate it ☐ 5. Unhappy ☐

Question 12

How do you feel if a standard measurement method was defined for the part status (Free or on the Jig)?	1. Like it ☐ 2. Expect it ☐ 3. Indifferent ☐ 4. Tolerate it ☐ 5. Unhappy ☐		How do you feel if was not any standard measurement method for the part status (Free or on the Jig)?	1. Like it ☐ 2. Expect it ☐ 3. Indifferent ☐ 4. Tolerate it ☐ 5. Unhappy ☐

Question 13

How would you feel if the High Temperature/High Humidity Storage condition was defined for the product?	1. Like it ☐ 2. Expect it ☐ 3. Indifferent ☐ 4. Tolerate it ☐ 5. Unhappy ☐		How would you feel if the High Temperature/High Humidity Storage condition was not defined for the product?	1. Like it ☐ 2. Expect it ☐ 3. Indifferent ☐ 4. Tolerate it ☐ 5. Unhappy ☐

Question 14

How would you feel if the Position of tracks on FPCs was determined?	1. Like it ☐ 2. Expect it ☐ 3. Indifferent ☐ 4. Tolerate it ☐ 5. Unhappy ☐		How would you feel if the Position of tracks on FPCs was not clear?	1. Like it ☐ 2. Expect it ☐ 3. Indifferent ☐ 4. Tolerate it ☐ 5. Unhappy ☐

		Quality		
		Customer's rejection rate		
Functional			Dysfunctional	
		Question 15		
How would you feel if the sample size was enough for measurement?	1. Like it ☐		How would you feel if the sample size was small for measurement?	1. Like it ☐
	2. Expect it ☐			2. Expect it ☐
	3. Indifferent ☐			3. Indifferent ☐
	4. Tolerate it ☐			4. Tolerate it ☐
	5. Unhappy ☐			5. Unhappy ☐
		Question 16		
How would you feel if the material of the metal frame was suitable to avoid damage to FPC foil?	1. Like it ☐		How would you feel if the material of the metal frame was not high quality, therefore, damaging the FPC foil?	1. Like it ☐
	2. Expect it ☐			2. Expect it ☐
	3. Indifferent ☐			3. Indifferent ☐
	4. Tolerate it ☐			4. Tolerate it ☐
	5. Unhappy ☐			5. Unhappy ☐

	Cost	

Functional			Dysfunctional	
Question 1				
How would you feel if the supplier was offered a Consignment contract?	1. Like it ☐		How would you feel if the supplier was not offered a Consignment contract?	1. Like it ☐
	2. Expect it ☐			2. Expect it ☐
	3. Indifferent ☐			3. Indifferent ☐
	4. Tolerate it ☐			4. Tolerate it ☐
	5. Unhappy ☐			5. Unhappy ☐
Question 2				
How would you feel if the supplier was provided a Cost Breakdown Sheet (CBDS) for tooling?	1. Like it ☐		How would you feel if the supplier was not provided a Cost Breakdown Sheet (CBDS) for tooling?	1. Like it ☐
	2. Expect it ☐			2. Expect it ☐
	3. Indifferent ☐			3. Indifferent ☐
	4. Tolerate it ☐			4. Tolerate it ☐
	5. Unhappy ☐			5. Unhappy ☐
Question 3				
How would you feel if the Packaging Cost of the product was insignificant?	1. Like it ☐		How would you feel if the Packaging Cost of the product was significant?	1. Like it ☐
	2. Expect it ☐			2. Expect it ☐
	3. Indifferent ☐			3. Indifferent ☐
	4. Tolerate it ☐			4. Tolerate it ☐
	5. Unhappy ☐			5. Unhappy ☐
Question 4				
How would you feel if all requirements for equipment set-up were met?	1. Like it ☐		How would you feel if some requirements for equipment set-up were not met?	1. Like it ☐
	2. Expect it ☐			2. Expect it ☐

