Proposition of an Integrated Framework for Reducing Communication Barriers Between Research & Development and Marketing Departments

by

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Proposition d’un cadre intégré pour réduire les barrières de communication entre les départements recherche & développement et marketing

Elmira SARANI

RÉSUMÉ

La collaboration au sein d’une entreprise entre les départements Recherche et Développement (R&D) et marketing impacte le succès du processus multifonctionnel de Développement de Nouveaux Produits (NPD). Dans ce processus multifonctionnel, plusieurs activités ont été menées par ces deux équipes professionnelles qui ont des expériences de connaissances, des langues et des cultures différentes. Depuis des décennies, plusieurs recherches scientifiques ont été menées pour faciliter la coordination entre les équipes R&D-marketing afin de lever les barrières dans leurs relations. Traditionnellement, la méthode de déploiement de la fonction qualité (QFD) a été utilisée comme un outil efficace pour piloter le processus de conception et de production afin de satisfaire les besoins des clients. Cependant, certaines études empiriques ont tenté d'utiliser diverses méthodes de conception afin d'augmenter l'efficacité de la prise de décision dans le NPD concernant les différentes exigences et les options alternatives. Pour résoudre ce problème, les scientifiques ont proposé d'intégrer les approches QFD et Analytics Hiérarchie Process (AHP). En conséquence, la stratégie QFD et AHP introduite a traduit les exigences client (CR) en exigences techniques (TR) et les a classées pour choisir une solution candidate appropriée. Bien qu’en utilisant l’approche d’extension QFD-AHP dont les données qualitatives seront traduites en données quantitatives, quelques problématiques demeurent. Grâce à cette méthodologie, la procédure d’analyse est accomplie subjectivement en tant qu’expérience des concepteurs et des équipes d’ingénierie et uniquement basée sur les demandes actuelles des clients. De plus, comme le jugement humain peut être imprécis, le succès de la compréhension exigences des clients potentiels ne sera pas garanti. Par conséquent, cette thèse tente de proposer une approche intégrée pour développer de manière efficace le processus de transfert d’informations entre les équipes R&D et marketing. Afin de mieux réutiliser les expériences passées, nous développons un modèle de système hybride séquentiel théorique en combinant la méthodologie QFD-AHP et Case-Based Reasoning (CBR). En ce qui concerne la voix du client (VOC), celle-ci sera analysée et les barrières de communication seront également étudiées du point de vue de la gestion des connaissances. Par conséquent, pour prédire avec précision les idées de conception qui ont échoué et éliminer les solutions problématiques, le CBR sera utilisé au début de la conception de la planification du produit via ce cadre intégré. Cela se fera en extrayant les expériences précédentes, en utilisant une approche de base de cas et en fournissant efficacement les solutions suggérées les plus proches. À cet égard, une étude de cas a été réalisée pour évaluer l’efficacité du système de cadre intégré proposé. L’exemple de produit est celui des cadenas de vélo pour sélectionner des idées de conception adaptées aux besoins des utilisateurs. Le résultat conduira à la conception d’un produit qui devrait satisfaire la plupart des RC. En effet, l’utilisation de la méthodologie CBR permet aux sous-systèmes QFD-AHP d’évaluer les décisions en recevant des retours sur les performances des solutions sélectionnées. Dans l’ensemble, le cadre intégré proposé vise à réduire les barrières de communication entre les départements de recherche et développement et de marketing.

Mots-clés : R&D et relations marketing, exigences client (CR), exigences techniques (TR), QFD, AHP, CBR, transfert de connaissances, barrières de communication.

Proposition of an Integrated Framework for Reducing Communication Barriers Between Research & Development and Marketing Departments

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ABSTRACT

Collaboration within a company between the Research and Development (R&D) and marketing departments impact the success of the multifunctional New Product Development (NPD) process. In this multifunctional process, several activities have been carried out by these two professional teams who have different knowledge experiences, languages, and cultures. For decades, several scientific research have been conducted to facilitate the coordination between the R&D-marketing teams to eliminate barriers in their relationships. Conventionally, the Quality Function Deployment (QFD) method has been employed as an effective tool to drive the design and production process to satisfy customer needs. However, some empirical studies have tried to use various design methods in order to increase the effectiveness of decision-making in NPD regarding different requirements and alternative options. To solve this problem, scientists have proposed integrating the QFD and Analytic Hierarchy Process (AHP) approaches. Accordingly, the introduced QFD and AHP strategy has translated the Customer Requirements (CRs) to Technical Requirements (TRs) and ranked them to choose a proper candidate solution. Although by using QFD-AHP extension approach qualitative data will be translated to quantitative one, there are a few remaining issues. Through this methodology, analysis procedure is accomplished subjectively as the experience of the designers and engineering teams and only based on current customers' demands. In addition, as human judgment could be imprecise, success in understanding potential customers needs will not be guaranteed. Therefore, this thesis attempts to put forward an integrated approach to develop the process of information transfer between R&D and marketing personals in an efficient manner. In order to better to reuse past experiences we develop a theoretical sequential hybrid system model through combining QFD-AHP and Case-based Reasoning (CBR) methodology. Thus, Voice of Customer (VOC) will be analyzed, and communication barriers will be also investigated from a knowledge management perspective. Hence, to accurately predict failed design ideas and eliminate problematic solutions, CBR will be employed in the early stage of product planning design through this integrated framework. This will be done by extracting previous experiences using a case base approach and providing the closest suggested solutions efficiently. In this regard, a case study was executed to assess the effectiveness of the proposed integrated framework system. The product example is bicycle locks for selecting suitable design ideas regarding user needs. The result will lead to a product's design that should satisfy most of the CRs. Indeed, utilizing CBR methodology enables QFD-AHP sub-systems to evaluate decisions by receiving feedbacks on the performance of selected solutions. Overall, the proposed integrated framework intends to reduce communication barriers between research & development and marketing departments.

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Keywords: R&D and marketing relations, Customer Requirements (CRs), product features, QFD, AHP, CBR, knowledge transfer, communication barrier

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LIST OF ABREVIATIONS

R&D	Research and Development
CRs	Customer Requirements
VOC	Voice of Customer
TRs	Technical Requirements
KM	Knowledge management
QFD	Quality Function Deployment
HOQ	House of Quality
AHP	Analytic Hierarchy Process
CBR	Case-Based Reasoning
CR	Consistency Ratio
CI	Consistency Index
RI	Random Index
AI	Artificial Intelligence

LIST OF SYMBOLS

A	matrix
a_{ij}	entry in the *i*th row and *j*th column in matrix
W	eigenvector
λ_{max}	highest eigenvalue
Sim	local similarity
X_i^{mem}	attributes of the case memory
X_{new}	attribute of the current case
SIM	global similarity
X	case in memory
X'	target case
W_i	importance weight

INTRODUCTION

In a competitive world, introducing a new product to the market can be challenging. For a business to introduce a product successfully to the market, it must have a thorough understanding of consumers and the market to offer a quality product to customers. New product development (NPD) is a complex process that many companies need for their project. This business process involves individuals from different functions who systematically transfer the idea into a usable product (Kratzer, Leenders, & Engelen, 2010). The NPD process comprises some dependent activities that make collaboration structured among cross-functional to understand the required task at different levels of the NPD process. The key point to success for any project is efficient interactions between the different teams. For example, communicating effectively between the different NPD teams and reusing the knowledge within a company can determine whether a new product will be established at a right time and within a budget (Gao & Bernard, 2018).

Generally, the NPD process starts with the idea generation phase in which a company has been gained these ideas from two sources. The internal idea source belongs to R&D departments where the employees, from a technical view, try to bring new solutions based on new technology and their engineering knowledge for designing a new product. Also, this department is well-known as the innovation center of an organization. In contrast, the source of the external ideas has been generated by marketing department teams. The information source has been extracted by interaction with customers, and this information is considered the primary resource for innovative design concept.

The main element in innovation is the knowledge. In innovation procedure collective knowledge has been disseminated and transferred into certain knowledge, which is a crucial asset for the organization to remain in today's competitive world (López-Nicolás & Merono-Cerdan, 2011). As a result, effective knowledge transmitting provides opportunity to teams and induvial in order improve their performance as well as creating innovative ideas. Exchanging knowledge has been indicated primarily a social, interactive, and complicated process involving tacit and explicit knowledge (Polanyi, 2009). Customer requirements (CRs) are determined as fundamental guidance for product designing, and if a product is manufactured without considering CRs, it will show less power of competitiveness (Duray, Ward, Milligan, & Berry, 2000).

The process of knowledge sharing is complicated and includes the combination of strategies and routines in any organization, such as capturing, integrating, and using information for development. Moreover, a practical strategy for this process incorporates technology, culture, measurement, and infrastructure to share knowledge across multiple areas in the organization. However, in sharing information among individuals, some obstacles have been recognized that individual educational levels and different academic backgrounds have been identified as majors' factor (Sani Kazaure, Dabai, Salisu, Sabo, & Salisu, 2016). A framework has been proposed by (Guribie & Tengan, 2019) that is shown seven Knowledge Management (KM) process-oriented with paying attention to the different methods and tools in knowledge exchange.

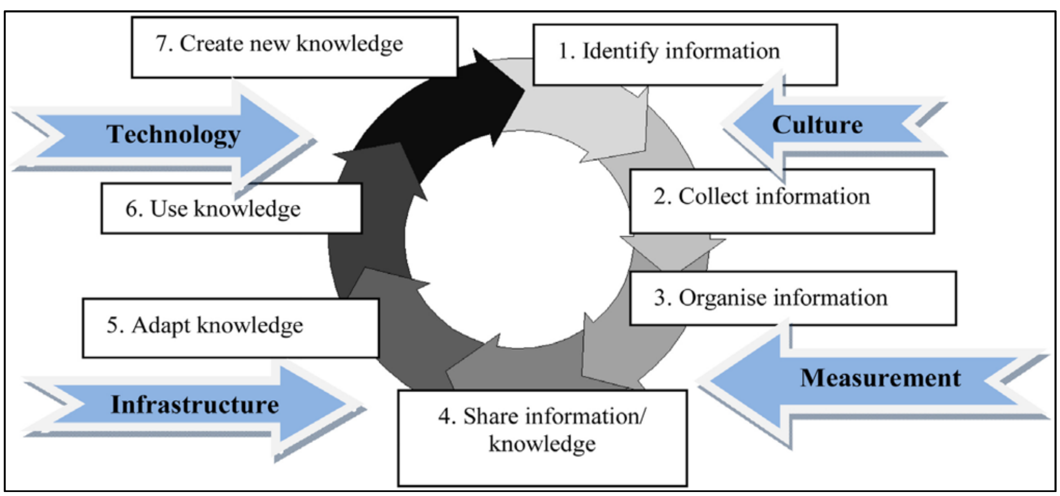


Figure 0.1 Knowledge transfer process
Taken from Guribie & Tengan (2019, p.5)

The relationship between professional/technical teams and their ability to connect for processing data and information is a complicated topic and contains a variety of aspects. Thus, this study proposes an additional framework by building on the selected models and methods, which expose the application of methods in KM field. The study direction is on knowledge sharing which this knowledge expressly refers to transforming of CRs between the R&D and marketing teams in the initial phase of NPD.

CHAPTER 1

PROBLEM DESCRIPTION

1.1 Background

Generally, customer requirements (CRs) display the features or characteristics of the product or services that fulfill customer needs. Throughout time, these expectations have changed, and in modern life, the customer desires more, such as proactive service and personalized interaction. Therefore, these requirements play an essential role in encouraging consumers to buy products. Nowadays, in the highly competitive market, the main challenge is how the companies respond to these requirements. Hence, they are exposed to new opportunities by creating added value to their products and being more profitable. Competition is unavoidable in today's world of business. Thus, understanding the potential customers and how to achieve competitive advantages over the rivers are the fundamental strategies. In addition, reasonable interpretation and applicable customer needs extraction help engineers and designers make wise decisions in product development.

The term cooperation between internal (employees) and the customers is understood as interaction and solution developments that enormously affect the firm's performance outcome. An earlier study (Moenaert, Souder, De Meyer, & Deschoolmeester, 1994) emphasized why this discussion is essential. Also, the study represented that the communication flows among R&D-marketing team members significantly effect on the successful outcome of new products. Moreover, another positive aspect of communication interface between R&D and marketing departments is uncertainty reduction while exchanging information between these two functional groups. In addition to this, most organizations create an inter-functional corporation between marketing and the R&D departments for success in response to customer expectations. Although, these two departments having their own added value for the organization and have specific independent roles in a company for developing products and services. For instance, marketing has responsibility for gathering data and assessing new applications for the product, troubleshooting customer problems, and preparing marketing campaigns. In comparison, the

R&D department has responsibility for the comprehensive research and development of the product design in a scientific way to propose solution for the future product and hence up-to-date regards to the newest technologies. Despite that the R&D and marketing departments have joint responsibility for developing a new product, determining opportunities for the next generation of products, and fixing technical designs and CRs trade-offs. Indeed, the joint tasks of these teams in the NPD process is related to the interpretation of customers' demands regarding a current product to progress it besides comparing it with other similar products available in the market (Griffin & Hauser, 1996). The key to success is to respond to diverse and dynamic CRs quickly and effectively and provide the product in a short time to the market (Lin, 2018). Both academics and firms have emphasized that the cross-functional relation between the marketing and R&D departments in the new product development (NPD) process is critical for the enhancement procedure in various industries. In this regard, the translation of customer needs is the principal shared responsibility between R&D and marketing teams.

However, several research have explored that the problem is breakdown in communication and cooperation areas between these two departments. This issue is the outcome of two perspectives regarding developing a product, differences in culture, languages, and personality. Practically, it is impracticable to eliminate the R&D-marketing integration barriers completely (Song & Song, 2010). Hence, if employees of the R&D and marketing teams do not have the ability to communicate and collaborate adequately, in that case, the information has been obtained from the market needs, and the knowledge of product design will disintegrate (P.-C. Li & Chen, 2016). Consideringly, the main problems to be addressed are highlighted below:

1- Lack of studies to investigate about customer requirements in the field of collaboration between R&D-Marketing during the procedure of new product development.

2- Lack of research to use technical tools and practical methodologies in this integration area

1.2 Research Objective

In this thesis, regarding the problem statement, to reduce the communication barrier between R&D and marketing departments through developing a product, there is a need to establish an approach to diminish misunderstanding among these team members. Therefore, the purpose is to develop an integrated framework to improve the process of information transfer between R&D and marketing departments in an efficient way. Through this procedure qualitative data (VOC), which are vague expressions, have been converted to quantitative data (product design requirements). For implementing this translation procedure, we applied QFD not only as a quality tool but also as a fundamental planning tool. Besides, because in this project, we were dealing with various demands among different possible solutions we used the AHP framework for structuring the decision-making process. Among other methods of multiple decision-making, the AHP is defined as a powerful method for solving complicated and unstructured problems that may have interactions and correlations among different objectives. On the other hand, we intend to present a way to moderate this confliction between the different specialist teams in order to use existing data from customer requirements and also extract the new demands in the market regarding developed products. Moreover, we implemented the QFD-AHP extension approach with the CBR method. In this research, the CBR's purpose is to sufficiently reuse past experiences in order to represent knowledge design to assist the designers and engineers in comprehending the targeting user.

The proposed objective considers the shared task between the R&D and marketing teams which includes customer needs interpretation. Translating VOC appropriately to the engineering and designer's languages at the practical level in the industry is a challenging procedure. The current study explores a hybrid methodology that consists of three different methods for analyzing and transforming customer data. This methodology helps specialists take action based on current requirements and learn from suggested failures or successful experiences in the past, and quickly resolve the target customer needs. Accordingly, this goal cannot be achieved without creating a process to prioritize customer requirements and then optimal design selected based on customer/user demands.

1.3 Research Contribution

According to the previous studies, many works have concentrated on the different integration mechanisms to overcome the relation barriers among R&D specialists and marketing teams. For instance, alternative solutions include:

- Relocation and physical facilities (Griffin & Hauser, 1996).
- Modifying the organizational structure and coordinating groups (Griffin & Hauser, 1996).
- Formal integrative management (López-Nicolás & Merono- Cerdan, 2011).
- The Stage-Gate process (P.-C. Li & Chen, 2016).

An essential amount of information is transmitted between R&D and marketing personnel. Market-based information is directed by marketers into R&D teams for internal decision-making. For this purpose, the QFD matrix have been utilized to define user expression into technical language. In other words, previous studies have been generated several QFD modifications to make this methodology more functional and representative (Zare Mehrjerdi, 2010). As a result, one of these extensions is the QFD-AHP integration approach which researchers have carried out to assist in a design project in order to meet CRs most effectively. After gathering and organizing all requirements, the first matrix of QFD (house of quality) matrix is implemented to convert qualitative data to quantitative data. In other words, this matrix is translating CRs to TRs languages and representing their relationships at this stage. With the help of AHP, through this procedure, all criteria and alternative solution is defined for the process of decision-making. Ultimately, the expertise generates and assign weight to criteria/sub-criteria through the pair-wise comparison computation. Hence, engineers could implement the latest innovative ideas and technology regarding the current VOC from this stage. The elaboration of theoretical process QFD-AHP is all shown in Figure 1.1.

