Tampere University of Applied Sciences

A Case Study on Optimizing Product Development: Integrating Risk-Driven Design for Customer Requirement Clarification

Anton Shcherbakov

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ABSTRACT

Tampereen ammattikorkeakoulu
Tampere University of Applied Sciences
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Anton Shcherbakov
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The research investigates the integration of Risk-Driven Design principles into the product development process, focusing on the possibility of optimizing customer requirement clarification through proactive risk management.

Understanding how risk management interacts with the process of developing new products, the theoretical part of the research examined the theoretical basis of the traditional risk management approach and the relevance to product development projects, with the intention to customer requirements. The concept of Risk-Driven Design was introduced as an alternative strategy to mitigate risks raised by wrong interpretation of customer requirements. The alternative strategy was verified through a practical case study in an actual development project, where the application of Risk-Driven Design was demonstrated to work with customer requirements and involve customers in the development process of a new product. Based on the results obtained from the case study, it is concluded that customer involvement and proactive risk management play a critical role in the product development process. The study recommends integrating these strategies into the development process to minimize uncertainties and align products with customer requirements. The insights provided by the study are practical and can be implemented to achieve optimal results.

In conclusion, the study's results underscore the potential benefits of implementing proactive risk management strategies. Furthermore, it provides a practical recommendation for using tools to work with customer requirements to enhance the alignment of products with customer needs, thereby reducing uncertainties and minimizing risks.

Key words: risk management, proactive risk management, risk-driven design, design for six sigma, customer requirements, voice of customer, development process.

CONTENTS

ABBREVIATIONS AND TERMS

ISO	International Organization for Standardization
PDP	product development process
COSO	Committee of Sponsoring Organizations
PESTLE	Political, Economic, Social, Technological, Legal and Environmental factors
FIRM	Financial Institutions Risk Management
IRM	Integrated risk management
BS	British Standard
RBS	Risk Breakdown Structure
SWOT	Strengths, Weaknesses, Opportunities, and Threats
FMEA	Failure mode and effect analysis
DFSS	Design for Six Sigma
DMADV	Define, Measure, Analyze, Design, Verify
DMADOV	Define, Measure, Analyze, Design, Optimize, Verify
DCCDI	Define Customer and Concept, Design, Implement
IDOV	Identify, Design, Optimize, Verify
VOC	Voice of customers
VOB	Voice of business
QFD	Quality Function Deployment
CTQ	Critical to Quality
CDP	Critical Design Parameters

1 INTRODUCTION

1.1. Background of the research idea

For most industrial companies' development projects are crucial; they play a significant role in the success of organizations in today's competitive business environment. Developing a new product or service involves various risks: technical, financial, market, operational, etc (Schmitz, 1998). Risks might originate from various facets of development projects and impact the result of the development process. For this reason, risk identification, assessment, and application of effective risk mitigation strategies are essential for the project's success (Hopkin, 2018).

Among the challenges encountered in any development project, the complexity of understanding customer needs stands as one of the most significant challenges that must be overcome to achieve successful results. Translating customer needs into practical design and development guidelines, in many cases, becomes a challenging task (S. Zhao, Zhang, Peng, & Fan, 2020). Misunderstandings, different viewpoints, changing customer expectations, and insufficiently established communication channels contribute to a mismatch between customers' desires and what the final product delivers. These disruptions not only have a negative impact on the development process but also influence customer satisfaction with the final product (Tegeltija, Oehmen, Kozine, & Geraldi, 2016; Q. Zhao, Zhao, Guo, Zhang, & Yu, 2022). Therefore, in addition to other risks, risks associated with the wrong interpretation of customer requirements present a unique challenge that requires a structured and balanced strategy.

1.2. Purpose of the thesis and research questions

The financial success of a new product or service depends on many components, such as customer preferences, time and money spent on the development, mini cost, technology, sales volume, etc. The influence of these factors could be considered as a set of uncertainties influencing a product’s financial and technical success. Therefore, possible to suggest that any development process could be examined as a structural approach, which aims is to avoid or minimize the dependence of the product’s success from those uncertainties, hence reducing possible risks generated by those factors (Birkhofer, 2011). Despite this, most well-known design frameworks used for the development process mainly focus on improving and increasing the efficiency of the product design system (Hansen, Willumsen, & Oehmen, 2022). Instead of opposing and addressing the uncertainties and, as a result risks, that arise during development processes, project management teams tend to overlook them and make decisions that are insensitive to risks and based on simplifications. Since they do not place a strong emphasis on reducing risks, however, many of the risks can be detected during the early stages of the development process and successfully mitigated (Kaplan & Mikes, 2012).

During the past decades, became popular frameworks that allocate reasonable attention to possible uncertainties and risks, such as Agile Risk Management, Six Sigma, Lean Six Sigma, etc (Stern, 2020). These modern frameworks have gained popularity because of their ability to provide a structured approach to risk management and enhance project outcomes.

This thesis aims to study the risks associated with product development and apply techniques for reducing risks associated with customer requirements. The research focuses on understanding the definition and classification of risks and strategies to prevent and mitigate them. Specifically, the study explores approaches to improve understanding of customer needs, preferences, and methods to mitigate such risks in product development projects. The objective is to enhance the effectiveness of risk management in interpreting customer requirements for development projects and improve overall project outcomes.