	3. Indifferent ☐		3. Indifferent ☐
	4. Tolerate it ☐		4. Tolerate it ☐
	5. Unhappy ☐		5. Unhappy ☐
Question 5			
How would you feel if tool strategy was available?	1. Like it ☐	How would you feel if tool strategy was unavailable?	1. Like it ☐
	2. Expect it ☐		2. Expect it ☐
	3. Indifferent ☐		3. Indifferent ☐
	4. Tolerate it ☐		4. Tolerate it ☐
	5. Unhappy ☐		5. Unhappy ☐
Question 6			
How would you feel if a reliable optical measurement report was available?	1. Like it ☐	How would you feel if a reliable optical measurement report was not available?	1. Like it ☐
	2. Expect it ☐		2. Expect it ☐
	3. Indifferent ☐		3. Indifferent ☐
	4. Tolerate it ☐		4. Tolerate it ☐
	5. Unhappy ☐		5. Unhappy ☐
Question 7			
How would you feel if the timeline for sourcing decisions was precise?	1. Like it ☐	How would you feel if the timeline for sourcing decisions was not precise enough?	1. Like it ☐
	2. Expect it ☐		2. Expect it ☐
	3. Indifferent ☐		3. Indifferent ☐
	4. Tolerate it ☐		4. Tolerate it ☐
	5. Unhappy ☐		5. Unhappy ☐
Question 8			
How would you feel if the amount of volume scenario was adequate?	1. Like it ☐	How would you feel if the amount of volume scenario was not adequate?	1. Like it ☐
	2. Expect it ☐		2. Expect it ☐

	3. Indifferent ☐		3. Indifferent ☐
	4. Tolerate it ☐		4. Tolerate it ☐
	5. Unhappy ☐		5. Unhappy ☐
Question 9			
How would you feel if all supply chain components were available?	1. Like it ☐	How would you feel if some supply chain components were not available?	1. Like it ☐
	2. Expect it ☐		2. Expect it ☐
	3. Indifferent ☐		3. Indifferent ☐
	4. Tolerate it ☐		4. Tolerate it ☐
	5. Unhappy ☐		5. Unhappy ☐
Question 10			
How would you feel if the product contained a sampling agreement document?	1. Like it ☐	How would you feel if the product does not contains sampling agreement document?	1. Like it ☐
	2. Expect it ☐		2. Expect it ☐
	3. Indifferent ☐		3. Indifferent ☐
	4. Tolerate it ☐		4. Tolerate it ☐
	5. Unhappy ☐		5. Unhappy ☐
Question 11			
How would you feel if the definition for raw material was clearly provided?	1. Like it ☐	How would you feel if the definition for raw material was not clearly provided?	1. Like it ☐
	2. Expect it ☐		2. Expect it ☐
	3. Indifferent ☐		3. Indifferent ☐
	4. Tolerate it ☐		4. Tolerate it ☐
	5. Unhappy ☐		5. Unhappy ☐
Question 12			
How would you feel if the target price was reasonable and met at any time and according to the PCB?	1. Like it ☐	How would you feel if the target price was not always met and according to the PCB?	1. Like it ☐
	2. Expect it ☐		2. Expect it ☐

	3. Indifferent ☐
	4. Tolerate it ☐
	5. Unhappy ☐

	3. Indifferent ☐
	4. Tolerate it ☐
	5. Unhappy ☐

		Sustainability		
		Globalization		
Functional			Dysfunctional	
		Question 1		
How would you feel if the supplier was considered a safe and sustainable transport system to produce the product?	1. Like it ☐ 2. Expect it ☐ 3. Indifferent ☐ 4. Tolerate it ☐ 5. Unhappy ☐		How would you feel if the supplier was not considered a safe and sustainable transport system to produce the product?	1. Like it ☐ 2. Expect it ☐ 3. Indifferent ☐ 4. Tolerate it ☐ 5. Unhappy ☐
		Question 2		
How would you feel if the commitment to the health and safety of employees was considered in the production processes?	1. Like it ☐ 2. Expect it ☐ 3. Indifferent ☐ 4. Tolerate it ☐ 5. Unhappy ☐		How would you feel if the commitment to the health and safety of employees was not considered in the production processes?	1. Like it ☐ 2. Expect it ☐ 3. Indifferent ☐ 4. Tolerate it ☐ 5. Unhappy ☐
		Question 3		
How would you feel if the responsibility of sustainability and transparency was considered in the production regulations?	1. Like it ☐ 2. Expect it ☐ 3. Indifferent ☐ 4. Tolerate it ☐ 5. Unhappy ☐		How would you feel if the responsibility of sustainability and transparency was not considered in the production regulations?	1. Like it ☐ 2. Expect it ☐ 3. Indifferent ☐ 4. Tolerate it ☐ 5. Unhappy ☐
		Sustainability		