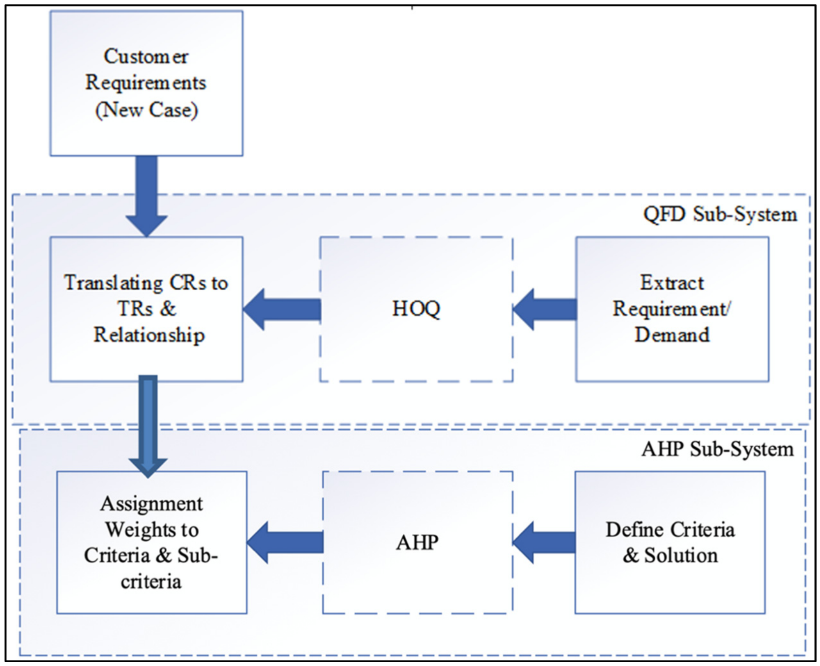


Figure 1.1 QFD-AHP integration process

However, the above human-based approach concentrates on current customer needs, and analysis process is carried out from the engineer's point of view. Therefore, the process of rating current CRs by comparison method is conducted with respect to their technical knowledge and experiences. Moreover, developing a product has almost evolved from existing product ideas, and the QFD-AHP methodology's limitation relies on the latest VOC captured (P. Wang, Gong, Xie, Liu, & Nee, 2017). As a result, it might lead to a deficient design and late delivery to customers.

In this thesis, a product case is defined as a new case which comprises user needs that usually possesses some qualitative properties. This study applies the QFD methodology to upgrade the interpretation of CRs and convert them to measurable values. Therefore, with the help of the QFD matrix, qualitative values are converted for statistical measurement. Further, the correlation between the QFD and the AHP will be performed to give requirements value weights in order to prioritize them based on their importance among various criteria.

Furthermore, the CBR method is added to make up for the deficiency of a system to assess the current market's needs and assist the engineers in proving the validity of the results. Eventually, with the aid of the knowledge retrieval technique, current CRs information regarding products and previous experiences from failed ideas and designs are utilized. It also helps select significant TRs for product configuration design. Through retrieval process when an existing case failed, in this situation this recorded experience is retained by system's memory and can be recognized and better utilized appropriately in the future. Regarding our contribution with literatures, we wish to provide an integrated framework to reduce the risk of presenting not helpful solutions during the product development.

1.4 Thesis Outline

The thesis consists of 4 chapters. Chapter 1 is an overview of the thesis research, including background and the problem statement. Chapter 2 introduces the QFD methodology with its core matrix and the extension of the method with other methods, the AHP tools and their application in various areas, and the CBR approach and the explanation of its fundamental procedure. Chapter 3 demonstrates step by step the research framework and the description of each sub-system in detail, which contains the process of each method. Chapter 4 represents the illustrative example to show how the system works. The case study is about to indicate how the framework system could be supported in the project of selecting the different models of bicycle locks design. Hence, the proposed framework will be tested with a target user to embrace whether the solution is adequate. The final part of the study is argued in the discussion section with the research limitation, conclusion, and future research.

CHAPTER 2

LITERATURE REVIEW

2.1 Quality Function Deployment

Quality Function Deployment (QFD) is a tool that was initially developed in the late 1960s in Shipyards in Kobe, Japan. Lately, this methodology has been popular in the US since the 1980s (Bolar, Tesfamariam, & Sadiq, 2017). Practitioners and researchers have been implemented this method from the automotive to various industries, for instance: aerospace, education, logistics, software, process engineering, health care, etc., in different countries. Historically, this method value was obtained by Akao, who attempted to employ his knowledge during the design phase of the product for design characteristics. He could have transformed design characteristics into accurate quality control spots in the manufacturing in a chart of quality control(Adiandari, Winata, Fitriandari, & Hariguna, 2020). The fundamental concept of QFD is a robust methodology that translates customer needs, which is called Voice of Customer (VOC). The VOC phrase used to describe what the customer wants into what the organization produces the product or service regarding those desires. Therefore, the essential input of the QFD method is the Customer Requirements (CRs) regarding the service or product. In addition, applying the QFD would help to obtain a competitive advantage via implementing CRs while the product manufacturing process. Thus, customer satisfaction can be increased through the quality attributes of products (Ginting, Ishak, Fauzi Malik, & Satrio, 2020). However, these expectations might change over time which could vary in demands. Hence, the companies should be up to date with VOC for developing its product. Also, they recognize that filtering the essential items implemented to a product can positively impact the market.

Technically, translating customer language into technical language means providing precise information about the customer's preferences for different development and production stages (Marketing, Planning process, engineering, and production process and prototype evaluation) (Ruiz-Vanoye et al., 2013) (Diaz, n.d.,2007) has emphasized the importance of the QFD in the four steps: product designing, development of the product , process designing , and production planning.

Over the last decades, QFD has been used successfully in the design phase, one of the challenging stages in the product life cycle. Indeed, QFD is a kind of translation practice designed to assist designers and engineers in planning and developing the functional specification of a product or service by understanding customers' desires. The most effective tool in QFD for analyzing CRs is the House of Quality (HOQ), in which the matrix looks like the shape of the house (Diaz, n.d.,2007).

2.1.1 The Core QFD Matrix (House of Quality)

(Garvin, 1987) demonstrated that there are many dimensions to what customers expect about the quality, and it is the main challenge in designing the product to satisfy all these dimensions. One of the significant ways to successfully implement the QFD function is to adapt to the fundamental matrix, House of Quality (HOQ), a suitable match for managing and identifying the design trade-offs. The HOQ is the conceptual plan that prepares the platform for inter-functional planning and communication for the people with different responsibilities such as marketing and R&D departments to prioritize design.

HOQ process starts with collecting and analyzing the customer requirements done in Market survey, Focus group, Individual interviews, Mail, Telephone, etc. The experts of HOQ try to protect customers' phrases, even cliches, knowing that they will translate them concurrently with the help of other teams like planners, designers, and engineers. However, all preferences are not equally important. Therefore, the HOQ approach measures the relative importance of customers' requirements which this weighting is generally based on the professionals' experiences in these fields or directly from their customers (Hauser & Clausing, 1988). Therefore, this framework transfers the degree of importance to CRs (the WHATs) into technical requirements (the HOWs). Generally, the HOQ structure contains six sections that are present in Figure 2.1.

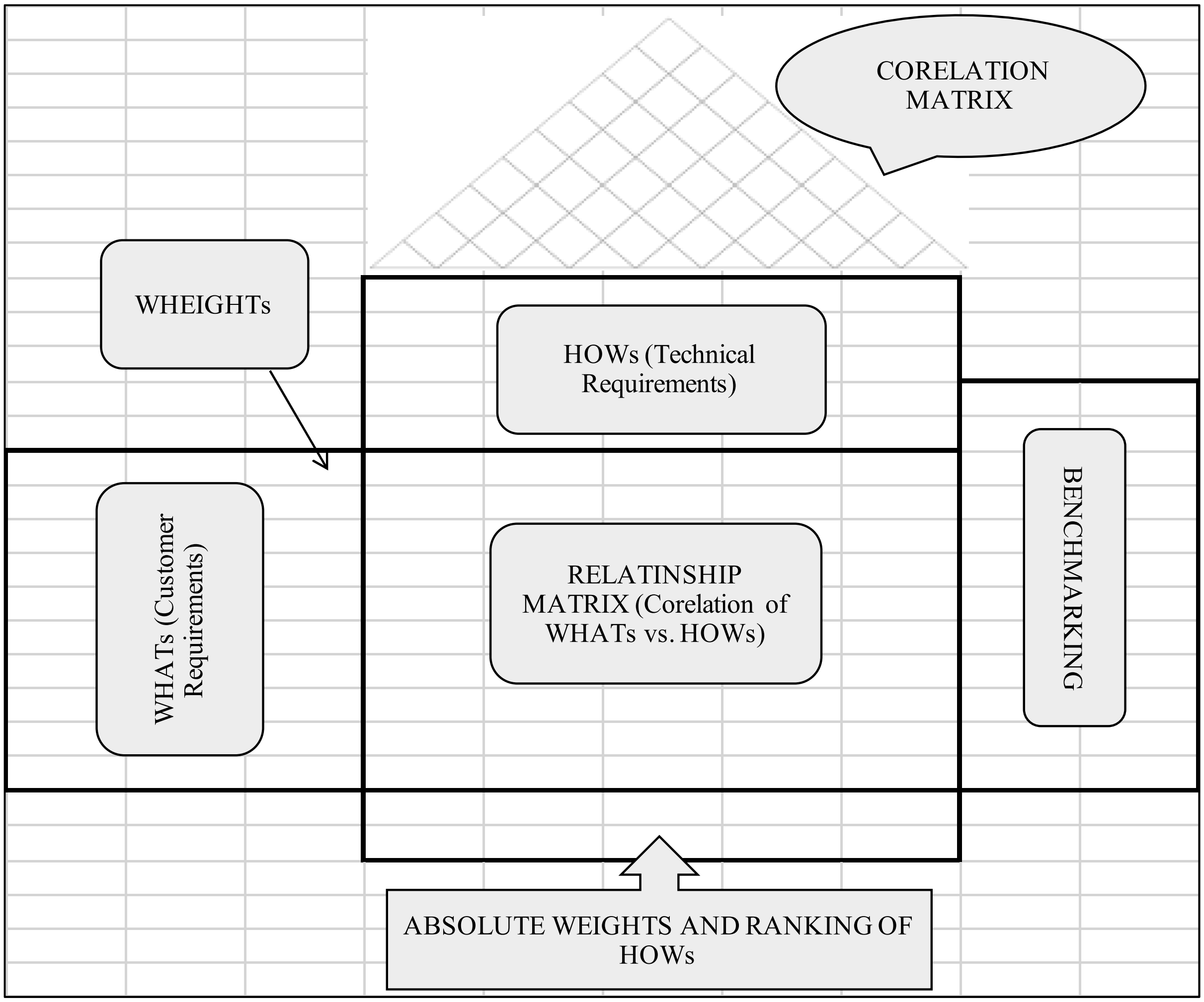


Figure 2.1 House of Quality (HOQ)

- The First Section (WHATs (Customer Requirements)): This section includes two columns: the first column lists the fundamental customer needs and preferences (WHATs). The second one is the importance rate of the user to those needs. Generally, the rate given by the customer to the criteria is on a scale of 1 to 5, meaning less to very important.
- The Second Section (HOWs (Technical Requirements)): The next step quantifies the customer's expression into the technical language (HOWs). TRs display the features selected by team of engineers and designers to provide the customers regarding their needs. They support the different disciplines working on the project to know CRs in the same meaning and avoid mistakes that can be viewed while interpreting the customer's needs.

Therefore, the design of product characteristics is classified to meet the WHATs, and it is significant to identify design specifications that correspond to each requirement.

- The Third Section (Benchmarking): In the Benchmarking section, the company's performance on answering each customer's needs has been compared with its main competitors' performance. The purpose is to analyze the best alternative for each customer expectation compared to main rivals to see how much the products can perform regarding the CRs.
- The Fourth Section (RELATINION MATRIX (Correlation of WHATs vs. HOWs)): The section is called Relationship Matrix, which illustrates the relation between what the customer demands from the required product and in what way the project team can meet that demand. In other words, the consideration in this step is understanding the contribution of TRs to the overall customer satisfaction level and recognizing how these TRs are helpful to satisfy each customer's expectation.
- The Fifth Section (Correlation matrix): The peak of the HOQ matrix represents the correlation between the difference in the HOWs, either it is positive or negative. It means the outcome of developing one specification depends on the other one (Younes & Bouami, 2015).
- The Sixth Section (Absolute weights and ranking of HOWs): the team of experts prioritize and weight the technical requirements in this section, hence the decision-making regarding design product in this part has a significant impact on the product’s success.

2.1.2 Extension to The QFD Methodology

Many recommended QFD extensions have been focused on assuring proper acquisition and analysis of customer information. Practitioners from the diversity industry proposed most of these modification approaches to make QFD methodology more viable. It is evidence that there is no distinct boundary for the QFD potential field of application. Due to this issue, whether the primary function of this method is a product development and quality management, it also has extended into the planning, decision-making, and management field**.** (Prasad, 1998) has reached the original concept of linking the data that had been gained by market research with

QFD to incorporate value engineering. By combining technical and customer importance rates with value graphs and engineering, engineers could get related preferences for quality characteristics. The process provides teams of the product development a combination tool to anticipate products that customers would be willing to buy in order to build the marketable products. Other research had been proposed by (Kwong & Bai, 2003), they used the conjoint analysis method for defining the relative importance of CRs; this method is similar to the practice of evaluation used in the analytic hierarchy process (AHP). Another work on the extension of QFD incorporated with other methods is (Bhattacharya, Geraghty, & Young, 2010) study. The author presented the combination of concurrent engineering technique, the AHP-QFD with cost factor measure to rank as methodology base model. Consequently, the results had been choosing applicant suppliers between various alternative, contradictory in nature criteria environments in a value-chain structure. Regarding the integration approach of QFD and AHP, (Awasthi, Sayadi, & Khabbazian, 2018) presented a gab analysis through a combination of these two methodologies in order to enhance the Logistics Service Quality. The power of their suggested strategy is that the opinion of various stakeholders had been used to specify service quality characteristics. Moreover, they discussed current important criteria, specifically those associated with sustainability, such as human resources, technological health.

In the field of innovative design, this study (Wu, Pan, Shao, & Wu, 2013) introduced a process of innovation process that has been improved according to the QFD method with the help of matter element theory. It enables the process of translating CRs into quality characteristics more comprehensively and intensely. Additionally, researchers have evaluated dependent functions for design criteria regarding the concepts of the Taguchi method. One of the recent studies was conducted by (E Stansfield & Azmat, 2017) regarding to the integration of QFD into the Internet of things. In this case the purpose of the study is to indicate the QFD goal which is adjusting new product system design to customer priorities with the help of Artificial Intelligent (AI). Also, they represented with this system target gathered information from market and technology can be analysed to enhance the usefulness of Internet of things.

2.2 Analytic Hierarchy Process

In modern society, rapid technology has caused considerable changes in various fields, making it challenging to confront complex decision-making problems to decide the solution. Therefore, multi-criteria decision-making is a practical approach that many industries have used while making decisions for different criteria and alternatives. First, the Analytic Hierarchy Process (AHP) generated by Thomas L. Saaty which has been attracted by many researchers essentially because of the excellent mathematical features of this methodology. The necessary information is relatively convenient to be obtained by this technique. Furthermore, the AHP has a well-defined advantage in decision-making methodology, which reduces redundant information to make the decision process more accurate regarding the demands in complex situations. Technically, the AHP is a tool that breaks down the problem into small parts by reaching various criteria and sub-criteria against different solutions to a problem. The AHP contains three fundamental functions: structuring complexness, measurement, and synthesis. A decision maker must take some significant actions in order to be made a proper decision (Saaty, 2005).. Those actions include:

- Determine the problem and the type of knowledge aimed
- Create a framework of the decision hierarchy
- Create matrixes to compute a set of pairwise comparisons
- Estimate the relative weight of the criteria in each level
- Inspect decision that has been made in this process
- Decision documentation

This structure is set up in a hierarchical scheme from up to lower levels the standard structure is displayed in Figure 2.2. The nature of the method integrates quantitative and qualitative analysis. The comparisons might be accomplished via applying significant numbers having ratio attributes. Hence, the ratio might be employed to prioritize the reflection of the relative importance of the decision criteria (Gokhale, 2007).

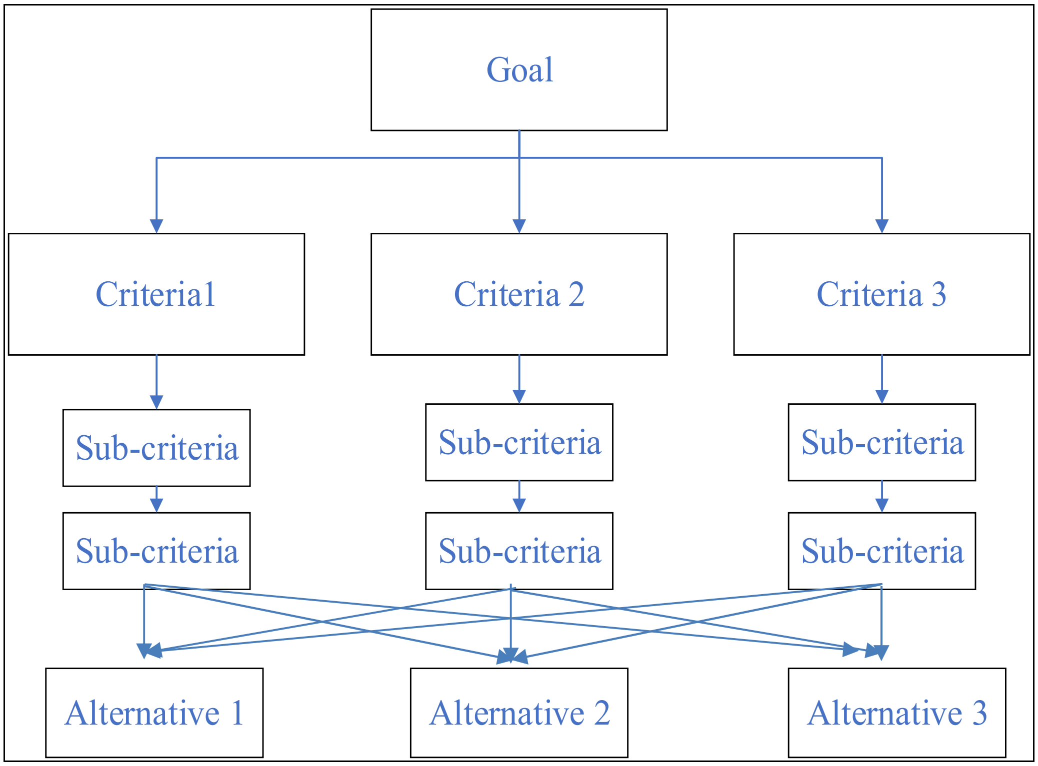


Figure 2.2 AHP process structure

2.2.1 Analytical Hierarchy Process Application

During these years, the AHP methodology application was utilized in manufacturing, educational system, engineering, political, governmental institution, and management fields. This extensive implementation is because of its simpleness, ease of use, and great flexibleness (Ho, 2008). A body of study on the AHP method focused on selecting alternatives to support decision-makers and reduce redundancy information. (Bevilacqua & Braglia, 2000) represented implementing the AHP process to select the best maintenance strategy. (Labib, 2011) compared the AHP tool with the fuzzy logic method to support the decision of the suitable supplier selection. They revealed how they could reach the similar purpose of demonstrating of human assessments in linguistic expressions by employing the AHP. Another combination method that has been provided by (Carnero, 2005) is strategy with the help of the AHP and factor analysis for the decision-making system in order to select the diagnostic methods and instrumentation in the preventive maintenance programs. The consequence of the research could have simplified the decision-making of the predictive maintenance program planner and support preventive method development. In order to classify the utilized tools of a power plant based on the several chosen criteria, the analytic hierarchy process has also been employed by (Singh & Kulkarni, 2013). In addition, to make the quantifying procedure easy, this proposed model used specialist assessments to quantify the related environmental data.