The research questions to be investigated are:

- What are the definitions of risks, and how could they be classified according to their characteristics?

- What are the risks associated with product development?
- What strategies can be implemented to prevent risks associated with incorrectly identifying requirements for a product under development?

1.3. Structure of the Thesis

Chapter 1 is devoted to the background of the research idea, deliverables, research questions, and thesis structure. It defines the critical significance of risk identification and effective risk mitigation strategies within development projects for industrial companies.

Chapter 2 consists of two parts. The first part provides a detailed overview of risks, including their definitions and different classifications. The chapter analyzes risks associated with product development projects, focusing on initial requirements and other technical aspects. The second part of the chapter considers the traditional risk management approach and concisely overviews its key steps. In contrast, the chapter introduces the concept of Risk-Driven Design as an alternative approach and highlights its application in mitigating risks throughout the development process.

Chapter 3 illustrates the practical application of Risk-Driven Design for customer requirement clarification in an actual development project. The chapter begins with an overview of the project's background, followed by a discussion of the challenges and targets for the project. Results obtained from interviews and other practical exercises are presented in Appendixes.

Chapter 4 concludes the thesis by summarizing key findings from applying Risk-Driven Design principles. It emphasizes the importance of customer involvement in efficient risk management and recommends integrating proactive risk strategies into development processes. The chapter acknowledges research limitations and suggests potential future avenues.

1.4. Research methodology

The first research method employed in the thesis is a literature review, which facilitated the implementation of a comprehensive theoretical study about the traditional risk management process and Risk-Driven Design as an alternative approach. Information for the literature review was gathered from relevant study books, scientific articles, and published research works.

The primary research method applied in this paper is the case study method. The selection of this approach is defined by the nature of the research topic and the need to thoroughly understand the process of implementing Risk-Driven Design in an actual development project. Utilizing the case study methodology facilitates the presentation of business challenges in a systematic and comprehensible format. Moreover, this method provides the opportunity for a comprehensive understanding of the researched subject through the detailed investigation of a single case (Eriksson & Kovalainen, 2016). For the case study method, the definition of boundaries plays a significant role, as a case study implies a close consideration of a specific and limited situation (event, project, or group of people) within a particular time and place (Creswell, 1998). In other words, a case study should closely focus on a real-life example to understand common patterns, achieved through discussing, experimenting, conducting different kinds of interviews, questionaries, and using data from different sources (Bhattacherjee, 2012).

According to the theory, there are two types of case studies: intensive and extensive case study research. Extensive case study research involves studying multiple cases to identify common patterns. This method aims to develop broad theories or insights applicable to a larger context. It emphasizes uncovering similarities and differences across cases. On the other hand, intensive case study research focuses on a single case and tries to understand its unique qualities and intricacies. This method is particularly useful for exploring complex phenomena in detail and providing in-depth insights (Eriksson & Kovalainen, 2016).

Executed research demonstrates a bland of extensive and intensive case study research methods, as obtained results could be extrapolated to verify common trends, mechanisms, and overarching strategies employed during the project execution. Alternatively, the detailed approach to implementing Risk-Driven Approach within the projects and repeated iterations of the process indicate features inherent to intensive case study research. Combining these approaches provides a holistic understanding of the Risk-Driven Design's application in an actual development project. This dual approach enhances research credibility and provides a macroscopic and microscopic view of the subject.

The chosen case study is a project at its initial stage, where applied practices aimed to reduce the risks associated with misinterpreting product requirements. The case study included quantitative and qualitative data collection approaches, including surveys, face-to-face interviews, and questionaries (online and offline).

2 RISKS IN THE PRODUCT DEVELOPMENT PROCESS: FROM UNDERSTANDING TO EFFECTIVE MANAGEMENT

2.1. Risk overview

2.1.1 What is a risk?

Risks are inherent in modern society and might be presented in various aspects of life. In the real world, people face financial, political, security, safety, information technology, and many other risks. Defining the concept of risk is challenging since the definition depends on the area where it is considered.

A simple and understandable definition for an average person can be found in the Oxford Dictionary, where the term is defined as “the possibility of something bad happening at some time in the future; a situation that could be dangerous or have a bad result” (*Oxford University*, 2023).

For a more in-depth and specialized definition of the term, reference must be made to the International Organization for Standardization (ISO). ISO characterizes a risk as “the effects of uncertainty on objectives” (Field, 2023).

Since the impact of risks on the product development process (PDP) is the main topic of this paper, it is important to give a contextual definition of the term within the context of this field. In the case of PDP, a risk could typically be defined as the possibility of an event that could affect the development process and lead to delays, increased costs, or a reduction in product quality. In essence, risk represents the probability and potential impact of not achieving a defined project goal (Kerzner, 2017).

It is evident that most definitions characterize the term negatively because risk is associated with uncertainty and, in most cases, has an unexpected and undesir-

able nature. However, considering risks should not only be limited to their possible negative effects because risks can also have a positive impact and contribute to creating opportunities (Anderson, 2013).
In the context of project management, risks could be defined as a composition of probability and consequence or hazard and safeguard:

- every risk consists of two main components: the probability of a specific event occurring and the impact/consequence associated with that event. An increase in any of these components leads to a higher risk
- any risk increases with possible potential hazards, while developed safeguards allow to overcome them and reduce the risk to an acceptable level (Kerzner, 2017).