		Pollution production		
Functional			Dysfunctional	
		Question 4		
How would you feel if the CO_2 emissions were less in the production process?	1. Like it ☐ 2. Expect it ☐ 3. Indifferent ☐ 4. Tolerate it ☐ 5. Unhappy ☐		How would you feel if the CO_2 emissions were more in the production process?	1. Like it ☐ 2. Expect it ☐ 3. Indifferent ☐ 4. Tolerate it ☐ 5. Unhappy ☐
		Question 5		
How would you feel if a product's environmental performance footprint was considered in the regulation?	1. Like it ☐ 2. Expect it ☐ 3. Indifferent ☐ 4. Tolerate it ☐ 5. Unhappy ☐		How would you feel if a product's environmental performance footprint was not considered in the regulation?	1. Like it ☐ 2. Expect it ☐ 3. Indifferent ☐ 4. Tolerate it ☐ 5. Unhappy ☐
		Question 6		
What do you feel if the product is developed with no potential toxicity to human?	1. Like it ☐ 2. Expect it ☐ 3. Indifferent ☐ 4. Tolerate it ☐ 5. Unhappy ☐		What do you feel if the product is developed with potential toxicity to human?	1. Like it ☐ 2. Expect it ☐ 3. Indifferent ☐ 4. Tolerate it ☐ 5. Unhappy ☐
		Question 7		
How would you feel if the product is climate pledge friendly?	1. Like it ☐ 2. Expect it ☐		How would you feel if the product is not climate pledge friendly?	1. Like it ☐ 2. Expect it ☐

	3. Indifferent ☐		3. Indifferent ☐
	4. Tolerate it ☐		4. Tolerate it ☐
	5. Unhappy ☐		5. Unhappy ☐
Question 8			
What do you feel if the wastewater discharge of production process has desirable quality?	1. Like it ☐	What do you feel if the wastewater discharge of production process has low quality?	1. Like it ☐
	2. Expect it ☐		2. Expect it ☐
	3. Indifferent ☐		3. Indifferent ☐
	4. Tolerate it ☐		4. Tolerate it ☐
	5. Unhappy ☐		5. Unhappy ☐
Sustainability			
Urbanization and Eco-design Energy			
Functional		Dysfunctional	
Question 9			
How would you feel if the operational water and energy consumption was low?	1. Like it ☐	How would you feel if the operational water and energy consumption was high?	1. Like it ☐
	2. Expect it ☐		2. Expect it ☐
	3. Indifferent ☐		3. Indifferent ☐
	4. Tolerate it ☐		4. Tolerate it ☐
	5. Unhappy ☐		5. Unhappy ☐
Question 10			
How would you feel if the product was developed with new sustainable materials?	1. Like it ☐	How would you feel if the product was developed without new sustainable materials?	1. Like it ☐
	2. Expect it ☐		2. Expect it ☐
	3. Indifferent ☐		3. Indifferent ☐

	4. Tolerate it ☐		4. Tolerate it ☐
	5. Unhappy ☐		5. Unhappy ☐
Question 11			
How would you feel if the raw materials was reduced through eco-design?	1. Like it ☐	How would you feel if eco-design was not applied to reduce the raw materials?	1. Like it ☐
	2. Expect it ☐		2. Expect it ☐
	3. Indifferent ☐		3. Indifferent ☐
	4. Tolerate it ☐		4. Tolerate it ☐
	5. Unhappy ☐		5. Unhappy ☐
Question 12			
How would you feel if the water consumption was reduced?	1. Like it ☐	How would you feel if the water consumption is not reduced?	1. Like it ☐
	2. Expect it ☐		2. Expect it ☐
	3. Indifferent ☐		3. Indifferent ☐
	4. Tolerate it ☐		4. Tolerate it ☐
	5. Unhappy ☐		5. Unhappy ☐
Question 13			
How would you feel if waste avoidance (Zero Waste-to-Landfill) was considered in the product?	1. Like it ☐	How would you feel if the Zero Waste-to-Landfill was not considered and there is waste in production?	1. Like it ☐
	2. Expect it ☐		2. Expect it ☐
	3. Indifferent ☐		3. Indifferent ☐
	4. Tolerate it ☐		4. Tolerate it ☐
	5. Unhappy ☐		5. Unhappy ☐
Question 14			
How would you feel if was considered the Circular Economy strategy (e.g., considering reusability, repairability, and re-manufacturability)?	1. Like it ☐	How would you feel if the Circular Economy strategy was not considered?	1. Like it ☐
	2. Expect it ☐		2. Expect it ☐
	3. Indifferent ☐		3. Indifferent ☐