Due to the AHP adaptability, this method is even integrated with mathematical programming techniques. Several scholars have researched the study domain of suppliers selection because the choice of suppliers is a multicriteria problem that generally contains qualitative and quantitative values. According to this subject (Ghodsypour & O'Brien, 1998) applied the AHP method with linear programming to solve this problem. The focus of their proposed model is to determine the optimal set of suppliers with respect to their importance weight incorporated into the function of linear programming to meet customer demand and the amount of raw materials needed to purchase from suppliers.

The AHP and the house of quality combination is a practical approach that the practitioners highly investigated in the customer requirements subject. For example, (Ravi & Mukherjee, 2006) applied these two integration approaches in the manufacturing industry to develop a comprehensive system for the rapid tooling process selection domain. By adopting the AHP technique, they could specify the weight of the tooling CRs. Besides that, they established a QFD matrix related to the tooling demands in order to set an applicable method for the tooling process. Environmentally product design is another case that the integration of the AHP-QFD is performed. (Madu, Kuei, & Madu, 2002) considered this issue, and in order to combine product characteristics and environmentally friendly design, they implemented the integrated framework. Their goal was to show how vital the potential groups or stakeholders need to incorporate into the primary product design stage and prioritize their demand. On the other hand, the manufacturer designed environmentally conscious. The QFD enabled this link between user requirements such as cost-effectiveness and performance and the operational sector to support the recycling method and the cost. In addition, the AHP was set priority for CRs to highlight critical elements present in the product.

The latest paper on the combination of AHP-QFD is (Liu & Wang, 2022) research. The investigated new methodology is based on text mining strategy and its application for online businesses. Their customer-oriented goal is established by the help of an intuitionistic fuzzy set, the Kano model, the AHP method, and the QFD matrix. Text mining instantly acquires information from unstructured data and then provides a scientific product development structure. They obtained overall weights of CRs extracted, which are functional and emotional requirements via fuzzy AHP, and then required technical requirements weights through fuzzy QFD. Finally, the combination method was implemented to a type of air conditioner as a case study. The result indicated that an intuitionistic fuzzy set is reliable in the context of text mining.

2.3 Case-Based Reasoning

Case-based reasoning (CBR) is a problem-solving method and one of AI strategies based on cognitive science and human memory. Initially, scientists extracted CBR from cognitive science on human memory and picked out experience-based behavior at higher levels of cognition. According to (Shekapure, 2015), The term case-based reasoning consists of three words. A case is an experience of a solved problem that it can interpret in many ways, and it is critical for CBR. A case-based contains the list of such cases. Another fact about cases is that these include the positive and negative cases representing the failure solution that can be the advice to select appropriate solutions. The Based means that the logic is regarded in cases that are the primary source for reasoning. The CBR most characteristic of the approach is reasoning. The basic idea has generated the assumption of solving similar problems with similar solutions; they are likely to be used for finding the solution to the new similar issues (Ozturk & Tidemann, 2014). In other words, CBR is a systematic procedure that means adopting input specifications with old cases to help decision-makers corresponding solutions based on previous similar cases. Therefore, existing solutions can accommodate current issues and warn of potential mistakes or failures (Ayeldeen, Shaker, Hegazy, & Hassanien, 2015). Generally, CBR consists of two main stages: Problem specification and Solution. The problem specification includes attribute values which, in this stage, attributes uniquely define the problem case and analyze it to predict solutions. In the solution stage, the reasoning mechanism manipulates the problem description to provide a solution.

2.3.1 Case-Based Reasoning Cycle

Mainly, all the Case-Based Reasoning procedures are standard in the general cycle, which is describes as the following steps, and Figure 2.3 shows the process:

1- Retrieve: The first step starts with retrieving the problem description, recovering comparable cases, and finishing with the most suitable matching case(s). These steps include sub-tasks:

- Classifying a collection of related problem descriptors.
- Matching the case and returning a set of adequately similar cases.
- Choosing the most desirable case from the set of cases returned.

2- Reuse: Reuse means introducing the solution for solving the current problem by reusing information and knowledge in the retrieved case(s). Indeed, reprocess data and interpret it to solve the current issue when perfect matching happens. Thus, reuse is the process step while one case is chosen for its solution to be reused.

3- Revise: Revising the case solution created by the procedure of reuse is essential when the answer is inaccurate. Also, it is a chance to learn from failure. Finally, it is familiarizing identical cases for comparison with other cases when ideal matches are not established.

4- Retain: Retaining the case contains whatever is applicable from the new case into the case-based. It means selecting types of information to need to keep and in which form to retain. Thus, it involves how to list the case for future process. (Shekapure, 2015).

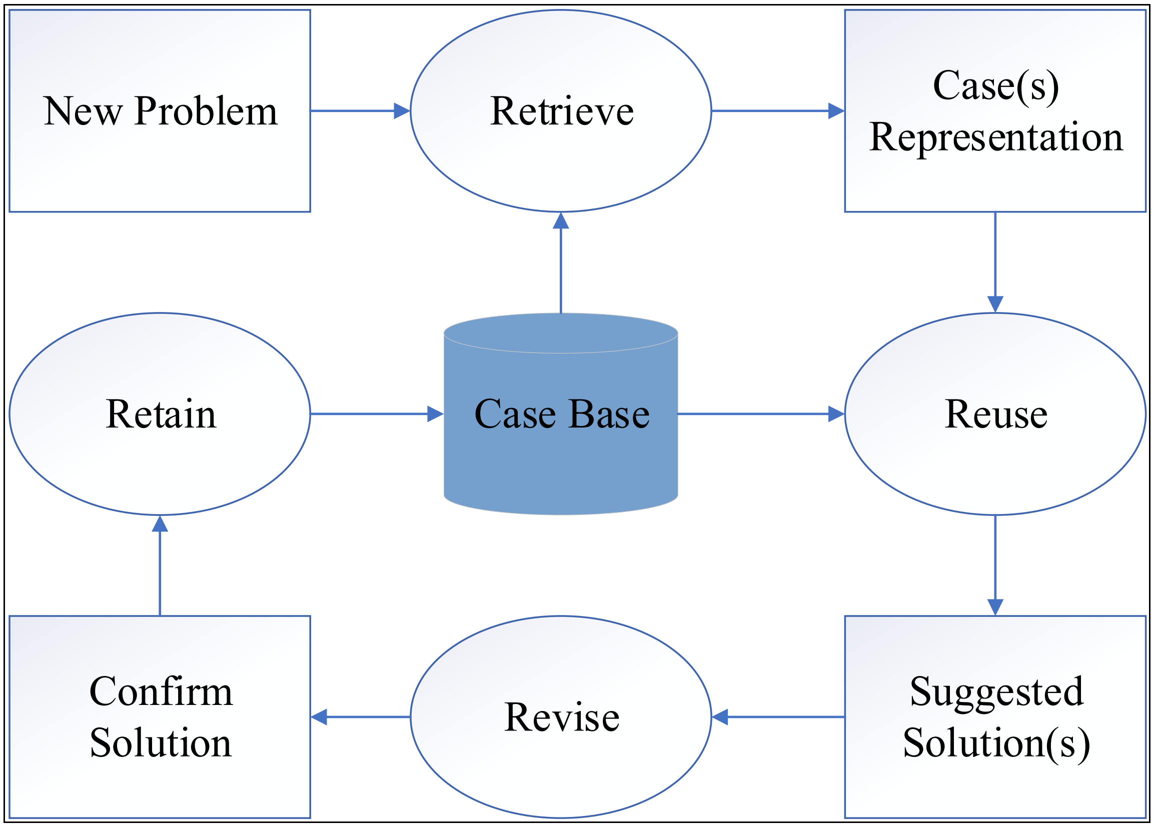


Figure 2.3 Case-Based Reasoning cycle
Adapted from Ozturk & Tidemann (2014, p.4)

2.3.2 Case-Based Reasoning Application

Practically, the CBR applications either the recorded cases have been stored in the case base and the current case can be employed for in the process of decision making in order to define the problem situation and solution domain (Abou Assali, Lenne, & Debray, 2009). CBR is a proper problem-solving method that has been used in various experiences to create numerous system applications in multiple fields such as diagnosis, help desk, design, assessment, and decision support (Shekapure, 2015).

- Diagnosis System: The system retrieves past cases with symptom files, lists the new case, and recommends diagnoses regarding the closeness case through retrieval process. The majority of procedure are various medical CBR diagnosing process.

- Help Desk System: The system is implemented in the customer service sector to handle product or service problems.
- Design System: The system supports designers in the architectural and industrial design area, which human designers have developed.
- Assessment System: The system defines old solutions and customer importance rating values for variables by associating them with something related to the known value.
- Decision Support System: This system is used in decision-making situations; while people face a complicated situation, they usually seek similar issues for potential answers. CBR operations can supported this problem in the retrieval process.

Specifically, CBR is an adopted methodology for aiding designers and engineers in the conceptual product design model. (B. M. Li & Xie, 2013) proposes a new method of retrieving cases and evaluating the issue of One-of-a-Kind products that elicited both customer requirements and customer preferences. Also, they presented a modularized generic product model for identifying data-related customers to facilitate retrieving processes. The application of CBR is also extended with other methodologies to provide a better function. (Kuo, 2010) introduced the CBR and AHP integration to present exceptional decision support for waste electrical and electronic equipment's recyclability during the design stage. Designers could assess the recyclability index of the material through the process of the CBR-AHP methodology. Indeed, they evaluated the recyclability rate for product design by extracting from past information and experiences through the CBR cycle. Also, the help of the AHP determines the similarity weight in the recycling index. Finally, the designers decided the situation of the components and treatment plan for recycling. (Bouhana, Abed, & Chabchoub, 2011) recommended a structure that combines the CBR system with a popular AHP methodology to improve the efficiency in case matching in the personalized itinerary search process. Indeed, the application presented how this procedure can help decision support by applying retrieval process for the most desirable itinerary to satisfy the user. In context of sustainability, (Ramos-Quintana et al., 2019) have been implemented the AHP-CBR approach in order to support the procedure of decision maker to decrease regional uncertain trends of the environmental state. The integration of these methodologies provided a great combination because the CBR is not only able to guarantee selecting of a set of acceptable environment management actions. Hence, this reason effects on the environmental performance of this system but the AHP can help with weighting and ordering variables for data without having the capacity to create an order of precedence.

2.3.3 Case Retrieved Strategy

To successfully execute the procedure of retrieving cases, it is significantly important to determine a set of criteria for choosing cases. Accordingly, it is decided which of them is the most appropriate for this process object. It is also helping the specialist to know what a retriever is exploring for in the case library either it is looking for a few similar features of the new case and old cases or is searching for the whole similar cases with the current case (Zia, Akhtar, Mughal, & Mala, 2014).

Therefore, in this procedure, the focus of CBR system is determining attributes of considering problem from the description, extracting the closest cases to the new problem similarity, and utilizing metrics to match related cases via retrieve process. First, the most similar case is employed as the model of design with function decomposition and unit separation. Next, the engineers are able to adjust the design model until CRs would be satisfied, which this process is called the reuse process of design knowledge. Indeed, knowledge acquisition during case retrieval procedure is captured similarity between each attributes values and matching the nearest associated cases from the database precisely and quickly. The whole retrieval procedure contains two phases. The first phase is extracting useful samples from the case base regarding on VOC specifications and designer experience of designers. The second phase is matching the most similar instances through the hybrid similarity model (H. Wang, Sun, & Shen, 2018).

In the cycle of case-based the procedure of retrieve cases focuses on matching useful old cases towards the optimal resolution of a new case. The primary stage of the CBR system is case representation where each case is demonstrated the set of descriptions related to the problem attributes and solutions (Elmogy & El-Sappagh, 2015). Regarding a new case description valuable list, the case-base is searched for previous cases that can provide decision support. The overall similarity of a new case with a case earlier is estimated by aggregating the similarities and descriptors using a matching function. The old cases that have kept after filtering will be matched and ranked in order to reduce the rate of similarity value. Matching is the manner that evaluates the degree of similarity of old cases with the presented case problem (Fan, Li, & Zhang, 2015).

CHAPTER 3

DESCRIPTION OF CONCEPT METHODODLOGY FRAMEWORK

3.1 Introduction

In this project, we focused on interpreting customers' needs through knowledge transformation between the R&D and marketing departments. Interpretation of CRs appropriately would consider a key source of a company's competitive advantage and the cause of business success. Because of the importance of this subject, the QFD has been utilized as one of the applicable methods in this domain. Later, the QFD-AHP has been proposed to enhance the chance of efficiency of designing products regarding current CRs and alternative solutions for design ideas. On the other hand, we provided an integrated framework to better reuse the past design experiences and present a suitable product design based on the current VOC. In this section, the problem is broken down into procedures that together form the whole framework. Thus, the proposed integrated framework incorporates three methods that comprise three main sub-systems: the Quality Function Deployment sub-system, the Analytical Hierarchy Process sub-system, and the Case-based Reasoning sub-system respectively. Indeed, the integrated framework methodology helps to diminish conflict communication between marketing and R&D departments by taking advantage of each method.

According to the earlier research (Punchihewa, 2010), the critical point is to visualize the product information like CRs, agreeable solutions, and experience-based data to help communication. Therefore, the contribution of these methodologies supports design information to facilitate the presentation of CRs and solutions between different teams. The efficient performance would maintain the gap between the users and the practitioners of design.

3.2 Methodology

For displaying the marketer with the engineer/designer, the Use case diagram has been conducted through Interaction process in two cases: selecting the bicycle's lock in high-risk and low-risk areas. The Use case diagram illustrates the visualization of functional behavior and relations between R&D-marketing departments. The purpose of using this diagram is to represent a communication way for complex ideas in the product development procedure between the R&D and marketing departments. The participation of actors in a use case is illustrated by connecting an actor to a use case by a solid link or association. In this thesis, the use case defines the relations between two different teams through various methodologies. Consequently, through the selection as solution part, the provided solution(s) by CBR method is identified the suitable bicycle locks based on requirements in low/high risk area. In Figure 3.1, the marketers & engineers interaction is depicted in the system platform.

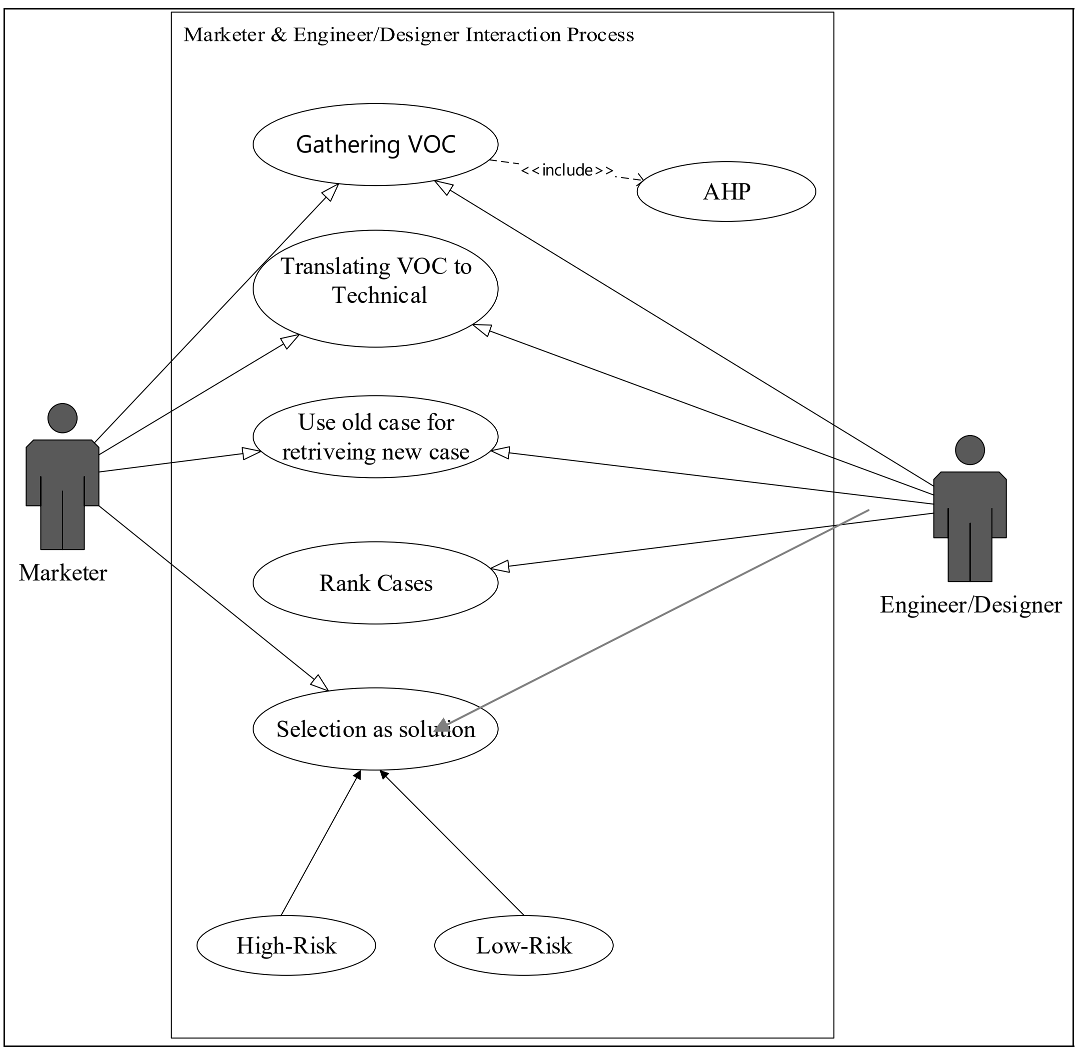


Figure 3.1 Use case diagram

The graph is classified in order of all main activities that are introduced in each sub-system. In this thesis, the method has been illustrated in accordance with a multi-criteria decision-making model with the aid of a QFD matrix for obtaining demands and categorizing them. Classification of basic requirements have been organized in the primary stage with the help of the QFD strategy. But access to the source case base, which contains different information, requires a systematic way to represent relevant information regarding similarity attributes; the AHP illustrates the flexible way in the case of varieties of criteria. In the next level, the CBR method has been retrieved the nearest cases into a new problem case and provided suitable solution(s) according CRs.