It is conceivable to conclude that every business activity involves interaction with risks. Therefore, to achieve the desired result, it is important to consider possible risks and determine their potential impact on the desired result.

2.1.2 Classification of risks by their characteristics

Initially, it is essential to identify the main characteristics of risk. Traditionally, in risk management, risks assign the following attributes:

- probability characterizes the likelihood of a risk event occurring
- source characterizes the origin of a risk
- impact, which evaluates the consequence of a risk event
- duration measures how long a risk can exist
- timing characterizes a moment when a risk event could occur
- mitigation assesses the possibility of reducing a risk event (Flaus, 2013; Tarantino & Cernauskas, 2012)

Risks can be classified based on their characteristics. Risk classification means the distribution of the risk to certain areas or categories by defined criteria. Proper risk classification allows to determine the place of the risk in the overall system, which enables the possibility for the effective application of risk management

methods. In line with the above, it is possible to conclude that risk classification consists of grouping risks according to their common characteristics.
Suppose the classification of risks is carried out in the business context; it is possible to mark out the following areas where risks could arise. The following classification can be given:

- Financial risks are a crucial part of an organization's overall risk landscape. They are defined as the potential possibility for a sudden financial loss related to the flow of funds within an organization. This risk category can be further broken down into market risk, credit risk, liquidity risk, and other relevant sub-categories.
- Strategic risks represent risks that arise due to the potential uncertainty associated with implementing an organization's business strategies, plans, and tactics. This category includes various types of risks, such as reputation risk, brand risk, competitive risk, and regulatory risk.
- Operational risks relate to internal factors within a company and arise from its processes, technology, compliance, and human errors. These risks could appear due to failures in process, technology, or human errors that can lead to operational disruptions.
- Legal risks include litigation, regulatory, and intellectual property risks arising from legal or regulatory actions (claims, non-compliance, violations of intellectual property rights).
- Reputation risk is the potential harm to a company's credibility caused by negative publicity, product recalls, and negative customer reviews.
- Hazard risks refer to potential threats that could cause harm to a company, employees, customers, or the environment. These risks can arise from natural disasters, terrorism, or supply chain disruptions (Gerdeman, 2022; Hull, 2018; Pritchard, 2014).

It is important to note that the above-listed risks are traditionally considered primary risks influencing a business. However, the list can be extended since there are other additional factors that present potential risks to a business.

As can be seen, risk classification is an important action; thus, many different classification approaches have been developed for risk categorization. Possible to list the following well-acknowledged risk management frameworks and standards that classify risks: Committee of Sponsoring Organizations (COSO), PESTLE, FIRM, Risk Management Standard by the Institute of Risk Management, BS 31100, ISO 31000, and many others.

The COSO framework guides on enterprise risk management and helps a company create an effective internal control system. The COSO framework classifies risks by assessing their likelihood and impact as a basis for determining how to manage them. For risk mitigation, the framework suggests using a combination of qualitative and quantitative risk assessment methodologies and considers how individual risks interrelate (Moeller, 2014).

As was mentioned, the COSO framework focuses on enterprise business risks and provides the following grouping of risks:

- strategic risks: external and internal factor risks
- operations risks: process, people, compliance risks
- finance risks: treasury, credit, trading risks
- information risks: financial, operations, technology risks

PESTLE (Political, Economic, Social, Technological, Legal, and Environmental) is a framework or strategic management technique that assesses external risks arising from macro-environmental factors that can impact a company's operations and create risks. According to PESTELE possible to identify risks under the following categories: Political, Economic, Sociological, Technological, Legal, Ethical, or Environmental (Hopkin, 2018).

FIRM (Financial Institutions Risk Management) is a risk management framework that guides the management of risks, mainly in financial institutions. The FIRM risk scorecard categorizes risks into four headings: Financial and Infrastructure risks, which are internal to the organization, and Reputational and Marketplace risks, which are external in nature (Hopkin, 2018).

IRM's risk management standards, BS31100, and ISO 31000 standards do not provide specifically predefined risk classification systems; instead, they suggest that companies could develop their own risk classification systems that align with an organization's specific needs and objectives (Hopkin, 2018).

There is no universal approach for risk classification because it is context-dependent and could vary depending on industry, organization, type of risk, etc. As a result, risk classification could be based on the business context.

2.1.3 Risk associated with product development projects

When it comes to the product development process, it is crucial to understand that there are risks specific to this process, which are different from typical general-level business risks. It should be noted that the product development process can be regarded as a project. Therefore, risks inherent to the product development process could potentially disturb the progress and impact the result of a project. These risks should be differentiated and considered separately from the more general risks associated with running a business.

The project management team could develop a faultless project plan; however, it is important to recognize that no project is free of risks. Consequently, risks could cause deviations from the initial project plan; thus, risk identification and mitigation are important parts of project activities.