	4. Tolerate it ☐			4. Tolerate it ☐
	5. Unhappy ☐			5. Unhappy ☐
		Question 15		
How would you feel if the energy was supplied from renewable sources?	1. Like it ☐		How would you feel if the sources of energy were not renewable?	1. Like it ☐
	2. Expect it ☐			2. Expect it ☐
	3. Indifferent ☐			3. Indifferent ☐
	4. Tolerate it ☐			4. Tolerate it ☐
	5. Unhappy ☐			5. Unhappy ☐
		Sustainability		
		Health and Safety		
Functional			Dysfunctional	
		Question 16		
How would you feel if the product was emitted a low amount of hazardous material (RoHS compliance)?	1. Like it ☐		How would you feel if the product was emitted a high amount of hazardous material (RoHS Noncompliance)?	1. Like it ☐
	2. Expect it ☐			2. Expect it ☐
	3. Indifferent ☐			3. Indifferent ☐
	4. Tolerate it ☐			4. Tolerate it ☐
	5. Unhappy ☐			5. Unhappy ☐
		Question 17		
How would you feel if road safety was considered in the process?	1. Like it ☐		How would you feel if the road was not safe in the process?	1. Like it ☐
	2. Expect it ☐			2. Expect it ☐
	3. Indifferent ☐			3. Indifferent ☐
	4. Tolerate it ☐			4. Tolerate it ☐
	5. Unhappy ☐			5. Unhappy ☐

Question 18			
How would you feel if the rate of accidents at work was low?	1. Like it ☐ 2. Expect it ☐ 3. Indifferent ☐ 4. Tolerate it ☐ 5. Unhappy ☐	How would you feel if the rate of accidents at work was high?	1. Like it ☐ 2. Expect it ☐ 3. Indifferent ☐ 4. Tolerate it ☐ 5. Unhappy ☐
Sustainability			
Water			
Functional		Dysfunctional	
Question 19			
How would you feel if water quality was not affected by the production process?	1. Like it ☐ 2. Expect it ☐ 3. Indifferent ☐ 4. Tolerate it ☐ 5. Unhappy ☐	How would you feel if water quality was influenced by the production process?	1. Like it ☐ 2. Expect it ☐ 3. Indifferent ☐ 4. Tolerate it ☐ 5. Unhappy ☐
Question 20			
How would you feel if the product avoided water scarcity?	1. Like it ☐ 2. Expect it ☐ 3. Indifferent ☐ 4. Tolerate it ☐ 5. Unhappy ☐	How would you feel if the product affected water scarcity?	1. Like it ☐ 2. Expect it ☐ 3. Indifferent ☐ 4. Tolerate it ☐ 5. Unhappy ☐

Delivery				
Functional			Dysfunctional	
Question 1				
How would you feel if the order lead-time was optimum?	1. Like it ☐		How would you feel if the order lead-time was not optimum?	1. Like it ☐
	2. Expect it ☐			2. Expect it ☐
	3. Indifferent ☐			3. Indifferent ☐
	4. Tolerate it ☐			4. Tolerate it ☐
	5. Unhappy ☐			5. Unhappy ☐
Question 2				
How would you feel if the delivery was more flexible?	1. Like it ☐		How would you feel if the delivery was not flexible?	1. Like it ☐
	2. Expect it ☐			2. Expect it ☐
	3. Indifferent ☐			3. Indifferent ☐
	4. Tolerate it ☐			4. Tolerate it ☐
	5. Unhappy ☐			5. Unhappy ☐
Question 3				
How would you feel if the communication and cooperation were optimum?	1. Like it ☐		How would you feel if the communication and cooperation were not properly existed?	1. Like it ☐
	2. Expect it ☐			2. Expect it ☐
	3. Indifferent ☐			3. Indifferent ☐
	4. Tolerate it ☐			4. Tolerate it ☐
	5. Unhappy ☐			5. Unhappy ☐
Question 4				
How do you feel if the Cut-off standard for releasing the transport order (TO) was available?	1. Like it ☐		How do you feel if the Cut-off standard for releasing the transport order (TO) was not considered?	1. Like it ☐
	2. Expect it ☐			2. Expect it ☐