3.2.1 Quality Function Deployment Sub-System

The main focus of the QFD sub-system is anticipating users' requirements by involving them in the early process through development because eventually, companies objective is customer's satisfaction about their product(s). The system of model methodology initiates with our customer (user) requirements which we considered a new case or problem in the last stage of the system. As the Figure 3.2 is illustrated, the sub-system operates from right to left side, starting with the extraction of the user desire regarding demand. Then, because the user's expression is usually vague and verbal, we applied the HOQ matrix to convert qualitative data to quantitative data. In other words, this matrix is translating these demands to engineers/designer languages. In the last part, through the matrix calculation, the importance rate of each requirement and the improvement percentage of CRs and TRs are defined.

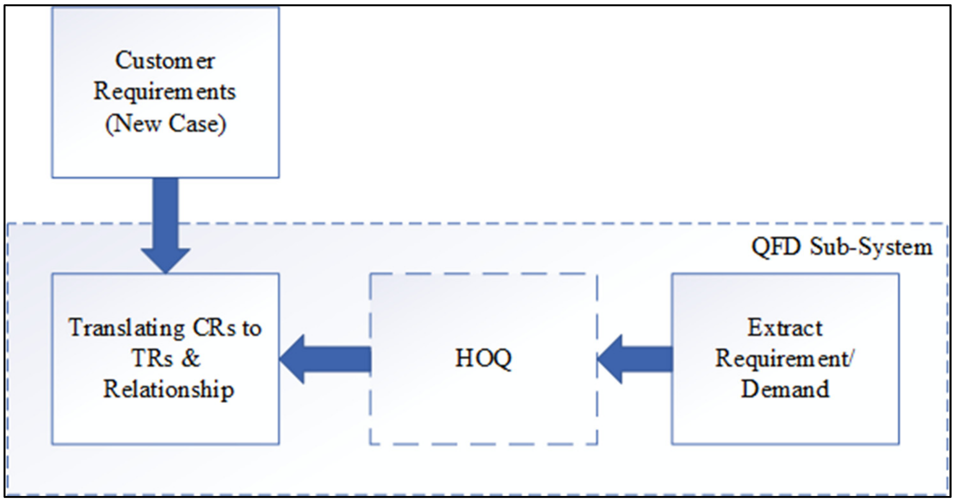


Figure 3.2 Quality Function Deployment sub-system

As mentioned before, the QFD as a tool is a user-centered and structured collaborative design approach to analyze customer demand to match the engineering standpoint. The essential feature in QFD is extracting the requirements from the customer. In this sub-system, the aim is to investigate the potential of the QFD design method to improve communication between customers and engineers in process planning solutions. Indeed, customer satisfaction is a significant element to the product's success in the competitive market. Therefore, designers need to recognize these requirements' relative importance and develop solutions that suit the users required to be given higher priority (Cross, 2021). The HOQ has been proved to have capability in streamlining to visualize the design information and then aid designers in terms of selecting proper solutions to progress in the design procedure for execution. (Punchihewa, 2010).

Therefore, this framework transfers the degree of importance to CRs (the WHATs) into technical requirements (the HOWs). Generally, the HOQ structure contains six main sections. In the third section which is benchmarking the product, the purpose is to analyze the best alternative for each customer expectation compared to main rivals to see how much the products can perform regarding the CRs. Therefore, this part is rated as the same as the first section by the user. As a result, the percentage of the total weight is calculated by the equation (3.1) to analyze how much the design requires to improve (Goetsch & Davis, 2021).

$$\%of\ Total\ Weight \equiv \left(\frac{Overall\ Weight}{Sum\ of\ Overall\ Weight}\right) \times 100 \qquad (3.1)$$

In the fourth section which is relationship matrix illustrates the relationship between what CRs based on the required product and in what way the project team can meet those requirements. On the other hand, the focus of this step is understanding the contribution of TRs to the overall customer satisfaction level and recognizing how these TRs are helpful to satisfy each customer's expectation. In Table 3.1, this comparison has been represented by symbols that are quantified 1-3-9 scale.

Table 3.1 Relations symbols

Relations Matrix		
Grade	Qualitative Symbol	Quantitative Weight
Low	●	1
medium	❍	3
High	▲	9

In the last section the team of expertise sum up all the values for each column of the TRs and write the sum at the bottom of the table which is the absolute importance of each individual engineering characteristics which the design making in this part has a significant impact on the product's success. The value of absolute importance is determined as follow in equation (3.2) (Rajesh & Malliga, 2013):

$$\begin{aligned} &Absolute\ Weight \\ &\quad = V(HOW)_{i1} \times IMP(WHAT_1) + \cdots \\ &\quad + V(HOW)_{in} \times IMP(WHAT_n) \end{aligned} \qquad (3.2)$$

Where $V(HOW)_{in}$ means the relationship value of (HOW_i) with $(WHAT_n)$, and $(IMP(WHAT_n))$ represents the importance of $(WHAT_n)$. After the calculations have been done for each technical measure, the weights have been analyzed, and the most important ones have been recognized. To calculate the relative importance:

$$Relative\ Importance = (Technical\ Priorities\ /Sum\ Score\ of\ Technical\ Priorities\ ) \times 100 \quad (3.3)$$

3.2.2 Analytical Hierarchy Process Sub-System

According to our model system, methodologies are created like a sequencing procedure. The second methodology we applied to the example is AHP. Hence, utilizing AHP in this step defines the weight of criteria and sub-criteria for analyzing case similarity in the next level, which is essential to retrieval cases. The related weight of each attribute describes their importance for calculating among cases. This step constructs use of corresponding data from the QFD matrix. The central part of this methodology is the mathematical process where we established a pair-wise comparison matrix amongst attributes. Consequently, the assignment weights to elements are likely to be used for the next phase seen in the Figure 3.3.

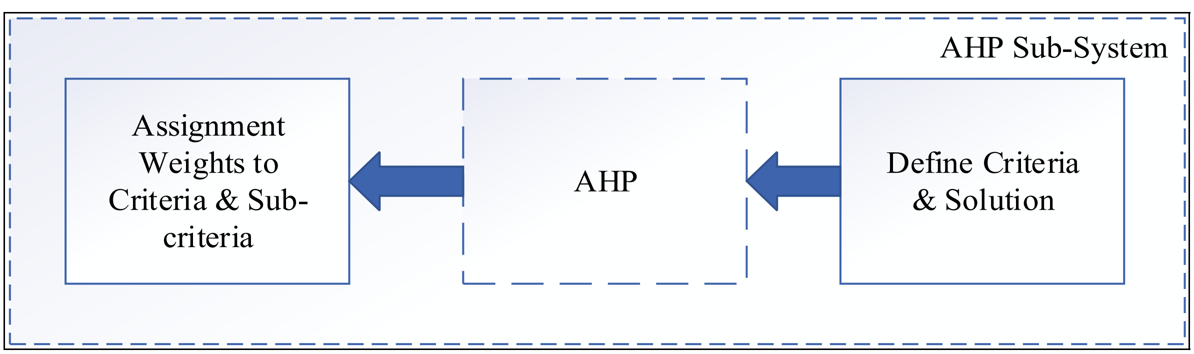


Figure 3.3 Analytical Hierarchy Process sub-system

The mathematical operation of this method started by applying numerical assessment for formulating a pairwise comparison matrix that is the process of comparing all elements. Each candidate matched with other candidates. To assist in the computation process, we used Saaty's interval number scale 1 to 9 which is shown in Table 3.2.

Table 3.2 Fundamental scale of comparison matrix
Taken from Puspitasari, Sari, Destarianto, & Riskiawan (2018, p.4)

Numerical Assessment	**Linguistic meaning**
1	Equal important
3	Moderately more important
5	Strongly more important
7	Very strongly important
9	Extremely more important
2,4,6,8	Intermediate values of importance

The type of mathematics is operated for comparison matrix is linear algebra. For instance, if the problem consists of n criteria, then decision matrix *A* that is shown below, takes the form of the dimension where is the number as '1' on the diagonal.

$$A = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix} \tag{3.4}$$

After identifying the dimension of the matrix *A* with objective, for comparing pairs of criteria at each level, it is required to arrange relative priorities with respect to their weights. The weighting vector of matrix *A* is formed below:

$$A = \begin{bmatrix} \frac{W_1}{W_1} & \frac{W_1}{W_1} & \cdots & \frac{W_1}{W_n} \\ \frac{W_2}{W_1} & \cdots & \cdots & \cdots \\ \vdots & \vdots & \vdots & \vdots \\ \frac{W_n}{W_1} & \frac{W_n}{W_2} & \cdots & \frac{W_n}{W_n} \end{bmatrix} \tag{3.5}$$

Let consider matrix A where is expounded as the degree of preference of ith criteria over jth criteria. Therefore, matrix A is generated with each positive value ($a_{ij} > 0$) (Srdjevic & Srdjevic, 2013) and the elements satisfy by the following conditions:

$$a_{ij} = \frac{w_i}{w_j} \quad , \; a_{ij} = \frac{1}{a_{ij}} \;\; \text{and} \;\; a_{ii} = 1 \quad \text{for all} \;\; i, j = 1,2, \dots, n. \tag{3.6}$$

The decision comparison matrix with the Saaty method is determined as the eigenvector or characteristics vector. The principal eigenvector is a necessary representation of the priorities derived from a positive reciprocal pairwise comparison judgment matrix $A = (a_{ij})$ and it demonstrates the inconsistency is less than or equal to a required value. Following, for providing the relative weights of criteria, estimating the matrix eigenvalues is needed to calculate which process is standard in mathematics. This level needs to normalize each column in A, where the .Thus, the relative weights are verified by solving the eigenvector problem (Srdjevic & Srdjevic, 2013) and we applied following equation to calculate maximum eigenvalue (3.7):

$$A \cdot W = \lambda_{max} \cdot W \tag{3.7}$$

Where A expresses the pairwise comparison matrix, W represents the eigenvector and the highest eigenvalue. Therefore, the hierarchy calculation process is as follows: at the top-level of the hierarchy, the acquired weight vector is multiplied with coefficients weight of the attributes at the upper-level till to the top of the hierarchy. Throughout the evaluation process, in order to reflect the decision maker's judgment consistency, an index of inconsistency should also be calculated by AHP. In this regard, equation (3.8) can be employed for calculating pairwise comparison and decision matrixes' index of inconsistency (Alptekin & Büyüközkan, 2011).

$$CI = (\lambda_{max} - n)/(n - 1) \tag{3.8}$$

Finally, the interpretation of the matrix calculation and the result displays that; if the Consistency Ratio (CR) is less than 0.10, the set of judgments is less inconsistent and reliable.

3.2.3 Case-Based Reasoning Sub-System

The last stage of the methodology framework is adapted to the concept of CBR methodology by inspiring from retrieving stage to choose appropriate solutions regarding the user desire. In fact, this section's objective is to precisely apply the retrieval phase to analyze the similarity between cases.

As illustrated in Figure 3.4, the sub-system procedure started by bringing up user requirements from other sub-systems through the CBR system as criteria. The foremost step after prioritizing requirements is the solution determination which typically uses the previous experience of the customers and practitioners. A database was considered beneficial to store the design information gathered from projects. It would store the information that is presented in the proposed QFD-based matrix.

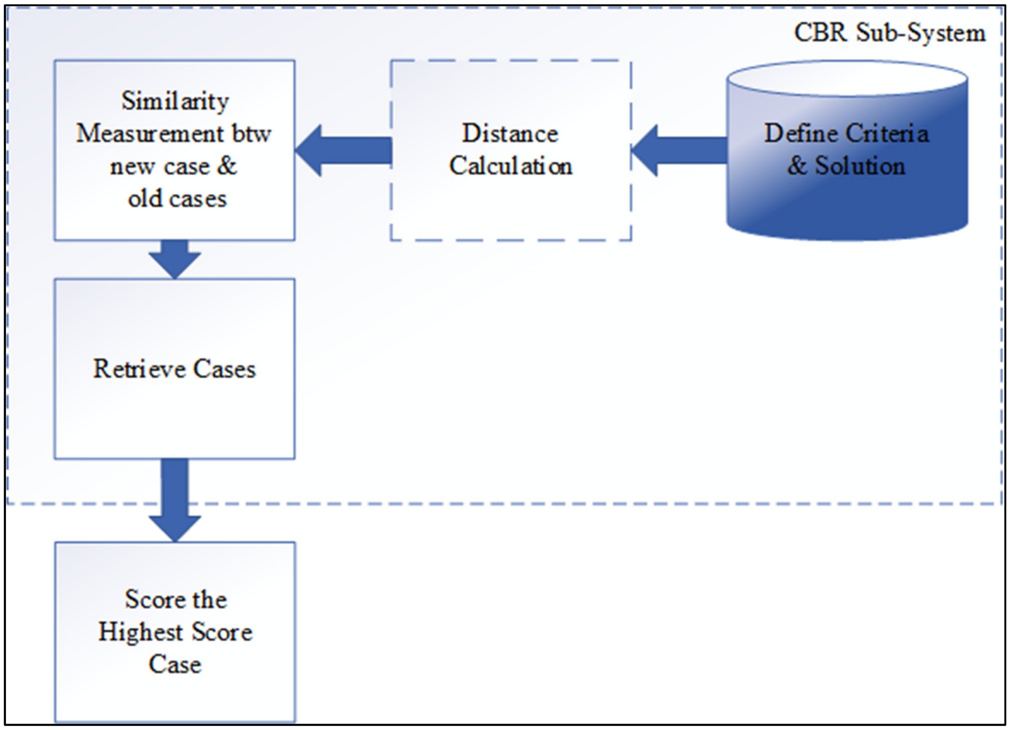


Figure 3.4 Case-Based Reasoning sub-system

The central operation part of CBR is related to the retrieving phase. The function of this stage depends on the cases' representation, indexing, and organization in the base of cases. The main pursuit is measurement of the closeness in order to search for the most similar case to the current issue in the case base. Hence, the degree of closeness matches to the utility/adaptability of possible solutions.

Technically, the similarity function is determined by specific objectives and includes a set of attributes. Accordingly, the similarity of one case to others is represented by averaging the distinct similarities of part of the case. For instance, a case with indexed attributes (x_i, x_j, x_z) will be similar to another case (y_i, y_j, y_z) if the attributes *i, j* and *z* of the cases x and y are similar to each other. Therefore, similarity index between the memory and the current case problem are calculated. We performed this procedure in two main steps. Firstly, calculation of the local similarity between attributes of new case with existing cases together has been done by selecting various measurements. This partial similarity by attribute is defined local similarity. In this regard, equation (3.9) that is local similarity measure formula has been employed when the attribute is continuous (Bouhana et al., 2011).

$$sim\ (X_i^{mem}, X_i^{New}) = 1 - \frac{|X_{mem} - X_{new}|}{X_i^{max} - x_i^{min}} \tag{3.9}$$

Where X_i^{mem} indicates case's attributes available in memory and X_{new} denotes the current case's attributes. In addition, x_i^{min} and x_i^{max} represent the minimum and maximum values concerning all the cases (involving the case that is our target) for the attributes, correspondingly.

For determination of the most similar case, weights' valuation is of great importance. However, in our model, the weights have been estimated through the AHP technique mentioned in the previous stage. Moreover, the last step of measuring similarity is calculating the global similarity between the case problem and database cases. The result represents the appropriate case for revising the solution(s) (Srdjevic & Srdjevic, 2013). For calculating global similarity, the formula (3.10) has been represented as follow:

$$SIM\ (x, x') = \frac{\sum_{i=1}^{n} T * W_i}{\sum_{i=1}^{n} W_i} \tag{3.10}$$

Where *x* presents the case already available in memory, *x'* denotes the target case, *n* indicates attributes' number of each case and *T= sim* displays the local similarity, and finally, W_i that is each case's weight is already gained from AHP analysis. Eventually, the case that has greater global similarity with the new case can be chosen.

CHAPTER 4

APPLICATION

4.1 An illustrative Example

We investigated the methodology model with an illustrative example. The bicycle theft issue is used to propose solutions for this prevalent problem. For this purpose, we mainly focused on the different types of bike locks to check out which one is proper, especially in high-risk areas like university or college campuses. The security of the bicycle has been considered all the time for those commuting with bikes daily. Thus, different types of locks have been produced and designed to provide more security. The key feature shared between many of them is not to make an unbreakable lock, but only to make it take as long as possible to break it. In addition, the shape of the lock is also significant, which allows attaching both frame and wheel. Therefore, we analyzed some popular bicycle locks in order to examine our integrated framework methodology.

4.1.1 Data Collection

The study was administered through the case study to assess the usability and practicability of the developed methodology for potential users. In the first step, we did initial communication with the user to gather the voice of the customer (user) for the demand-based data. Then, we prioritized the user requirement based on the importance rating that we had asked the user to give the rate using the Liker type scale (1=The less Important to 5= The Most Important). The evaluation of CRs needs to understand user demand, behaviors, and experiences regarding the product. Further, we reviewed some websites to collect data related to the various design of bike lock with different purposes and the customer perspective in the market. After completing this part, we started analyzing the procedure by applying related data into the HOQ matrix; then, we continued to implement other methodologies step-by-step.