The literature review shows a wide array of risk classifications associated with the process of product development projects. For example, Herber Birkhofer, in his book “The Future of design methodology”, considers risk in the product development process as a result of uncertainty being integrated into the product development process, which impacts a product. In the product development process, risks could be categorized based on uncertainty in the input factors, potentially impacting a product design process. These uncertainties could be listed as follows:

- Technology uncertainties impact various aspects of the product development process:
    a. Technology maturity affects performance reliability.

    b. Systems integration influences overall performance and reliability.
    c. Production system maturity impacts cost and lead time.
    d. Service system maturity affects operation and maintenance costs.
- Uncertainties in customers' needs and their understanding by the project team significantly influence project performance.
- Company-internal uncertainties exist in communication and work coordination processes, project status, and forecasting. They impact cost, schedule, and performance.
- Market uncertainties generated by environmental factors, demographic changes, social trends, and competitor actions could significantly alter target specifications.
- Supplier uncertainties generated by supplier performance during the development process can lead to performance, schedule, and cost risks (Birkhofer, 2011).

Problems that occur during the product development process are often the result of knowledge lack, which brings uncertainty. Thus, these uncertainties could be categorized as “tame problems” and “wicked problems”:

- "Tame problems" are caused by aleatory uncertainty, which is a type of uncertainty that can be quantified. Typical examples are lack of experts, solving technical problems, etc.
- "Wicked problems" are caused by epistemic uncertainty, which is a type of uncertainty that cannot be quantified. Typical examples are stakeholder disagreements, unclear requirements, supplier problems, etc (Batie, 2008).

Keizer, J. Vos, and J. Halman offer a risk reference framework designed for identifying risks in technological product development projects. The framework classifies risk into 142 interconnected critical innovation risks and 12 primary categories. These 12 risk categories are:

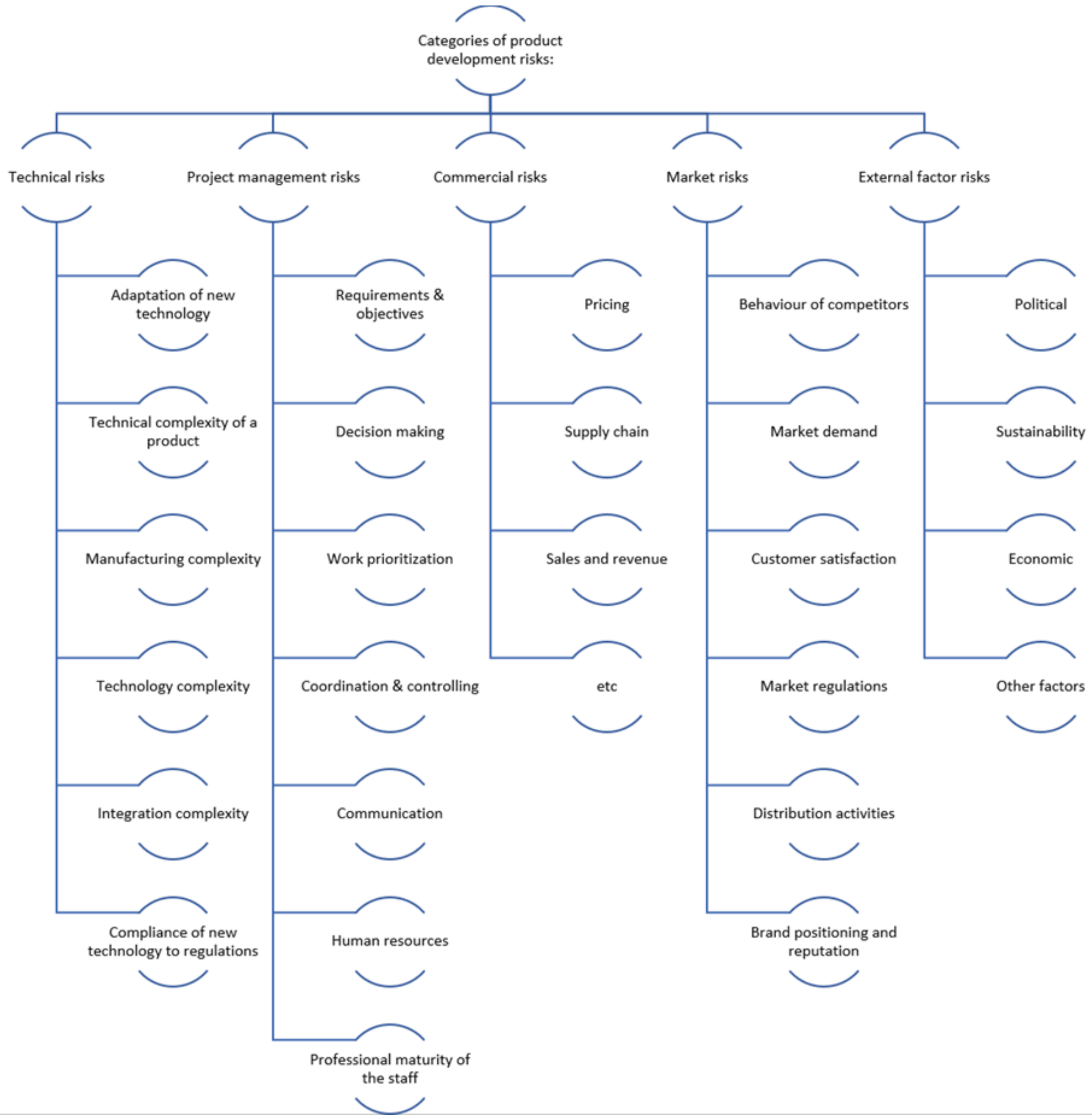
1. Risks related to commercial viability
2. Risks associated with competitors
3. Risks of consumer acceptance and marketing
4. Risks of public acceptance
5. Risks related to intellectual property