	3. Indifferent ☐		3. Indifferent ☐
	4. Tolerate it ☐		4. Tolerate it ☐
	5. Unhappy ☐		5. Unhappy ☐
Question 5			
How would you feel if special transport was available?	1. Like it ☐	How would you feel if special transport was not available?	1. Like it ☐
	2. Expect it ☐		2. Expect it ☐
	3. Indifferent ☐		3. Indifferent ☐
	4. Tolerate it ☐		4. Tolerate it ☐
	5. Unhappy ☐		5. Unhappy ☐
Question 6			
How would you feel if the minimum order quantity was optimum?	1. Like it ☐	How would you feel if the minimum order quantity was not optimum?	1. Like it ☐
	2. Expect it ☐		2. Expect it ☐
	3. Indifferent ☐		3. Indifferent ☐
	4. Tolerate it ☐		4. Tolerate it ☐
	5. Unhappy ☐		5. Unhappy ☐
Question 7			
How do you feel if Electronic Data Interchange was available?	1. Like it ☐	How do you feel if there was a lack of Electronic Data Interchange?	1. Like it ☐
	2. Expect it ☐		2. Expect it ☐
	3. Indifferent ☐		3. Indifferent ☐
	4. Tolerate it ☐		4. Tolerate it ☐
	5. Unhappy ☐		5. Unhappy ☐
Question 8			
How do you feel if KANBAN call-offs were defined?	1. Like it ☐	How do you feel if KANBAN call-offs were not defined?	1. Like it ☐
	2. Expect it ☐		2. Expect it ☐

	3. Indifferent ☐		3. Indifferent ☐
	4. Tolerate it ☐		4. Tolerate it ☐
	5. Unhappy ☐		5. Unhappy ☐
Question 9			
How would you feel if the Start-up and phase-out control was considered?	1. Like it ☐	How would you feel if the Start-up and phase-out control was not considered?	1. Like it ☐
	2. Expect it ☐		2. Expect it ☐
	3. Indifferent ☐		3. Indifferent ☐
	4. Tolerate it ☐		4. Tolerate it ☐
	5. Unhappy ☐		5. Unhappy ☐
Question 10			
How do you feel if the delivery of Sub-suppliers were done properly?	1. Like it ☐	How do you feel if the delivery of Sub-suppliers were not sufficient?	1. Like it ☐
	2. Expect it ☐		2. Expect it ☐
	3. Indifferent ☐		3. Indifferent ☐
	4. Tolerate it ☐		4. Tolerate it ☐
	5. Unhappy ☐		5. Unhappy ☐
Question 11			
How would you feel if the maximum time for storage is optimum?	1. Like it ☐	How would you feel if the maximum time for storage was long?	1. Like it ☐
	2. Expect it ☐		2. Expect it ☐
	3. Indifferent ☐		3. Indifferent ☐
	4. Tolerate it ☐		4. Tolerate it ☐
	5. Unhappy ☐		5. Unhappy ☐
Question 12			
How would you feel if the transportation time was short?	1. Like it ☐	How would you feel if the transportation time was long?	1. Like it ☐
	2. Expect it ☐		2. Expect it ☐

	3. Indifferent ☐		3. Indifferent ☐
	4. Tolerate it ☐		4. Tolerate it ☐
	5. Unhappy ☐		5. Unhappy ☐
Question 13			
How would you feel if the Production progress information was available?	1. Like it ☐	How would you feel if the Production progress information was not available?	1. Like it ☐
	2. Expect it ☐		2. Expect it ☐
	3. Indifferent ☐		3. Indifferent ☐
	4. Tolerate it ☐		4. Tolerate it ☐
	5. Unhappy ☐		5. Unhappy ☐
Question 14			
How would you feel if the number of parts in the package were optimum?	1. Like it ☐	How would you feel if the number of parts in the package were not optimum?	1. Like it ☐
	2. Expect it ☐		2. Expect it ☐
	3. Indifferent ☐		3. Indifferent ☐
	4. Tolerate it ☐		4. Tolerate it ☐
	5. Unhappy ☐		5. Unhappy ☐
Question 15			
How would you feel if the package was easy to handle?	1. Like it ☐	How would you feel if the package was difficult to handle?	1. Like it ☐
	2. Expect it ☐		2. Expect it ☐
	3. Indifferent ☐		3. Indifferent ☐
	4. Tolerate it ☐		4. Tolerate it ☐
	5. Unhappy ☐		5. Unhappy ☐
Question 16			
How would you feel if the package was stackable?	1. Like it ☐	How would you feel if the package could not be stacked?	1. Like it ☐
	2. Expect it ☐		2. Expect it ☐