4.1.2 Customer Requirements Analysis

Identifying CRs necessitates gathering the user demand for selecting the applicable bike lock. Then, the data received from customers is translated into the engineering design platform, where the main components for determining the model. In this context, we did not have enough respondents. However, it was decided to focus on a target user who is a student and lives in Montreal. Also, she uses the bicycle as a way of transportation for commuting almost every day to the university, doing grocery shopping, etc. Therefore, we assumed one user requirement data to evaluate the proposed method based on an example and obtain the primary outcome through the responder's information. On the other hand, CRs have been considered as initial data corresponding to the study's main problem feature.

Concerning the fundamental design of locks and the safety of bicycles, researchers' investigation came to order the product's characteristics into four groups: Appearance, Performance, Functionality, and Usability (Rianmora & Werawatganon, 2021). Hence, the result of categorizing specific requirements is illustrated in the Figure 4.1.

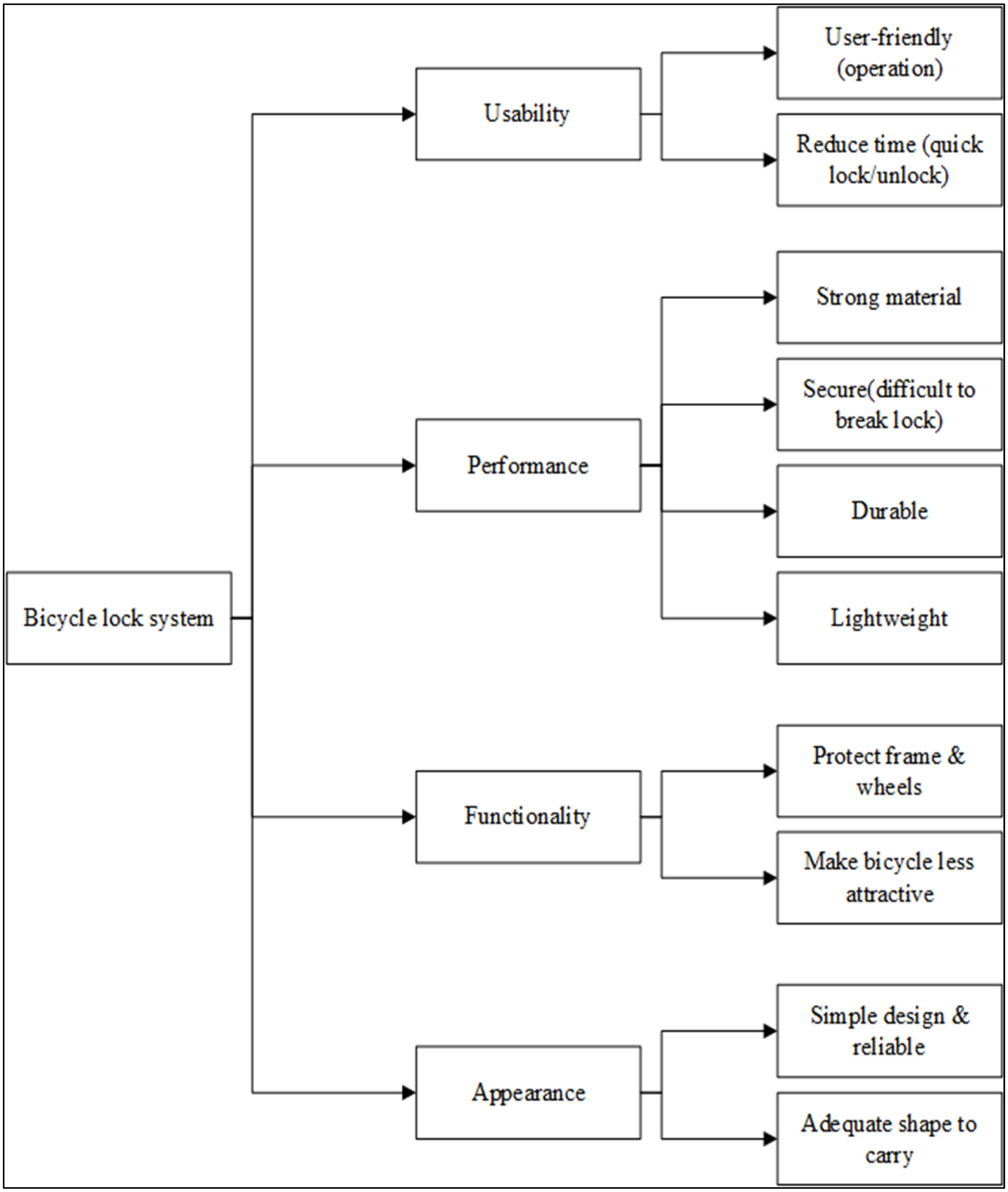


Figure 4.1 Tree diagram of specific requirement

4.1.3 Market Research

Generally, there are two organizations for bicycle lock standard rating Sold Secure and ART; they evaluate and test the level of resistance and safety of different bicycle locks based on how long the lock can attack by many methods. ART standard rates on the scale of 1-5, being the best to worst, and Sold Secure standard evaluated based on four categories of Diamond, Gold, Silver, and Bronze. Nevertheless, choosing the right bicycle lock depends on the situation. Accordingly, we gave from 0 to 4 scored for showing factors that increase or decrease risk of bicycle theft. These three questions below, presented in Table 4.1, can quickly help select a bike lock to specify which level is suitable for the user.

Table 4.1 Bicycle lock evaluation questions based on the risk
Adapted from Ellis (2021, p.10)

Risk factor	Level of risk	Score
Parking location	Well overlooked car park	1
	Poorly overlooked car park	2
	In street with lots of activity	2
	In street with low activity	3
Time left park	More than 1 hour	3
	Less than 1 hour	1
Security level of the lock(s) used	Dimond/Gold	0
	Silver	1
	Bronze	2
	No standard	3
The general level of street crime in the area	Low	1
	High	4

After market research, we consider six main bicycle locks, typically categorized into high-risk and low-risk areas for their suitability purposes. These bike lockers are recognized as U-Lock, Chain lock, Tex-lock, Smart Bike lock, Seaty lock, and Folding lock. The details of each are demonstrated in Table 4.2. After market research, we consider six main bicycle locks, typically categorized into high-risk and low-risk areas for their suitability purposes. These bike lockers are recognized as U-Lock, Chain lock, Tex-lock, Smart Bike lock, Seaty lock, and Folding lock. The details of each are demonstrated in Table 4.2.

Table 4.2 Market research on types of bicycle locks

Characteristic	**Shape**
Medium to High-security level, practical-sized for a different type of bicycle, and the heavy locks (Suitable for High-Risk area)	
Medium to High- security level, the flexible to load more locking opportunities, and the heavy weight lock (Suitable for High-Risk area)	
Medium to High-security level, Variety in size and length, high technology material, and the light to medium weight lock (Suitable for High-Risk area)	
Mid-security level, it is keyless operation, unlocking with technology application, and smart theft alarm. (Suitable for Low-Risk area)	

Table 4.2 Market research on types of bicycle locks (cont'd)

Characteristic	Shape
Mid-security level, the long enough to lock around bicycle, No need to carry, mountain on the bike. (Suitable for Low-Risk area)	
Mid-security level, easy and flexible unlock, re-lock around the bicycle, and light weight lock (Suitable for Low-Risk area)	

4.2 Analyzing Through Multiple Research Methodologies

The process starts with the initial input of the user's requested information and is known as a new case in the system. Then, the problem features function in each sub-system. Finally, the solution's focus is identifying the desired design based on the prioritizing requirements to satisfy customers. The integrated framework is illustrated in Figure 4.2.

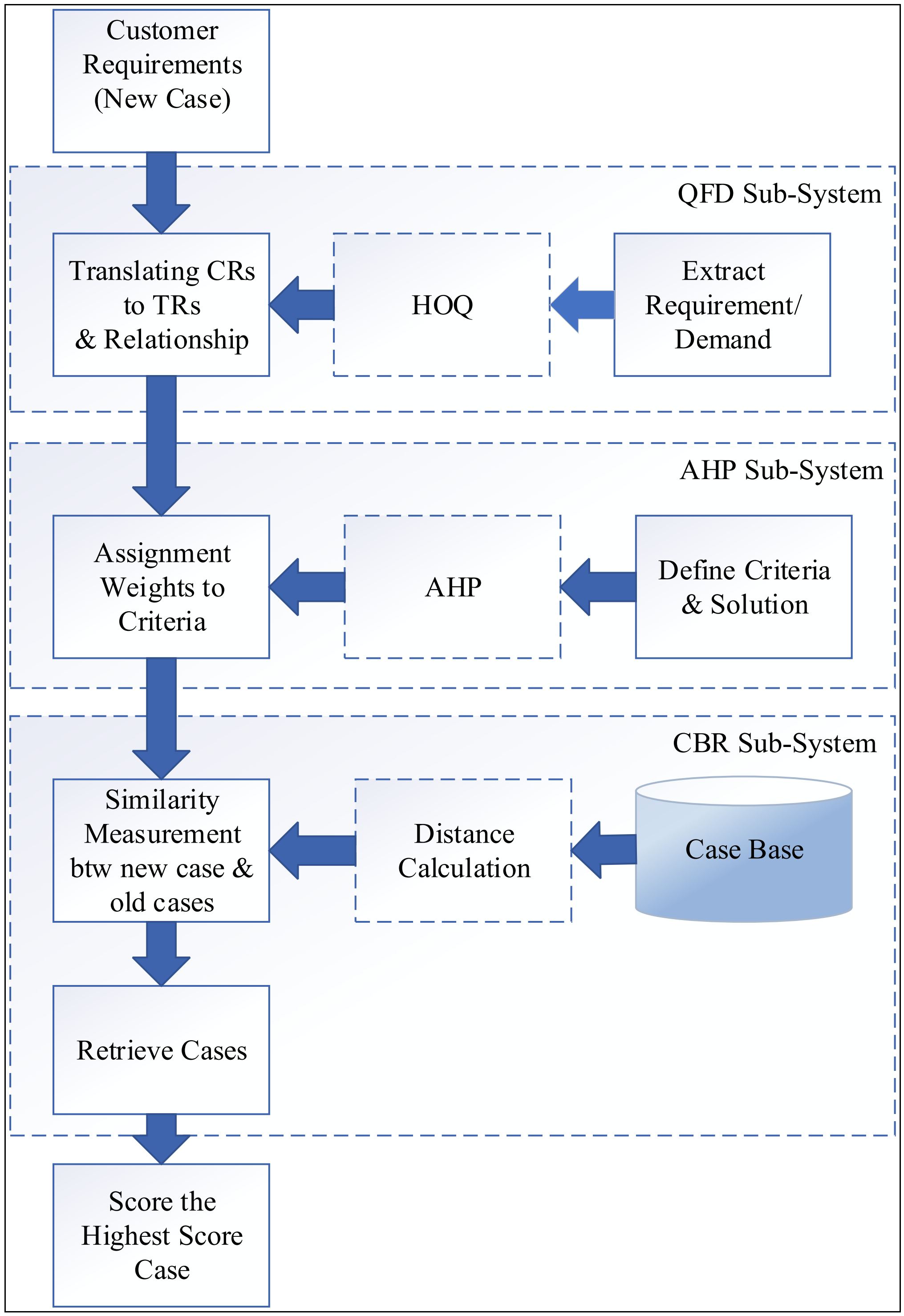


Figure 4.2 Methodology integrated framework

4.2.1 Voice of Customer-House of Quality Matrix

In chapter 3, we specified our target user requirements in a tree diagram. We considered asking customer why she had such demands until essential requirements became apparent. The problem is selecting an appropriate bicycle lock which the student wants to lock her bike in a high-risk area such as a university or downtown area. A feature explanation of the customer's voice terms is represented in Table 4.3 below:

Table 4.3 Product characteristics definition

Voice of customer	**Definition**
User-friendly (operation)	The lock mechanism is not complicated, and an easy-to-use interface is provided.
Reduce time (quick lock/unlock)	The product is designed in such a way that installing or uninstalling the lock is fast and does not require special skills to open or close it.
Strong material	Technically, for different types of locks for making the strong lock, the hardened steel material is used in this way; the product has been put through several hardening processes.
Secure (difficult to break lock)	The lock should test for high resistance against thieves' methods used to defeat locks, cutting, and hammering.
Durable	The level of resistance is enough against any damages by variant equipment.
Light weight	The bike lock can be smoothly moved and relocated.
Protect the frame and wheel	The adequate size creates a tiny gap to reduce the amount of space as long as it rounded the wheel and the frame to fix the objective.
Make the bicycle less attractive	Reduce the chance of being stolen
Adequate shape to carry	The product provides the possibility to attach or mountain to the bicycle frame or cyclist.
Simple design	It is more convenient for repairing and has higher reliability

Now we start to draw the HOQ matrix. The main component of this matrix is user requirements that located on the left side, and the following column indicates the importance range of these requirements. The matrix's second significant component is engineering requirements that appears on the top of the house. Moreover, to display the relationship between CRs and TRs, we use qualitative symbols. The location of the comparison is in the middle of the matrix. To clarify the following symbols, we reposition them to quantitative value Table 4.4, and these symbols express the quantitative weight by the value of 9 for strong, 3 for medium and 1 for weak range. Then, each importance rate of customer requirements (WHATs) is multiplied to quantitative value of each engineering requirements. The result represents the relationship matrix between CRs and TRs. The next step is to sum up all the values for each column of the TRs and write the sum at the bottom of the table which is the absolute importance of each individual engineering characteristics.

Table 4.4 Customer requirements and technical requirements relation

HOWs / WHATs	Importance Rate (1-5)	Established market opportunity	Long enough to protect both frame and wheel	Big shackles thickness	Hardened steel for protecting from attack	Flexible lock frame	Foldable lock	Time to lock(s)	Innovative design	Integarting with technology	Alarm system	Performance expectation (action, behavior)	Test standard for effective security
User-friendly (operation)	4	4	12			12	12	12	4	36		4	
Reduce time (quick lock/unlock)	3	3	3			9	27	27	3	9		3	
Strong material	5	5		45	45	5			15	5			5
Secure (difficult to break Lock)	5	15		45	45			15	15		5	5	45
Durable	4	4		36	36	36			12	4		12	12
Lightweight	3	27		27	3		9					27	3
Protect the frame and wheel	5	45	45			15	45		45			15	5
Make the bicycle less attractive	4	4		4							36	4	
Adequate shape to carry	3	3	3			27	27		3				
Simple design	2	2	18			6	6	6	2			6	2
Absolute Importance		112	81	157	129	110	126	60	99	54	22	76	72

Furthermore, the entire matrix is provided in the Figure 4.3. In order to demonstrate the mathematical calculations and description of other parts of the HOQ matrix, a first user's requirement "User-friendly" (operation) is mentioned. The right side of our table belongs to analyzes the performance of six varieties of bicycle locks that; the user rating scale provides the process from 1-5 to the performance of each of them based on their requirements. The outcome of this column is the percentage of the total weight that is calculated by equation (3.1) and the result of first customer's requirement, corresponds to:

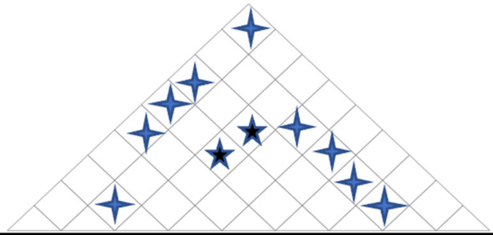
$$\%\, total\ weight = \left({}^{4}/_{47}\right) \times 100 \approx 9\% \tag{4.1}$$

The measurement results of all requirements are represented a column in HOQ matrix which depicts the improvement consideration for the target product compared to competitors.

On the top of the house, there is a triangle shape that expresses the correlation between each TRs; and also, for this part, we used two symbols for just visualizing. These two symbols display the strong correlation (✦) and weak correlation (★). Hence, the row below the triangle shape mentions the direction of improvement for each TRs. The last step is the computation of the bottom of the matrix house. The result corresponds to the absolute importance and relative importance of the CRs and TRs relationship by multiplying each importance rate that we have already calculated in equation (4.2) and (4.3).The results for the "Establish market opportunity" with all CRs is provided below:

$$\begin{aligned} &Absolute\ Importance \\ &= (4 \times 1) + (3 \times 1) + (5 \times 1) + (5 \times 3) + (4 \times 1) \\ &+ (3 \times 9) + (5 \times 9) + (4 \times 1) + (3 \times 1) + (2 \times 1) \\ &= 112 \end{aligned} \tag{4.2}$$

$$Relative\ Importance = \left({}^{112}/_{1098}\right) \times 100 \approx 10\% \tag{4.3}$$



WHATs / HOWs	Importance Rate (1-5)	Established market opportunity	Long enough to protect both frame and wheel	Big shackles thickness	Hardened steel for protecting from attack	Flexible lock frame	Foldable lock	Time to lock(s)	Innovative design	Integarting with technology	Alarm system	Performance expectation (action, behavior)	Test standard for effective security	Current performance	Competitor 1 (U-Lock)	competitor2 (Chain Lock)	competitor3 (Folding Lock)	competitor4 (Seaty Lock)	competitor5 (Smart Bike Lock)	competitor6 (Tex- Lock)	Target	Improvement factore	Overall weight	% of Total weight
Direction of Improvement		↑	↓	↓	↓	↓	↓	↑	↑	↑	↑	↑	↓											
Usability																								
User-friendly (operation)	**4**	●	○			○	○	○	●	▲		●		5	4	4	5	4	4	5	**5**	**1**	**4**	**9%**
Reduce time (quick lock/unlock)	**3**	●	●			○	▲	▲	●	○		●		3	5	4	5	3	4	4	**4**	**1.2**	**3.6**	**8%**
Performance																								
Strong material	**5**	●		▲	▲	●			○	●			●	2	5	5	4	3	4	4	**5**	**1.6**	**8**	**17%**
Secure (difficult to break lock)	**5**	○		▲	▲			○	○		●	●	▲	2	5	5	4	3	3	4	**4**	**1.4**	**7**	**15%**
Durable	**4**	●		▲	▲	▲			○	●		○	○	3	5	4	4	3	4	4	**4**	**1.2**	**4.8**	**10%**
Lightweight	**3**	▲		▲	●		○					▲	●	4	3	2	4	5	5	5	**5**	**1.2**	**3.6**	**8%**
Functionality																								
Protect the frame and wheel	**5**	▲	▲			○	▲		▲			○	●	5	4	3	5	5	2	5	**5**	**1**	**5**	**11%**
Make the bicycle less attractive	**4**	●		●							▲	●		3	4	3	3	4	4	4	**4**	**1.2**	**4.8**	**10%**
Apperance																								
Adequate shape to carry	**3**	●	●			▲	▲		●					2	3	3	5	5	5	4	**4**	**1.4**	**4.2**	**9%**
Simple design	**2**	●	▲			○	○	○	●			○	●	4	4	4	5	5	3	4	**4**	**1**	**2**	**4%**
Absolute Importance		112	81	157	129	110	126	60	99	54	22	76	72											
Relative Importance		10%	7%	14%	12%	10%	11%	5%	9%	5%	2%	7%	7%											
Competitor 1		8	6	9	9	2	5	6	6	6	3	8	9											
Competitor 2		8	8	8	8	7	6	6	5	3	1	7	5											
Competitor 3		6	7	4	3	8	9	7	8	3	1	6	5											
Competitor 4		4	7	4	3	8	8	5	9	4	1	6	4											
Competitor 5		4	3	5	7	3	4	8	9	9	9	6	4											
Competitor 6		5	7	7	7	8	7	7	9	9	1	8	8											
Target		**8**	**8**	**6**	**8**	**9**	**7**	**7**	**6**	**7**	**7**	**7**	**8**											

Figure 4.3 House of Quality

4.2.2 Prioritization in Analytical Hierarchy Process

Technically, the fundamental structure of AHP depends on the problem's complexity. Our sample hierarchy model has a three-layer structure, and the first layer indicates our central issue bicycle lock system. Then, the second layer includes the main criteria level, which we considered four criteria: Usability, Performance, Functionality, and Appearance. Ultimately, the last layer contains ten sub-criteria that are: User-friendly (operation), Reduce time (quick lock/unlock), Strong material, Secure (difficult to break lock), Durable, Lightweight, Protect the frame and wheel, Make the bicycle less attractive, Simple design, and Adequate shape to carry. Finally, the case or the problem feature consists of four main criteria, ten sub-criteria, and six alternatives representing the solution (bicycle lock) to fulfill the user requirements and are structured the case-based construction in this example.