6. Risks associated with manufacturing technology
7. Risks related to organization and project management
8. Risks of the product family and brand positioning
9. Risks related to product technology
10. Risks in screening and appraisal
11. Risks in supply chain and sourcing
12. Risks associated with trade customers (Keizer, Vos, & Halman, 2005)

N. Munier states that at the beginning of a project, it is crucial to identify the areas of highest risk, whether they pertain to financing, technical aspects, or logistics. According to this logic, it is possible to list the following areas as sources of risks: technical, execution (performance), financing, schedule, cost, environment societal opinion, quality, communications, legal, closing, and external factors (Munier, 2014).

Referring to risk classification related to the process of software development projects, possible to distinguish the following risk areas: task distribution, knowledge management, geographical distribution, collaboration structure, cultural distribution, stakeholder relations, communication infrastructure, and technology setup (Persson, Mathiassen, Boeg, Madsen, & Steinson, 2009).

Possible to conclude that product development processes and projects have a lot of different risks generated by different kinds of uncertainties. There are a lot of different classifications and categorizations of risks for product development projects; however, it is possible to mark out some of the fundamental groups presented in the Picture 1.



Picture 1. Categories of risks associated with the product development process (Birkhofer, 2011).

2.1.3.1. Risk associated with initial requirements

For product development projects, one of the significant risks is a misinterpretation of initial customer demands and a wrong interpretation of product requirements. Misunderstanding or misinterpretation of requirements can lead to serious consequences such as misuse of resources, customer dissatisfaction, loss of competitive advantage, and delayed time to market (Birkhofer, 2011; J Oehmen, Dick, Lindemann, & Seering, 2006; Tegeltija et al., 2016).

In product development, correct requirements are the base for successful project outcomes. All processes related to collecting, documenting, and managing initial requirements are crucial and play a significant role in the success. The work associated with initial requirements and related management processes is complicated, challenging, and tied up with different risks. Low-quality requirements present a risk and might lead to an undesired result; therefore, risks associated with requirements highlight the importance of understanding and managing them (Leffingwell, 1997).

According to the literature possible to give the following examples of risks related to requirements:

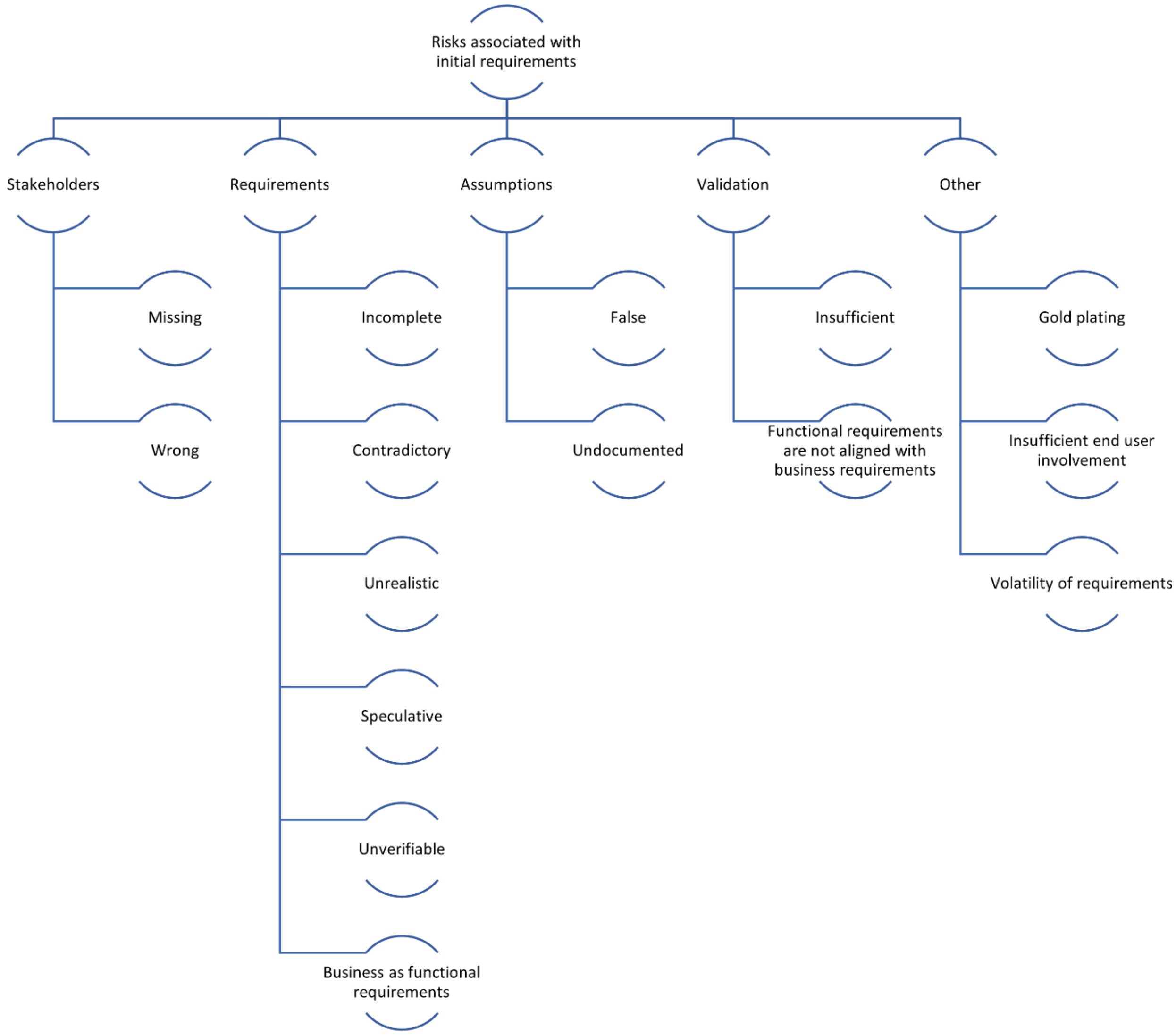
- incomplete requirements that may lead to unusable or generally not acceptable by a client product
- contradictory requirements appear since different stakeholders present different groups, and their wishes for the final product may conflict with each other's in various ways
- unrealistic requirements that exceed the capacities of the organization
- speculative requirements are poorly specified and leave the possibility for misinterpretation or misunderstanding; they appear since stakeholders formulating open-ended requirements to avoid decisions
- unverifiable requirements have unclear verification criteria
- identification of business requirements as functional requirements
- all required stakeholders are not properly identified and not involved in the requirement process (missing stakeholders)
- involving in the requirement management process stakeholders who lack the necessary information and cannot correctly validate, provide, or approve requirements
- false assumptions are a significant source of risks, as they could be overly pessimistic/optimistic
- requirements that are feasible only in cases when a specific set of undocumented assumptions is valid (undocumented assumptions)
- functional requirements that couldn't be matched with appropriate business requirements