	3. Indifferent ☐		3. Indifferent ☐
	4. Tolerate it ☐		4. Tolerate it ☐
	5. Unhappy ☐		5. Unhappy ☐
Question 17			
How would you feel if the product was traceable?	1. Like it ☐	How would you feel if the product was not traceable?	1. Like it ☐
	2. Expect it ☐		2. Expect it ☐
	3. Indifferent ☐		3. Indifferent ☐
	4. Tolerate it ☐		4. Tolerate it ☐
	5. Unhappy ☐		5. Unhappy ☐
Question 18			
How would you feel if corrosion prevention and moisture control strategies were considered in the product?	1. Like it ☐	How would you feel if corrosion prevention and moisture control strategies were not considered in the product?	1. Like it ☐
	2. Expect it ☐		2. Expect it ☐
	3. Indifferent ☐		3. Indifferent ☐
	4. Tolerate it ☐		4. Tolerate it ☐
	5. Unhappy ☐		5. Unhappy ☐
Question 19			
How would you feel if the product transportation was secure?	1. Like it ☐	How would you feel if the product transportation was unsecured?	1. Like it ☐
	2. Expect it ☐		2. Expect it ☐
	3. Indifferent ☐		3. Indifferent ☐
	4. Tolerate it ☐		4. Tolerate it ☐
	5. Unhappy ☐		5. Unhappy ☐
Question 20			
	1. Like it ☐	How would you feel if the risk and crisis management was not considered in the delivery process?	1. Like it ☐
	2. Expect it ☐		2. Expect it ☐

How would you feel if the risk and crisis management (e.g., Natural disasters, Strikes, Epidemics) was considered in the delivery process?	3. Indifferent ☐		3. Indifferent ☐
	4. Tolerate it ☐		4. Tolerate it ☐
	5. Unhappy ☐		5. Unhappy ☐
Question 21			
How would you feel the logistics failures considered in the product delivery?	1. Like it ☐	How would you feel the logistics failures not considered in the product delivery?	1. Like it ☐
	2. Expect it ☐		2. Expect it ☐
	3. Indifferent ☐		3. Indifferent ☐
	4. Tolerate it ☐		4. Tolerate it ☐
	5. Unhappy ☐		5. Unhappy ☐
Question 22			
How would you feel if the supply chain was digitalized?	1. Like it ☐	How would you feel if the digital supply chain was not considered?	1. Like it ☐
	2. Expect it ☐		2. Expect it ☐
	3. Indifferent ☐		3. Indifferent ☐
	4. Tolerate it ☐		4. Tolerate it ☐
	5. Unhappy ☐		5. Unhappy ☐
Question 23			
How would you feel if the product bag was made of a suitable material?	1. Like it ☐	How would you feel if the product bag was made of unsuitable material?	1. Like it ☐
	2. Expect it ☐		2. Expect it ☐
	3. Indifferent ☐		3. Indifferent ☐
	4. Tolerate it ☐		4. Tolerate it ☐
	5. Unhappy ☐		5. Unhappy ☐
Question 24			
How do you feel if the maximum handling weight of the box is low?	1. Like it ☐	How do you feel if the maximum handling weight of the box is high?	1. Like it ☐
	2. Expect it ☐		2. Expect it ☐