We started the essential mathematical part by creating the square compassion matrix. In matrix A1, we implemented a series of algebra procedures to compare four criteria elements together from hierarchy to determine their weight. Suppose the comparison is n=4, which is the number of our criteria. In that case, the logic explication of the matrix is as follows: firstly, we provided the initial matrix table in which the principal diagonal includes entries of 1 that explain each element is as important as itself. In addition, an integer signifies that the row entry is more important than the column entry; in this table, the inverse is used when the column is more important. Then, with the help of matrix (3.4), we could display the comparison. For instance, we consider 5 for the second entity "Performance" in the column with compare "Usability" criteria and vice versa; the value 1/5 is given in a row in the matrix. The implemented process for all criteria can be seen in Table 4.6.

Table 4.5 Pair-wise comparison matrix

A1				
Criteria	Usability	Performance	Functionality	Appearance
Usability	1	1/5	1/4	4
Performance	5	1	2	5
Functionality	4	1/2	1	6
Appearance	1/4	1/5	1/6	1
Sum	10.25	1.9	3.42	16

Now, it is required to normalize the previous comparison matrix table, which indicates dividing each value by the sum of the column value, and the total of each column is equal to "1". After normalizing the matrix, we have calculated the criteria weight that is measured by averaging all the elements in the row. We have just added all these values and divided them by the number of criteria, which is 4, and the result will be criteria weight. All the operation is shown in equation and Table 4.7.

Table 4.6 Normalized matrix

A2					
Criteria	Usability	Performance	Functionality	Appearance	Criteria weight
Usability	1/10.25=0.10	0.11	0.07	0.25	0.13
Performance	5/10.25=0.49	0.53	0.59	0.31	0.48
Functionality	4/10.25=0.39	0.26	0.29	0.38	0.33
Appearance	0.25/10.25=0.02	0.11	0.05	0.06	0.06
Sum	1	1	1	1	1

$$Criteria\ weight = \frac{0.10 + 0.11 + 0.07 + 0.25}{4} = 0.13 \qquad (4.4)$$

The next step is to calculate the consistency that checks whether the calculated values are correct or not. Accordingly, we used Table 4.7 which is not normalized, so each value in each column is multiplied by its criteria weighted value. For illustration, the first column in the Table 4.8 indicated the operation. Likewise, the operation is similarly applied for all columns.

Table 4.7 Measuring the consistency (1)

A3				
Criteria weight	0.13	0.48	0.33	0.06
Criteria	Usability	Performance	Functionality	Appearance
Usability	1*0.13=0.13	0.096	0.0825	0.24
Performance	5*0.13=0.65	0.48	0.66	0.3
Functionality	4*0.13=0.52	0.24	0.33	0.36
Appearance	0.25*0.13=0.32	0.096	0.055	0.06

In the following Table 4.9 for measuring the consistency, we carried out the weighted sum value, which is measured by taking the sum of each element in the rows. In the equation can be seen that by adding all these terms, we will get a weighted sum value. In order to calculate the Consistency ratio (CR), primarily, it is needed to specify the value of and the number of factors. In this respect, the further step is measuring the ratio of weighted sum value and criteria weigh for each row, and the results are demonstrated in Table 4.10.

Table 4.8 Measuring the consistency (2)

A4						
Criteria	Usability	Performance	Functionality	Appearance	Criteria weight	Weighted sum value
Usability	0.13	0.096	0.0825	0.24	0.13	0.55
Performance	0.65	0.48	0.66	0.3	0.48	2.09
Functionality	0.52	0.24	0.33	0.36	0.33	1.45
Appearance	0.32	0.096	0.055	0.06	0.06	0.24

$$Weighted\ Sum\ Value = 0.13 + 0.096 + 0.0825 + 0.24 = 0.55 \tag{4.5}$$

Table 4.9 Measuring the consistency (3)

A5	
Usability	$\frac{0.55}{0.13} = 4.23$
Performance	$\frac{2.09}{0.48} = 4.35$
Functionality	$\frac{1.45}{0.33} = 4.39$
Appearance	$\frac{0.24}{0.06} = 4.06$

The maximum eigenvalue (λ_{max}) is now calculated by the arithmetic average of all the values from Table 4.10. The operation can be represented in the following equations (4.6) and (4.7) below:

$$\lambda_{max} = \frac{\sum_{i=1}^{n} \alpha_i}{n} \tag{4.6}$$

$$\lambda_{max} = \frac{4.23 + 4.35 + 4.39 + 4.06}{4} = 4.26 \tag{4.7}$$

The further step is to calculate the Consistency Index (CI) to reflect evaluation decisions. The result is shown by equation (4.8), where *n* is the number of evaluated criteria.

$$CI = \frac{(4.26 - 4)}{(4 - 1)} = 0.086 \tag{4.8}$$

The last evaluation in order to verify the CI is adequate. Besides, the CR has been calculated which has been given by the division of CI with Random index (RI) by showing in the following formula. The RI value is the consistency index of the randomly generated pair-wise matrix and is a fixed value up to 10 criteria and in our example the value for 4 criteria is 0.9, as can be seen in the Table 4.11.

Table 4.10 Random Index (RI) Taken from (Gokhale, 2007)

N	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

$$CR = \frac{CI}{RI} < 0.1 \sim 10\% \tag{4.9}$$

$$CR = \frac{0.086}{0.9} = 0.096 < 0.1 \sim 10\% \tag{4.10}$$

The result shows that the matrix can be assumed consistent and trustful as long as the value is less than 10%. The following bar chart in the Figure 4.4 demonstrates the priority outcome for the criteria in the first level.

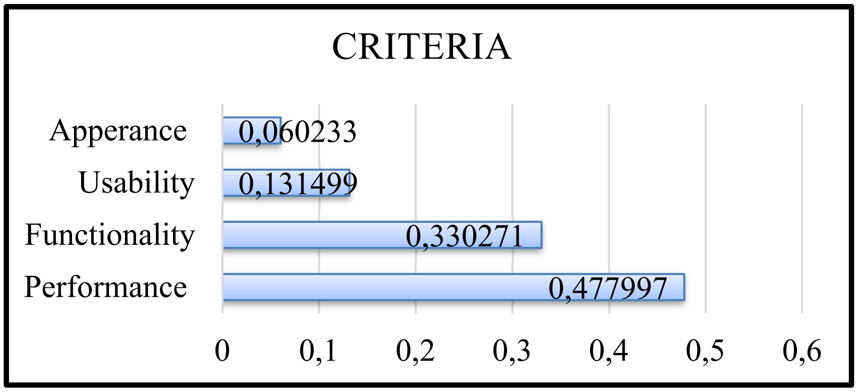


Figure 4.4 Priority weight results

The following Table 4.12, 4.13, 4.14, and 4.15 demonstrate the comparison pair-wise matrix for all sub-criteria.

Table 4.11 Pair-wise comparison matrix for sub-criteria (1)

Usability		
Sub-criteria	User-friendly	Reduce time
User-friendly	1	4
Reduce time	1/4	1
sum	1.25	5

Table 4.12 Pair-wise comparison matrix for sub-criteria (2)

Performance				
Sub-criteria	Strong material	Secure	Durable	Lightweight
Strong material	1	3	3	6
Secure	1/3	1	2	4
Durable	1/3	1/2	1	3
Lightweight	1/6	1/4	1/3	1
Sum	1.83	4.75	6.33	14

Table 4.13 Pair-wise comparison matrix for sub-criteria (3)

Functionality		
Sub-criteria	Protect whole body	Less attractive
Protect whole body	1	2
Less attractive	1/2	1
Sum	1.50	3

Table 4.14 Pair-wise comparison matrix for sub-criteria (4)

Appearance		
Sub-criteria	Adequate shape	Reliable
Adequate shape	1	2
Reliable	1/2	1
Sum	1.5	3

The bar charts Figure 4.5, 4.6, 4.7, and 4.8 below represent the sub-criteria's priority results for each criteria group regarding their weights.

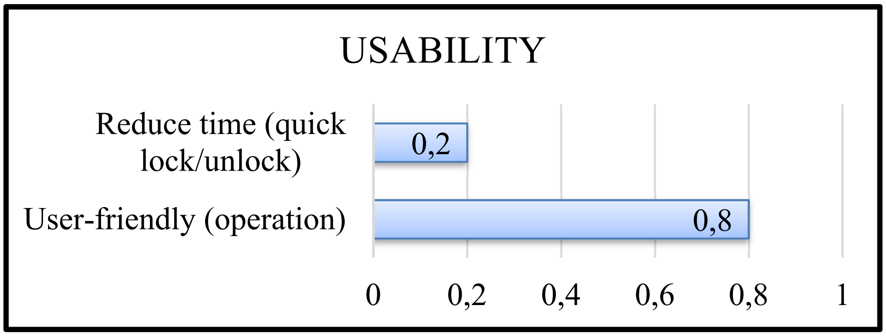


Figure 4.5 Priority weight results for sub-criteria (1)
Inconsistency= 0

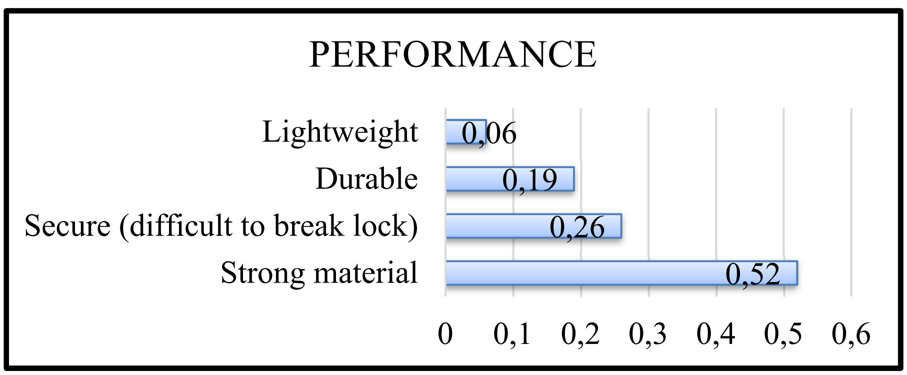


Figure 4.6 Priority weight results for sub-criteria (2)
Inconsistency= 0.07

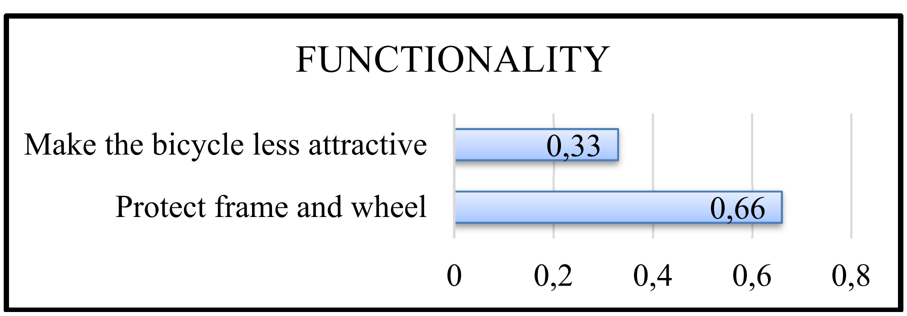


Figure 4.7 Priority weight results for sub-criteria (3)
Inconsistency=0

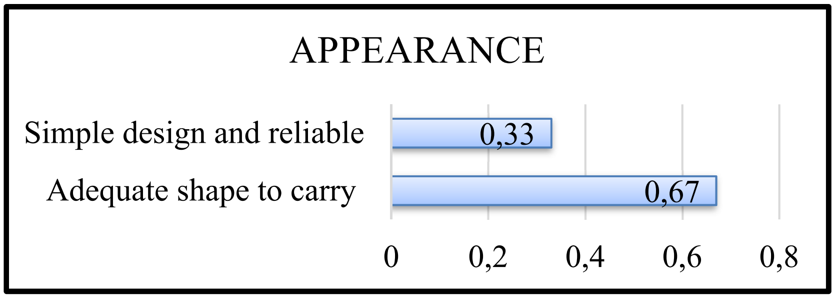


Figure 4.8 Priority weight results for sub-criteria (4)
Inconsistency=0

The last steps in this sub-system is defining global priority for each criteria by multiplying each priority weight on the first level by its respective priority weight on the second level which is the sub-criteria. Ultimately, the results of priority weight with their rank can be seen in the Table 4.16.

Table 4.15 Global priority for each criterion

Main Criteria	**Weight**	**Priority**	**Rank**
Usability	0.13		
User-friendly (operation)	0.8	11%	5
Reduce time (quick lock/unlock)	0.2	3%	9
Performance	0.47		
Strong material	0.52	25%	1
Secure (difficult to break lock)	0.26	12%	3
Durable	0.19	9%	6
Lightweight	0.06	3%	8
Functionality	0.33		
Protect the frame and wheel	0.66	22%	
Make the bicycle less attractive	0.33	11%	4
Appearance	0.06		
Adequate shape to carry	0.67	4%	7
Simple design and reliable	0.33	2%	10

4.2.3 Case-based Reasoning (CBR) Process

Customer requirements have been analyzed and their importance rates defined in previous sections to simplify the matching process in accordance with user needs. Now, in this section, in order to show performance of CBR method, CBR sub-system is applied in our example. Technically, the purpose during this phase is choosing a suitable locker design idea for a bicycle to protect the bike from theft and stealing. Indeed, through the adaption procedure, which is retrieve stage of CBR method, the outcome with the highest global similarity would be the best-case solution. Accordingly, the bicycle locks database has been provided to support index design evaluation utilizing the CBR methodology. This database contains old cases that are related to the problem case. Therefore, cases are of great significant in this method. The case index includes three groups of information: information about description of structure (DoS), adaption data (Ad), and solution of problem (SoP). The bicycle lock database is determined according to this formula:

$$DB = Case_{i=1}^{n}\{DoS_i, Ad_i, SoP_i\} \tag{4.11}$$

Where:

$\mathrm{Case}_{\mathrm{i=1}}^{\mathrm{n}}$- i-th old case from database,

$\mathrm{DoS_i}$- i-th description of bicycle lock structure (usability, performance, functionality, and appearance),

$\mathrm{Ad_i}$- i-th quantitative data regarding to each value for using adaption procedure,

$\mathrm{SoP_i}$- i-th solution of problem which is referred to various types of locks,

n- numbers of existing cases available in database

Accordingly, presented solutions are information about several types of bicycle lockers (u-locks, chain locks, folding locks, compact locks, smart bike locks, and rope type locks), which have been clustered into database as the name of "bicycle locks" with the same goal. Specifically, the categorized information of different type of lock is defined such as: the security level, the usage purposes in different areas, and the weight of the lock. In addition, the function's attributes of different product cases are shown in the "Market Research" section, Table 4.2 Besides, Figure 4.9 displays the implemented algorithm for adaption solution regarding choosing appropriate bicycle lock according CBR method.