- insufficient validation of requirements by appropriate experts
- sometimes, the project development team could include extra requirements that are outside of a project scope, based on their assumptions that the end user would like additional functionality (this phenomenon is so-called “gold plating”)
- changes and additions to the requirements after the requirement identification phase
- insufficient end-user involvement leads to an inadequate interpretation of their needs and results in wrong requirements and product changes at the late stages of the development process (Haskins et al., 2004; Leffingwell, 1997; Spacey, 2023).

For listed above risks related to requirements could be applied group categorization presented in the Picture 2.

The main result of problems related to requirements is rework, which usually occurs at the late stages of the product development process. For example, in the case of software development, studies show that this rework can increase development costs by up to 50 percent, and wrong requirements account for around 75 percent of the rework cost (Leffingwell, 1997). This excessive rework is inefficient and could be avoided by investing more time and resources to obtain higher-quality requirements, which will be paid back by greater product quality and productivity. Poor requirements management puts projects at risk for failure by not meeting user expectations or exceeding budget or schedule.

Therefore, could be concluded that properly defined requirements are important and allow straightly move forward to the design phase. However, organizations frequently do not take the necessary steps to improve their requirements and requirements management processes.



Picture 2. Groups of risks associated with initial product requirements (Haskins et al., 2004).

2.1.3.2. Technical risks

Technical risks are an essential part of any product development process. These risks appear due to the potential challenges related to the technical aspects of designing, manufacturing, and delivering new products. These potential challenges bring risks that might significantly impact the success of the product development process.

Common technical risks arise for the following reasons:

- complexity of the product design, which could bring different technical difficulties related to technical limitations, compatibility, performance limitations, integration issues of different subsystems and components, etc.
- manufacturability factors, including material selection, production processes, and tooling supply chain management, relate to the ability to efficiently manufacture new products at a desired quality level
- failures, insufficiency, or absence of sufficient testing, validation, and quality control activities result in the product's reliability, durability, safety, or compliance with regulations and standards
- technological obsolescence occurs because of the rapid development of modern technologies, which might lead to the potential obsolescence of certain components within a product or system during its development (Calantone & Cooper, 1979; Goodman, 2007; Polk, Plank, & Reid, 1996)

Identifying and addressing technical risks in the early stages of the product development process requires work with prototypes, testing, modeling, simulations, and feasibility studies. The active participation of experienced engineers and the research and development department greatly influences the effective management of technical risks. In addition, clear technical specification, regular design reviews, and open communication with stakeholders contribute to the effective management of technical risks (Ayal & Raban, 1990; Piteiu-Apostol, 2023).

2.2. RISK MANAGEMENT

2.2.1 Traditional Risk Management Approach

Previous chapters indicated that identifying and mitigating risks are crucial for the success of product development projects. Proactive identification and mitigation of risks reduce project delays, cost overruns, and other negative outcomes. All activities related to risks with projects refer to risk management.

Risk management is an important integrated part of project management activities intended to identify, assess, and mitigate potential risks that could impact the product development process. Effective risk management ensures business continuity, improves decision-making processes, and keeps a competitive advantage. It should be noted that the appropriate approach to risk management activity is to consider it as an integral part of project management throughout the project lifecycle that accomplishes various project processes such as overall project management, systems engineering, cost management, design/engineering, quality, and more (Kerzner, 2017; Munier, 2014).