	3. Indifferent ☐			3. Indifferent ☐
	4. Tolerate it ☐			4. Tolerate it ☐
	5. Unhappy ☐			5. Unhappy ☐
Question 25				
How would you feel if the size of the pallets were proper?	1. Like it ☐		How would you feel if the size of the pallets were not appropriate considering the spec?	1. Like it ☐
	2. Expect it ☐			2. Expect it ☐
	3. Indifferent ☐			3. Indifferent ☐
	4. Tolerate it ☐			4. Tolerate it ☐
	5. Unhappy ☐			5. Unhappy ☐
Question 26				
How would you feel if the “clean returnable packaging” agreement was considered?	1. Like it ☐		How would you feel if the “clean returnable packaging” was not agreed?	1. Like it ☐
	2. Expect it ☐			2. Expect it ☐
	3. Indifferent ☐			3. Indifferent ☐
	4. Tolerate it ☐			4. Tolerate it ☐
	5. Unhappy ☐			5. Unhappy ☐
Question 27				
How would you feel if the intermediate layers or nesting elements were from materials not releasing particles?	1. Like it ☐		How would you feel if the intermediate layers or nesting elements were from materials which make particles?	1. Like it ☐
	2. Expect it ☐			2. Expect it ☐
	3. Indifferent ☐			3. Indifferent ☐
	4. Tolerate it ☐			4. Tolerate it ☐
	5. Unhappy ☐			5. Unhappy ☐

Appendix 2 – CR and SA Relationship Matrix

	SA1	SA2	SA3	SA4	SA5	SA6	SA7	SA8	SA9	SA10	SA11	SA12	SA13	SA14	SA15	SA16	SA17	SA18	SA19	SA20	SA21
CR1		3																			
CR2	3																				
CR3												3									
CR4									3												
CR5																					
CR6																					
CR7																					
CR8			3							3											
CR9																					
CR10																					
CR11																					
CR12																					
CR13																					
CR14						3															
CR15							3														
CR16										3											
CR17																		3			
CR18				3										2							
CR19																					
CR20				3										1							
CR21								2													3
CR22																					
CR23																					
CR24													3								
CR25																					
CR26				1										3							
CR27											3										
CR28												3									
CR29											1										
CR30																					
CR31																					
CR32																					
CR33																					
CR34																					
CR35																					
CR36															3	3					
CR37																					
CR38																					
CR39																					
CR40															2	2					
CR41																					
CR42																					
CR43																					
CR44																					
CR45															3						
CR46																					
CR47																					
CR48																					
CR49																					
CR50																					
CR51																			3		
CR52																					
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CR54																					
CR55																					
CR56																					3
CR57																					
CR58																					
CR59																					
CR60																					
CR61																					
CR62																					
CR63					3																
CR64																	3		3	3	1
CR65																					
CR66																		3			

	SA22	SA23	SA24	SA25	SA26	SA27	SA28	SA29	SA30	SA31	SA32	SA33	SA34	SA35	SA36	SA37	SA38	SA39	SA40	SA41	SA42
CR1																					
CR2																					
CR3																					
CR4																					
CR5											2										
CR6										3											
CR7										3											
CR8																					
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CR13			3																		
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CR16																					
CR17																					
CR18																					
CR19																					
CR20																					
CR21												2									
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CR26																					
CR27														2							
CR28																					
CR29														3							
CR30																					
CR31																					
CR32																				3	1
CR33																				2	2
CR34							2		2												
CR35																		2			1
CR36																					3
CR37								3										3			
CR38																		2			
CR39																2	2	3			
CR40																			3		
CR41							2		3								2				
CR42									2												
CR43																1	2				
CR44																		3	1		
CR45																					2
CR46																				3	
CR47																					
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CR58																					
CR59		3																			
CR60	3						3														
CR61																					
CR62																					
CR63																					
CR64							3														
CR65																					
CR66																					

	SA43	SA44	SA45	SA46	SA47	SA48	SA49	SA50	SA51	SA52	SA53	SA54	SA55	SA56	SA57	SA58	SA59	SA60	SA61	SA62	SA63
CR1																					
CR2																					
CR3																					
CR4																					
CR5																					
CR6																					
CR7																					
CR8																					
CR9																					
CR10										3											
CR11																					
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CR32							3	2													
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CR35	3																				
CR36								1													
CR37	1																				
CR38			2																		
CR39			2																		
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CR41		2																			
CR42											2	3									
CR43												3									
CR44		2																			
CR45	2																				
CR46							3	2													
CR47											3	1									
CR48			3								2										
CR49																					
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CR51						3															
CR52																					
CR53						3															
CR54						3															
CR55																				3	2
CR56						1															
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