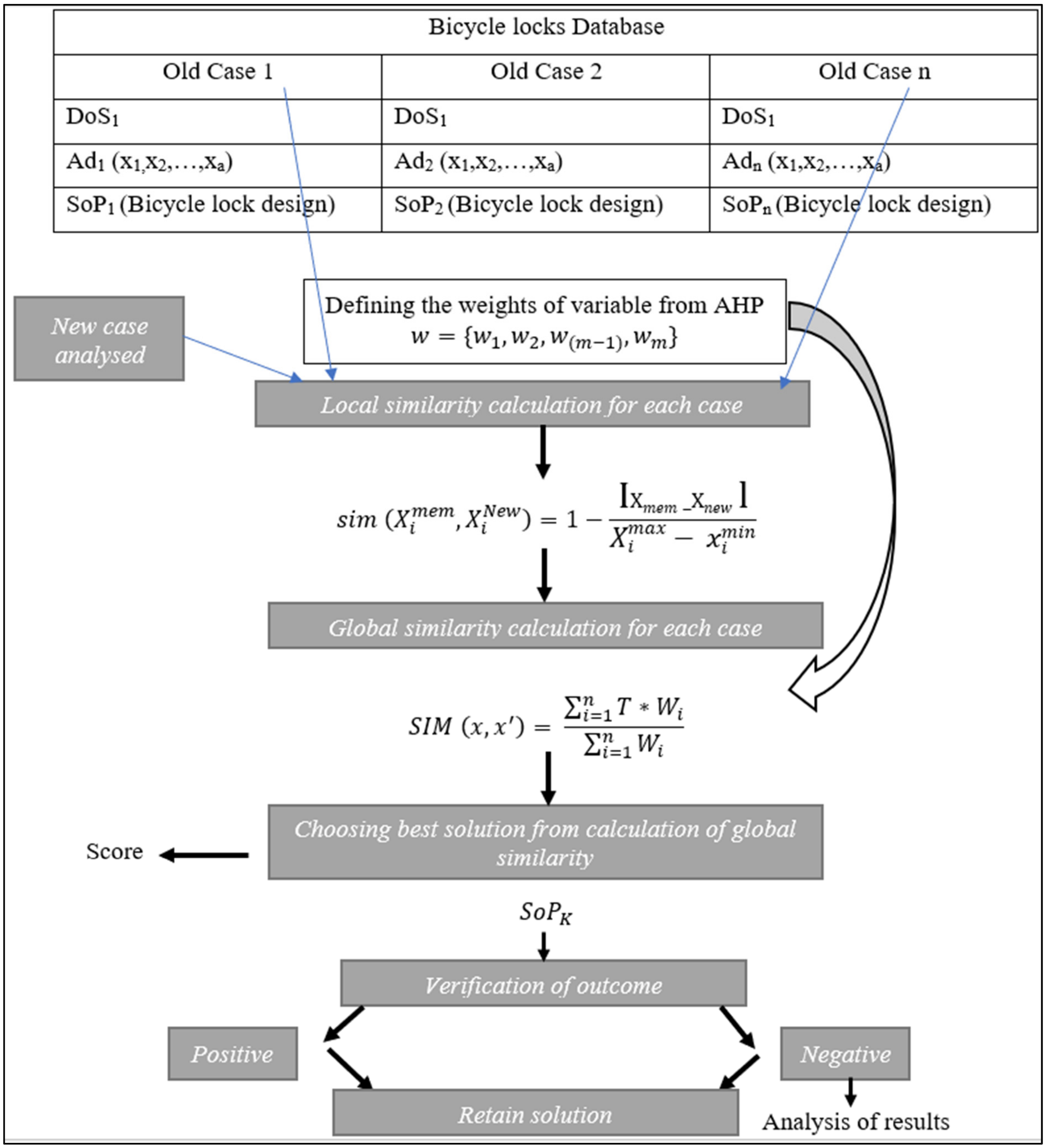


Figure 4.9 CBR procedure algorithm

After analyzing CRs through previous methods and by reusing related information in CBR approach, this process would be started. To clarify this, retrieval stage is initialized with a brief description of problem features. Each of these features categorizes related products cases in one type. For instance, in the example of this research, the case description includes the keywords such as “to protect against theft and stealing” and “provide maximum security”. Then, searching of a new case through strings between problem features and old cases’ descriptions can be implemented. Therefore, they can obtain the most similar product case by measuring the total similarity between the target case and source cases (Sànchez-Marrè, 2010). As also illustrated in Figure 4.10, in the revising phase, after selecting the desired case or the nearest cases to the problem case, it will be decided if the chosen product is adapted or whether it will again be considered as a case and retained in the case base.

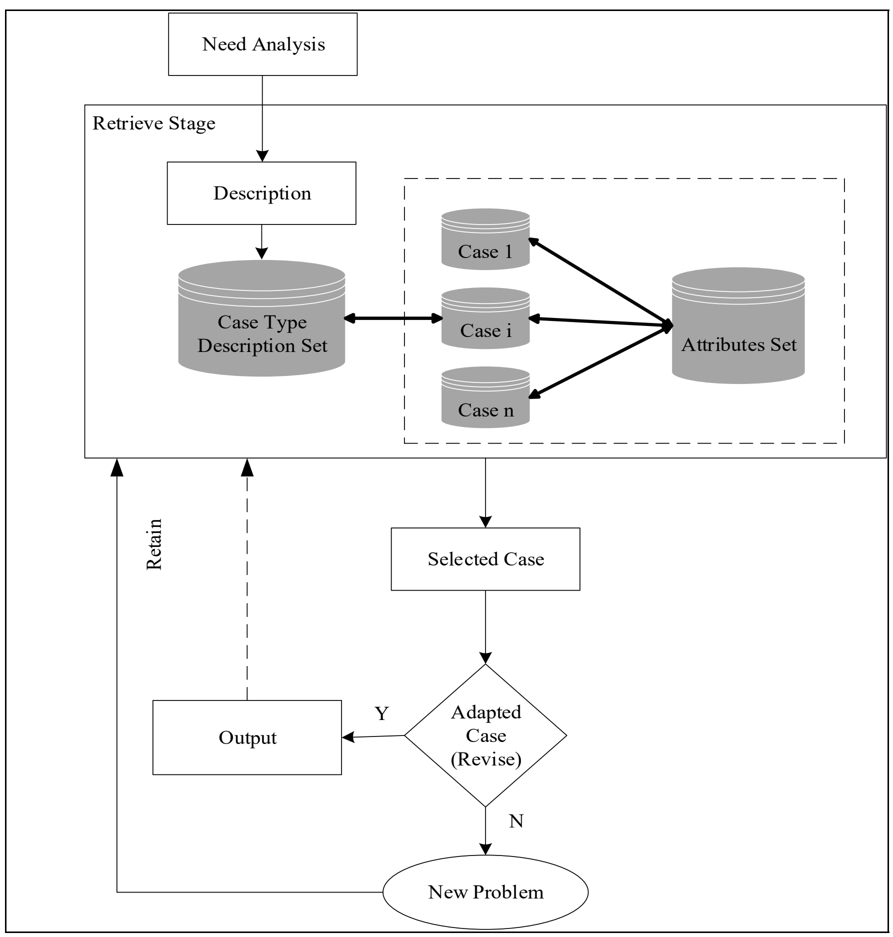


Figure 4.10 Case selection process in CBR

The key in this section is searching for a suitable solution for the new case, which has the same attributes as other cases in the data set. Considering the presented integrated framework, the attribute values of the source cases and the target cases that are scores rated from the "benchmarking section" from the QFD matrix are provided in Table 4.17 as shown below. Indeed, these data contains six different bicycle lock types that the user rated them based on requirements. Both target and existing case data are rated on a 1-5 scale from less important (1) to very important (5). Likewise, the attribute weights are included in this Table.

Table 4.16 Case base construction for the bicycle lock selection problem

Cases								
Attribute	**Weight**	**C0**	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**
User-Friendly (operation)	0.11	5	4	4	5	4	4	5
Reduce Time (quick lock/unlock)	0.03	4	5	4	5	3	4	4
Strong material	0.25	5	5	5	4	3	4	4
Secure (difficult to break Lock)	0.12	4	5	5	4	3	3	4
Durable	0.09	4	5	4	4	3	4	4
Lightweight	0.03	5	3	2	4	5	5	5
Protect the frame and wheel	0.22	5	4	3	5	5	2	5
Make the bicycle less attractive	0.11	4	4	3	3	4	4	4
Adequate shape to carry	0.04	4	3	3	5	5	5	4
Simple design and reliable	0.02	4	4	4	5	5	3	4

Regarding the aim of this sub-system, which is measuring similarities, by applying equation (3.9), we could estimate the similarity between attributes in each case with the same attributes in a new case. Here in Table 4.18, the attributes value is represented by A_i, and cases are shown by C_j with the $i = 1,2 \ldots ,10$, and $j = 1,2 \ldots ,6$ values.

Table 4.17 Local similarity calculation

$Sim\left(X_i^{mem}, X_i^{New}\right)$	C1	C2	C3	C4	C5	C6
A1	0	0	1	0	0	1
A2	0.5	1	0.5	0.5	1	1
A3	1	1	0.5	0	0.5	0.5
A4	0.5	0.5	1	0.5	0.5	1
A5	0.5	1	1	0.5	1	1
A6	0.33	0	0.66	1	1	1
A7	0.66	0.33	1	1	0	1
A8	1	0	0	1	1	1
A9	0.5	0.5	0.5	0.5	0.5	1
A10	1	1	0.5	0.5	0.5	1

Eventually, the importance weights of attributes are applied in equation (3.10) for measuring global similarity between cases. The results of the global similarity calculation for each case and their rank can be seen in Table 4.18 Accordingly, rank 1 means the closest case to the new case problem, and rank 6 is the last selected solution cases to our case problem.

Table 4.18 Global similarity calculation

Case	Total Similarity	Global Similarity	Rank
C1	0.65	65%	3
C2	0.536	54%	4
C3	0.747	75%	2
C4	0.51	51%	5
C5	0.4377	44%	6
C6	0.8829	88%	1

4.3 Result

The QFD is a well-known technique for obtaining, categorizing, and converting customer requirements to product characteristics for development and design departments of various industries. In the first stage, according to the gained information, the outcome has been classified as a list of voice of customer and product features. Indeed, correlations strength of the CRs and the TRs have been denoted by the HOQ matrix. The CRs have been narrowed down to four main groups namely usability, performance, functionality, and appearance. Furthermore, in this regard, the whole process of data translation can be seen in Figure 4.3.

Following, the AHP has been performed in order to support the quality of the decision-making in the multicriteria problem. In addition, quantified data through the mathematical procedure is precedence based on their importance rate to compare the influences factor to each other, such as criteria and sub-criteria properties. The eigenvector value has been found in the AHP; it represents the contribution rate of that specific criteria to the objective's outcome. Consequently, the presented results have proved that the Performance criteria have a high impact on selecting the product, among other criteria regarding the weight factor of 47.77. In contrast, the Usability criteria participates with 6.02 of weighting factor to the goal. On the other hand, estimation of the importance weight of a lower level of criteria is required. Referring to the Table 4.20, it can be observed that the normalized global weight of the "Strong Material" sub-criteria from the Performance group is 3% higher than the "Protect Frame and Wheel" sub-criteria from the Functionality group. This result denotes that Strong Material sub-criteria has the highest score compared to other customer’s requirements. On the other hand,, considering two other criteria, namely Usability and Appearance, “User-friendly” and “Adequate Shape to Carry” which are their respective sub-criteria, have the most relative impact. However, it should be mentioned that there is a significant difference between these two indicators, with weights factor of 11% and 4%, respectively. Thus, it is evident that the "Strong Material" sub-criteria is worthier to be considered among other sub-criteria with a 25% weighting factor. Finally, these CRs and all the subsets that belong to the "Performance" group criteria have more impact in reaching the goal. Furthermore, it is logical to mostly rely on this sub-criterion value by engineers and designers for developing the product features.

Table 4.19 Sub-criteria weighting factor percentage

Criteria	Sub-criteria	Weighting factor percentage
Usability	User-friendly (operation)	11%
	Reduce time (quick lock/unlock)	3%
Performance	Strong material	25%
	Secure (difficult to break lock)	12%
	Durable	9%
	Lightweight	3%
Functionality	Protect frame and wheel	22%
	Make the bicycle less attractive	11%
Appearance	Adequate shape to carry	4%
	Simple design and reliable	2%

In order to facilitate the selection of functional design, the CBR concept has been applied and reusing available information from previous methodologies has also helped us to have a thorough understanding of CRs. Besides, the CBR sub-system can assist in the development process by adopting a new design problem characteristic of a similar case. Furthermore, technical features found in old cases might be directly applied to the design, or at least it can provide helpful information for transforming the new elements (Villanueva & Sànchez-Marrè, 2010). Adaption is also the appropriate approach in the construction of problem-solving tasks such as configuration and designing products. According to our example, the normalized global weight has been extracted from the last step in order to evaluate the desired design configuration based on the user experiences and demands. Consequently, the selected bicycle lock among existing locks in the case base with the first rank is C6 with the highest similarity of 88%, which is Tex-Lock. This bicycle lock is made with high technology material suitable for being employed in medium to high-risk areas; it is also resistant to breaking with hard tools.

As a result, while the new case has been successfully adapted and meets CRs regarding taking proper bicycle locks for a high-risk area, the main option is to insert a new experience into the case library. Meanwhile, this case has been replaced in the neighborhood of memory, where it would be used for future retrieval. On the contrary, suppose that the presented similar solution does not support the problem in our example, then we keep go on for analyzing second or third nearest cases to our problem case. If these solutions would not help for solving the problem, we would call it a failure experience. In this situation, to avoid failure cases in the future, this case is stored in the case knowledge in a separate structure section (Mántaras, 2001).

4.4 Discussion

In the competitive marketplace, customer satisfaction is a significant indicator for a business. Several studies have indicated the general definition of this concept as the measurement of how the company's product or services meet or surpass customer expectations. Because of the importance of this source, implementing the appropriate strategy for comprehending more practical customer requirements is critical. The result represents that involving different methodologies can help translate user demand to product features more accurately in the performance of NPD.

Many research for extracting customer needs and interpreting them for developing their product in various contexts have been integrated different methodologies. This finding is also consistent with the previous literature. Our perspective for the solution to reducing communication barriers between R&D- marketing teams is presenting the hybrid approach. Our concern in this area have been converting the qualitative data to quantitative data, which in this way, we took advantage of three methods and techniques to analyze the data related to user expectations.

As mentioned earlier, this thesis methodology framework represents a multidisciplinary theory that uses different methods. Over time many scholars utilized these methodologies depending on various strategies and purposes. On the other hand, despite their application in various domains, each presented technique has drawbacks. Some of the highlighted advantages and limitations that numerous studies have been reviewed, can be seen in Table 4.21 (Canco, Kruja, & Iancu, 2021) (Munier & Hontoria, 2021) (Wolniak, 2018) (Kraujalienė, 2019).

From an academic aspect, one of the breakthroughs supports is the integration of the QFD-AHP extension method with the CBR as an integrated framework. In the conventional approach to reduce communication barriers between engineers and the marketer teams to understand their customer needs, the suggested solutions focused on modifying the organizational environment and involving user ideas in the design process. Nevertheless, in this thesis, the interpretation of CRs from their desired product has been regarded as an essential factor between R&D-marketing groups with different cultural word thoughts. Furthermore, it is notable to mention that the relations cycle between marketing and R&D teams starts with determining CRs by the marketing experts. Then, these critical CRs are associated with primary functional TRs, which specialist from the R&D team evaluates.

Table 4.20 Advantages and limitation of methodologies

Methodology	**Advantage**	**Limitation**
QFD	It takes into consideration CRs	It may ignore factors like product life cycle, resource availability, and long-term strategy
	Planning continuously to enhance product quality according to user's demand	Frequently in a subjective nature, a substantial amount of data is analyzed
	Enable to be aware of the organization's advantages and drawbacks concerning other companies	Applying complex matrices and analyses, in the case of extended versions, is too comprehensive
	Advancement of communication among the cross-functional team with various knowledge	A little knowledge and inadequate training about this methodology
	Facilitate obtaining competitive advantages because of adequately satisfying the user requirements	Making a proper relationship between CRs and product features is time-consuming and laborious
AHP	Provide an efficient system for comparing alternatives in multicriteria problem	Fixing measurement scales and various outcomes directly relate to the form of hierarchical structure

Table 4.20 Advantages and limitation of methodologies
(cont’d)

Methodology	Advantage	Limitation
AHP	Simplify problematic issues by splitting them into smaller stages	Because extensive problems have many hierarchical levels, it is hard to do comparison procedures
	Not instruct authentic information sets	The largescale problem must be applied by the specialist and required training
	The system is designed to normalization needs	It possesses mathematical computation for applying comparison-pairwise that needs algebra knowledge
CBR	The focus of the tool is not data-intensive	The method can construct a reasonable solution, but it is not guaranteed that it is the best solution to solve the problem.
	It develops gradually through time while more cases are contained in a data system	The method application costs many investments like human resources, c, time resources, and budget.
	The system works nature is inspired by the human reaction regarding with solving problems	The method may expand the processing time while the case-based reasoner is about to match applicable cases.
	Ability to anticipate a new solution's success	The method demands great storage in order to retain all the cases.

This thesis integrated framework has advantages in this domain. Firstly, based on the research objective, it has been decided to utilize different approaches. As well as the applications of presented techniques have almost been applied in various fields and industries. Thus, this advantage makes them flexible for adoption even if they are proposed with an integration form. Secondly, in this integrated framework, due to the retrieving procedure of CRs, the database is upgraded with each set of CRs, which as new cases is provided to the dataset. As a result, this structure can be a factor in bridging the communication gap between R&D-marketing employees to be knowledgeable about current requirements and speed up the customization process (Lin, 2018). Last but not least, in the design and development process, customer needs have been defined for material and product characteristics. Hence, through the operation, the data is quantified and weighted. Therefore, in this model once this process is done by the user in the HOQ matrix and once in AHP calculation by expertise that the result has been shown similarity result between them. Ultimately, giving weight to requirements from two aspects makes the outcome more valid for the judgment and helps decide based on what has been demanded.

Despite the advantages mentioned above, this integrated methodology also has a drawback. Because of the complexity of this methodology framework, practically, it is hard to implement it in industry. Therefore, applying this integrated framework will require expertise and be challenging and time-consuming for businesses, especially small companies.

CONCLUSION

The focal point of this thesis is to demonstrate an effective transfer of CRs between R&D and marketing teams in order to decrease commination barriers in NPD project from an academic perspective. This information mainly refers to VOC that have been gathered regarding a specific product. It should be highlighted that VOC-based information has been also known as a critical element of competitive advantage for a business. Fundamentally, developing a product during NPD project involves various teams with different functions, including designing, marketing, and manufacturing. Accordingly, productive collaboration between R&D and marketing employees in success of launching a product is key. As a result, communication barriers between these two departments have been analyzed by many researchers. At this point, this master thesis aimed to develop an integrated framework based on the QFD-AHP with an extension of CBR technique. This integrated framework intends to improve the interpretation of the CRs by marketing and R&D teams by reducing misunderstandings regarding new designs/products. To this aim, CBR methodology helps in a product development process using previous related knowledge.