Risk management should be considered as a systematic and structured process that includes the following key elements: risk identification, risk analysis, risk mitigation, risk monitoring, and risk communication.

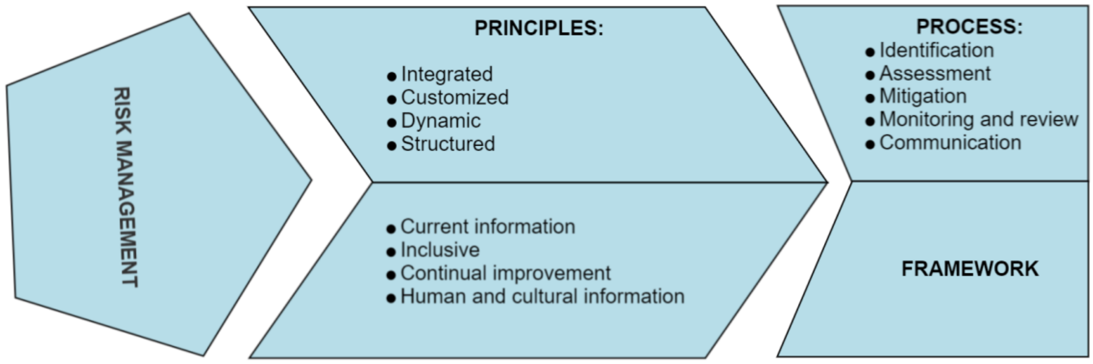
- Risk identification: The process of systematically identifying and documenting potential risks that could impact the product development process. This involves analyzing internal and external factors, conducting risk assessments, and considering various risk categories.
- Risk assessment: The evaluation of identified risks based on their likelihood of occurrence and potential impact on the product development process. This step involves quantitative and qualitative analysis to prioritize risks and allocate resources accordingly.
- Risk mitigation: The development and implementation of strategies and response actions to reduce, control, or transfer risks. This may involve implementing preventive measures, creating contingency plans, etc.
- Risk monitoring and review: Ongoing monitoring of identified risks, assessing the effectiveness of risk response actions, and updating risk management strategies if necessary. Regular reviews help ensure that risk management practices remain relevant and aligned with the changing environment.
- Risk communication: Effective communication with stakeholders regarding identified risks, mitigation strategies, and their potential impact (Akram & Pilbeam, 2015; Kerzner, 2017; Munier, 2014; J Oehmen et al., 2006).

One of the main risk management purposes is identifying risk events and evaluating their causes and consequences to plan for more acceptable outcomes of such events. Therefore, risk management is a proactive activity aimed at achieving acceptable results in the face of potential risks. This necessitates appropriate planning and preparation of response actions beforehand to effectively mitigate and address the identified risks (Anderson, 2013; Kerzner, 2017).

The International Organization for Standardization ISO31000 suggests the following fundamental principles to ensure effective risk management:

- Integrated: Risk management is embedded in decision-making across all departments and levels of an organization.
- Structured and Comprehensive: Risk management is a systematic and structured approach that ensures efficiency and consistency of results.
- Customized: Risk management is tailored to the organization's context and objectives.
- Inclusive: Stakeholders' involvement ensures that their knowledge provides relevance and transparency for risk management.
- Dynamic: Risk management adapts to changing contexts and emerging risks.
- Best Available Information: Decisions are based on the most relevant data.
- Human and Cultural Factors: Risk management should consider human behavior and organizational culture.
- Continual Improvement: Risk management should adapt and change based on learned experience (Field, 2023; 'ISO 31000', 2021).

Risk management is facilitated through various established frameworks, while the above principles are inherent to any risk management framework. The choice of the most appropriate framework for risk management relies on the particular risks and the context in which they are addressed. There are numerous internationally recognized standard frameworks for risk management.



Picture 3. A high-level graphical representation of risk management (‘ISO 31000’, 2021).

Possible to assume that the most critical components in risk management are risk identification, assessment, mitigation, and action plan. These components form a comprehensive approach to managing risks. There are a lot of traditional tools and management methods that guide the required activities for each of these components. The next subchapters briefly review the most popular techniques for each of the mentioned components.

2.2.1.1. Risk identification

The initial phase in traditional risk management is risk identification. This process aims to identify and document potential risks that may have a negative impact on a development project. During risk identification, a wide range of risk categories is considered, including operational, financial, strategic, compliance, reputational, and technical risks. Various sources of risks, such as events, circumstances, or situations that could lead to undesired outcomes, are identified and documented. The outcome of the risk identification phase is a list of identified risks with their detailed descriptions, potential causal factors, and potential consequences. This list serves as a fundamental basis for further stages of the risk management process (Kerzner, 2017; Munier, 2014; Josef Oehmen, Olechowski, Robert Kenley, & Ben-Daya, 2014).

Different methods have been developed to identify risks in the product development process. Below are some of the most widely applied techniques (Keizer et al., 2005; Munier, 2014; J Oehmen et al., 2006).

Brainstorming is a collaborative technique used to identify and address potential risks in a project. During a brainstorming session, team members are encouraged to think creatively and freely share their ideas. This technique promotes open and innovative thinking, allowing different perspectives to be considered (Munier, 2014).