The performance of this integrated framework has been examined in a case study of choosing the appropriate design for bicycle locks. There are various lock models and designs available in the market which are used with different purposes. Therefore, for cyclists choosing a right bicycle lock regarding their demands is challenging. Technically, by employing the proposed transformation system, the customers' requirements will be defined effectively. Through this study, CRs regarding bicycle locks' designs have been translated to TRs with the help of the QFD method. Then, with the help of the AHP pairwise comparison matrixes, we managed to identify which requirements have to be considered more in designing based on an importance rate. Furthermore, during the retrieval procedure of the CBR technique, we intended to find nearest design ideas to current CRs from a case-based, which in this example, the closest selected case was case number 6 with 88% rated to the problem case. This lock's design has medium to high security level and made with special technology material. Hence, this provided design idea according to the most considerable requirements of customers can meet their needs for choosing appropriate bicycle lock. However, if the presented solution has not been adapted to our new case, we can continue to analyze the second or third closest rated to the problem case. Otherwise, if none of these solutions will not support our problem, it is retained and stored into memory for the retrieved process in future for similar case.

RECOMMENDATIONS

In this thesis, one of the significant limitations is the sample size. In this case, in order to prove the methodology's utilization, the requirements of only one user have been gathered, and the study's methodology has been analyzed according to her needs. Accessing more CRs and their experiences helps evaluate appropriately and make decisions closer to what users are satisfied with a new product. Consequently, the lack of data regarding the number of customers restricts showing the whole procedure's complexity. In the process of analyzing, we found that if more data diversity related to user requirements had been covered, we would have reached more promising results. Hence, it is recommended to implement on a larger CRs scale to illustrate the methodology framework precisely.

One of the challenges this integrated framework encounters is running the CBR system. Based on the result, the suggested case from case-based was successful and met the most notable CRs. However, if the system fails in adaption after evaluation in the retrieve process, it must hinder itself from the same mistake in the future. Moreover, the recommendation for further research is to employ other methods such as structural or derivational adaptation to improve the CBR approach's retrieval structure.

In other words, retrieving and retaining circulation instructs oversized knowledge fundamentals to evaluate and manage information adequately based on case-based library background. Accordingly, in the future, if this integrated framework will be implemented for any business projects, it is significant to consider types of company size. For instance, because of the vast knowledge management system, big companies can manage complex procedures of sorting data and have more chances to extract relevant cases successfully. However, small-sized companies may not have the CBR application in their project due to a lack of experience. So, the better the CBR's efficiency, the better the advantages of this integrated framework will be.

LIST OF REFERENCES

Abou Assali, A., Lenne, D., & Debray, B. (2009). Case Retrieval in Ontology-Based CBR Systems. In B. Mertsching, M. Hund, & Z. Aziz (Eds.), *KI 2009: Advances in Artificial Intelligence* (pp. 564–571). Berlin, Heidelberg: Springer. https://doi.org/10.1007/978-3-642-04617-9_71

Adiandari, A., Winata, H., Fitriandari, M., & Hariguna, T. (2020). Improving the quality of Internet banking services: An implementation of the quality function deployment (QFD) concept. *Management Science Letters*, *10*(5), 1121–1128.

Alptekin, G., & Büyüközkan, G. (2011). An integrated case-based reasoning and MCDM system for Web based tourism destination planning. *Expert Syst. Appl.*, *38*, 2125–2132. https://doi.org/10.1016/j.eswa.2010.07.153

Awasthi, A., Sayadi, R., & Khabbazian, A. (2018). A combined approach integrating gap analysis, QFD and AHP for improving logistics service quality. *International Journal of Logistics Systems and Management*, *29*, 190. https://doi.org/10.1504/IJLSM.2018.089171

Ayeldeen, H., Shaker, O., Hegazy, O., & Hassanien, A. E. (2015). Case-Based Reasoning: A Knowledge Extraction Tool to Use. In *Advances in Intelligent Systems and Computing* (Vol. 339, pp. 369–378). https://doi.org/10.1007/978-81-322-2250-7_37

Bevilacqua, M., & Braglia, M. (2000). The analytic hierarchy process applied to maintenance strategy selection. *Reliability Engineering & System Safety*, *70*(1), 71.

Bhattacharya, A., Geraghty, J., & Young, P. (2010). Supplier selection paradigm: An integrated hierarchical QFD methodology under multiple-criteria environment. *Applied Soft Computing*, *10*(4), 1013–1027. https://doi.org/10.1016/j.asoc.2010.05.025

Bolar, A. A., Tesfamariam, S., & Sadiq, R. (2017). Framework for prioritizing infrastructure user expectations using Quality Function Deployment (QFD). *International Journal of Sustainable Built Environment*, *6*(1), 16–29. https://doi.org/10.1016/j.ijsbe.2017.02.002

Bouhana, A., Abed, M., & Chabchoub, H. (2011). An integrated Case-Based Reasoning and AHP method for personalized itinerary search. *2011 4th International Conference on Logistics*, 460–467. https://doi.org/10.1109/LOGISTIQUA.2011.5939443

Canco, I., Kruja, D., & Iancu, T. (2021). AHP, a Reliable Method for Quality Decision Making: A Case Study in Business. *Sustainability*, *13*, 13932. https://doi.org/10.3390/su132413932

Carnero, C. (2005). Selection of diagnostic techniques and instrumentation in a predictive maintenance program. A case study. *Decision Support Systems*, *38*, 539–555. https://doi.org/10.1016/j.dss.2003.09.003

Cross, N. (2021). *Engineering Design Methods: Strategies for Product Design (5th ed.)*. Chichester: John Wiley & Sons. Retrieved from https://www.wiley.com/en-gb/Engineering+Design+Methods%3A+Strategies+for+Product+Design%2C+5th+Edition-p-9781119724407

Diaz, L. (2007). *Engineering Design*. Retrieved from https://www.academia.edu/22269444/Engineering_Design_Springer_2007_1846283183

Duray, R., Ward, P. T., Milligan, G. W., & Berry, W. L. (2000). Approaches to mass customization: Configurations and empirical validation. *Journal of Operations Management*, *18*(6), 605–625. https://doi.org/10.1016/S0272-6963(00)00043-7

E Stansfield, K., & Azmat, F. (2017). Developing high value IoT solutions using AI enhanced ISO 16355 for QFD integrating market drivers into the design of IoT offerings. https://ieeexplore.ieee.org/abstract/document/7918967/metrics

Ellis, C. (2021, September). Find a Bike Lock that Works. Retrieved July 2, 2022, from The Best Bike Lock website: https://thebestbikelock.com/best-u-lock/

Elmogy, M., & El-Sappagh, S. H. (2015). *Case Based Reasoning: Case Representation Methodologies*.

Fan, Z.-P., Li, Y.-H., & Zhang, Y. (2015). Generating project risk response strategies based on CBR: A case study. *Expert Systems with Applications*, *42*. https://doi.org/10.1016/j.eswa.2014.11.034

Gao, J., & Bernard, A. (2018). An overview of knowledge sharing in new product development. *The International Journal of Advanced Manufacturing Technology*, *94*(5), 1545–1550. https://doi.org/10.1007/s00170-017-0140-5

Garvin, D. A. (1987, November 1). Competing on the Eight Dimensions of Quality. *Harvard Business Review*. Retrieved from https://hbr.org/1987/11/competing-on-the-eight-dimensions-of-quality

Ghodsypour, S. H., & O’Brien, C. (1998). A decision support system for supplier selection using an integrated analytic hierarchy process and linear programming. *International Journal of Production Economics*, *56–57*, 199–212. https://doi.org/10.1016/S0925-5273(97)00009-1

Ginting, R., Ishak, A., Fauzi Malik, A., & Satrio, M. R. (2020). Product Development with Quality Function Deployment (QFD): A Literature Review. *IOP Conference Series: Materials Science and Engineering*, *1003*(1), 012022. https://doi.org/10.1088/1757-899X/1003/1/012022

Goetsch, D. L., & Davis, S. (2021). *Quality management for organizational excellence: Introduction to total quality* (Ninth edition). Boston: Pearson.

Gokhale, M. (2007). Use of analytical hierarchy process in university strategy planning. *Masters Theses*. Retrieved from https://scholarsmine.mst.edu/masters_theses/4608

Griffin, A., & Hauser, J. R. (1996). Integrating R&D and Marketing: A Review and Analysis of the Literature. *Journal of Product Innovation Management*, *13*(3), 191–215. https://doi.org/10.1111/1540-5885.1330191

Guribie, F. L., & Tengan, C. (2019). A Proposed Knowledge Management Implementation Framework for the Ghanaian Construction Industry. *Journal of Building Construction and Planning Research*, *07*(01), 1. https://doi.org/10.4236/jbcpr.2019.71001

Hauser, J. R., & Clausing, D. (1988, May 1). The House of Quality. *Harvard Business Review*. Retrieved from https://hbr.org/1988/05/the-house-of-quality

Ho, W. (2008). Integrated analytic hierarchy process and its applications – A literature review. *European Journal of Operational Research*, *186*(1), 211–228. https://doi.org/10.1016/j.ejor.2007.01.004

Kraujalienė, L. (2019). COMPARATIVE ANALYSIS OF MULTICRITERIA DECISION-MAKING METHODS EVALUATING THE EFFICIENCY OF TECHNOLOGY TRANSFER. *Business, Management and Education*, *17*, 72–93. https://doi.org/10.3846/bme.2019.11014

Kuo, T. C. (2010). Combination of case-based reasoning and analytical hierarchy process for providing intelligent decision support for product recycling strategies. *Expert Systems with Applications*, *37*(8), 5558–5563. https://doi.org/10.1016/j.eswa.2010.02.057

Kwong, C. K., & Bai, H. (2003). Determining the Importance Weights for the Customer Requirements in QFD Using a Fuzzy AHP with an Extent Analysis Approach. *IIE Transactions*, *35*(7), 619–626. https://doi.org/10.1080/07408170304355

Labib, A. W. (2011). A supplier selection model: A comparison of fuzzy logic and the analytic hierarchy process. *International Journal of Production Research*, *49*(21), 6287–6299. https://doi.org/10.1080/00207543.2010.531776

Li, B. M., & Xie, S. Q. (2013). Product similarity assessment for conceptual one-of-a-kind product design: A weight distribution approach. *Computers in Industry*, *64*(6), 720–731. https://doi.org/10.1016/j.compind.2013.04.001

Li, P.-C., & Chen, Y.-C. (2016). Exploring interaction-based antecedents of marketing-R&D collaboration: Evidence from the Taiwan's semiconductor industry. *Innovation*, *18*(3), 352–372. https://doi.org/10.1080/14479338.2016.1219618

Lin, C. (2018). *Product configuration design based on customer requirement modelling and optimization method* (Thesis). https://doi.org/10.32657/10356/75895

Liu, Y., & Wang, W. (2022). Research on Quality Evaluation of Product Interactive Aging Design Based on Kano Model. *Computational Intelligence and Neuroscience*, *2022*, 3869087. https://doi.org/10.1155/2022/3869087

López-Nicolás, C., & Merono-Cerdan, A. (2011). Strategic knowledge management, innovation and performance. *International Journal of Information Management - INT J INFORM MANAGE*, *31*, 502–509. https://doi.org/10.1016/j.ijinfomgt.2011.02.003

Madu, C. N., Kuei, C., & Madu, I. E. (2002). A hierarchic metric approach for integration of green issues in manufacturing: A paper recycling application. *Journal of Environmental Management*, *64*(3), 261–272. https://doi.org/10.1006/jema.2001.0498

Mántaras, R. (2001). Case-Based Reasoning. In *Machine Learning and Its Applications* (pp. 127–145). https://doi.org/10.1007/3-540-44673-7_6

Moenaert, R. K., Souder, W. E., De Meyer, A., & Deschoolmeester, D. (1994). R&D-marketing integration mechanisms, communication flows, and innovation success. *Journal of Product Innovation Management*, *11*(1), 31–45. https://doi.org/10.1016/0737-6782(94)90117-1

Nagahanumaiah, Ravi, B., & Mukherjee, N. P. (2006). Rapid hard tooling process selection using QFD-AHP methodology. *Journal of Manufacturing Technology Management*, *17*, 332–350. https://doi.org/10.1108/17410380610648290

Nolberto Munier, & Eloy Hontoria. (2021). *Uses and Limitations of the AHP Method*. Retrieved from https://link.springer.com/book/10.1007/978-3-030-60392-2

Ozturk, P., & Tidemann, A. (2014). A Review of Case-Based Reasoning in Cognition-action Continuum: A step towards Bridging Symbolic and Non-symbolic Artificial Intelligence. In press. *The Knowledge Engineering Review*, *20*, 51–77. https://doi.org/10.1017/S000000000000000

Polanyi, M. (2009). *The Tacit Dimension* (A. Sen, Ed.). Chicago, IL: University of Chicago Press. Retrieved from https://press.uchicago.edu/ucp/books/book/chicago/T/bo6035368.html

Prasad, B. (1998). Synthesis of market research data through a combined effort of QFD, value engineering, and value graph techniques. *Qualitative Market Research: An International Journal*, *1*(3), 156–172. https://doi.org/10.1108/13522759810235250

Punchihewa, H. (2010). *The potential of Quality Function Deployment (QFD) in reducing work-related musculoskeletal disorders*.

Puspitasari, T. D., Sari, E. O., Destarianto, P., & Riskiawan, H. Y. (2018). Decision Support System for Determining Scholarship Selection using an Analytical Hierarchy Process. *Journal of Physics: Conference Series*, *953*, 012119. https://doi.org/10.1088/1742-6596/953/1/012119

Rajesh, G., & Malliga, P. (2013). Supplier Selection based on AHP QFD Methodology. *Procedia Engineering*, *64*, 1283–1292. https://doi.org/10.1016/j.proeng.2013.09.209

Ramos-Quintana, F., Tovar-Sánchez, E., Saldarriaga-Noreña, H., Sotelo-Nava, H., Sánchez-Hernández, J. P., & Castrejón-Godínez, M.-L. (2019). A CBR–AHP Hybrid Method to Support the Decision-Making Process in the Selection of Environmental Management Actions. *Sustainability*, *11*(20), 5649. https://doi.org/10.3390/su11205649

Rianmora, S., & Werawatganon, S. (2021). Applying Quality Function Deployment in Open Innovation Engineering. *Journal of Open Innovation: Technology, Market, and Complexity*, *7*(1), 26. https://doi.org/10.3390/joitmc7010026

Ruiz-Vanoye, J. A., Díaz-Parra, O., Nolazco-Flores, J. A., Saenz, A. C., Hernández, V. H., & Gongora, H. M. (2013). *Quality Function Deployment (QFD) House of Quality for Strategic Planning of Computer Security of SMEs*. *4*(1), 16.

Saaty, T. (2005). *Analytic Hierarchy Process*. https://doi.org/10.1002/0470011815.b2a4a002

Sànchez-Marrè, M. (2010). *Providing intelligent decision support systems with flexible data-intensive case-based reasoning*. Retrieved from https://www.academia.edu/2918149/Providing_intelligent_decision_support_systems_with_flexible_data_intensive_case_based_reasoning

Sani Kazaure, A., Dabai, U., Salisu, M., Sabo, M., & Salisu, S. (2016). Identify obstacles to knowledge sharing is as organization. *Dutse Journal of Pure and Applied Science (DUJOPAS)*, *2*, 8.

Shekapure, S. (2015). *PROBLEM SOLVING USING CASE BASED REASONING METHODOLOGY*. https://doi.org/Doi:01.0401/ijaict.2015.11.16

Singh, R. K., & Kulkarni, M. S. (2013). Criticality analysis of power-plant equipment using the analytical hierarchy process. *International Journal of Industrial Engineering & Technology (IJIET), 3*(4), 14.

Song, L. Z., & Song, M. (2010). The Role of Information Technologies in Enhancing R&D–Marketing Integration: An Empirical Investigation. *Journal of Product Innovation Management*, *27*(3), 382–401. https://doi.org/10.1111/j.1540-5885.2010.00723.x

Srdjevic, B., & Srdjevic, Z. (2013). Synthesis of individual best local priority vectors in AHP-group decision making. *Applied Soft Computing*, *13*(4), 2045–2056. https://doi.org/10.1016/j.asoc.2012.11.010

Villanueva, B. S., & Sànchez-Marrè, M. (2010). *Providing Intelligent Decision Support Systems with Flexible Data-Intensive Case-Based Reasoning*. 11.

Wang, H., Sun, B., & Shen, X. (2018). Hybrid similarity measure for retrieval in case-based reasoning systems and its applications for computer numerical control turret design. *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture*, *232*(5), 918–927. https://doi.org/10.1177/0954405416654432

Wang, P., Gong, Y., Xie, H., Liu, Y., & Nee, A. Y. (2017). Applying CBR to machine tool product configuration design oriented to customer requirements. *Chinese Journal of Mechanical Engineering*, *30*(1), 60–76. https://doi.org/10.3901/CJME.2016.0113.007

Wolniak, R. (2018). The use of QFD method advantages and limitation. *Production Engineering Archives*, *18*, 14–17. https://doi.org/10.30657/pea.2018.18.02

Wu, C.-T., Pan, T.-S., Shao, M.-H., & Wu, C.-S. (2013). An Extensive QFD and Evaluation Procedure for Innovative Design. *Mathematical Problems in Engineering*, *2013*, e935984. https://doi.org/10.1155/2013/935984

Younes, M., & Bouami, D. (2015). A New Approach for the Transition between QFD Phases. *Procedia CIRP*, *26*. https://doi.org/10.1016/j.procir.2014.07.172

Zare Mehrjerdi, Y. (2010). Quality function deployment and its extensions. *International Journal of Quality & Reliability Management*, *27*(6), 616–640. https://doi.org/10.1108/02656711011054524

Zia, S., Akhtar, P., Mughal, T., & Mala, I. (2014). Case Retrieval Phase of Case-Based Reasoning Technique for Medical Diagnosis. *Proceedings of the Latvian Academy of Sciences Section B Natural Exact and Applied Sciences*, *32*, 451–458. https://doi.org/10.5829/idosi.wasj.2014.32.03.230