Risk Breakdown Structure (RBS) is a hierarchical and source-oriented grouping representation of potential project risks. RBS organizes, defines, and ensures that all potential risks are identified and evaluated. This technique provides detailed definitions of risk sources at each level (Juranić, Marjanović, & Pavković, 2016).

Delphi Technique is an iterative and anonymous communication system used to collect input from experts regarding identifying and evaluating project risks. The experts who are dispersed and unknown to each other should respond to questionnaires prepared by a coordinator. The responses are analyzed, aggregated, and then returned to the experts for further refinement. This process continues until a consensus is reached or the responses converge (Hofman & Grela, 2015).

SWOT (Strengths, Weaknesses, Opportunities, and Threats) risk identification approach, implemented through identifying and evaluating the strengths, weaknesses, opportunities, and threats of a product under development. It involves evaluating internal factors (strengths and weaknesses) and external factors (opportunities and threats) to gain insights into potential risks and opportunities. Evaluating these aspects opens the possibility of assessing competitive advantages, areas for improvement, and external factors that may cause risks (Gao & Low, 2014; Munier, 2014).

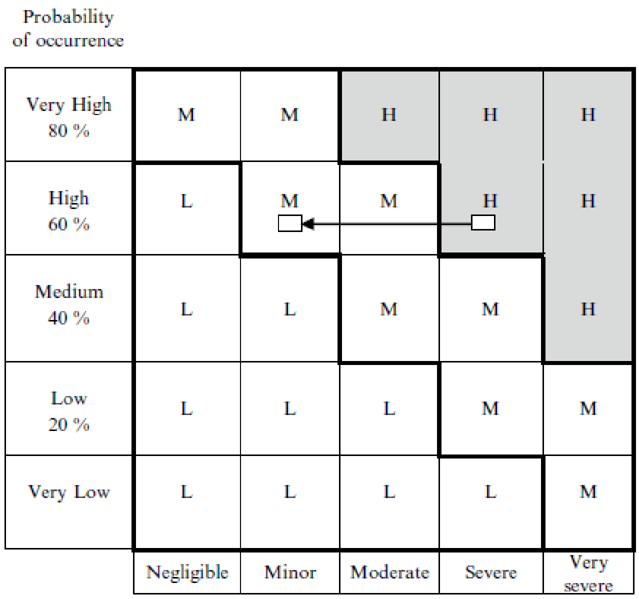
Checklist Analysis provides predefined lists of common risks that can serve as a starting point. Tailored to product development domain checklists ensure that all relevant factors are considered. Checklists can serve as reminders of known risks or risks encountered in past projects, offering detailed and structured lists of risk sources and impacts. While checklists require an initial investment of time to develop and customize, they are easy to apply once created and capture valuable knowledge and experience (Juranić et al., 2016; J Oehmen et al., 2006).

2.2.1.2. Risk assessment

The next step in the risk management process is risk assessment, which involves estimating the identified risks for the determination of their significance and prioritizing further action. The primary objective is to evaluate the probability of each potential impact triggered by risks. Risk assessment should generate a probability distribution of various scenarios, highlighting the range of possible outcomes. The focus is placed on the most critical risks to ensure that needed attention and resources are given to the risks that matter most (Munier, 2014; J Oehmen et al., 2006).

Risk assessment methods could be divided into qualitative and quantitative methods. Qualitative methods rate risks based on the probability and severity of consequences, while quantitative methods rate risks based on available statistical data (Kerzner, 2017; Munier, 2014; J Oehmen et al., 2006).

Literature review indicates the availability of different qualitative risk analysis methods, like root cause analysis, expert judgment, etc. The primary approach is the probability and impact risk matrix, a graphical tool that combines each risk's probability of occurrence and impact.



Picture 4. Risk Matrix (Munier, 2014).

It consists of a grid where the likelihood of a threat is plotted on one axis and the impact it can have on the other. The matrix allows risks to be categorized into different priority levels based on their values. It helps identify the most dangerous situations by highlighting the shaded area of the matrix (Munier, 2014; J Oehmen et al., 2006). For quantitative risk analysis methods, it is possible to list the following methods: Monte Carlo analysis, scenario analysis, decision tree analysis, etc (Kerzner, 2017).

Should be noted that *Failure mode and effect analysis (FMEA)* could be used in both categories, qualitative and quantitative methods, depending on the implementation approach. FMEA is a systematic approach used in risk assessment, especially in product development. It investigates potential failures at all process stages and estimates their occurrence frequency. This technique considers possible failures by imagining different scenarios and modes in which these failures can occur, which allows a risk assessment process. FMEA makes conclusions for the entire system by analyzing individual components of the system, breaking down the system into its components, and examining potential failure modes; FMEA helps prevent defects (Keizer et al., 2005; Munier, 2014).

2.2.1.3. Risk mitigation

Once the critical potential risks have been identified, the next step is to select the appropriate risk mitigation actions to address them. Since each project has its own set of risks, the mitigation strategies could be tailored accordingly. Mitigation strategies could be categorized as follows (Artto, Martinsuo, & Kujala, 2011; Bernard et al., 2019; Hubbard, 2009):

Bearing responsibility for the risk accepts the risk within the project and implies the usage of project management procedures to mitigate unfavorable effects. This approach requires monitoring the risk's development and making necessary adjustments to objectives and contingencies.

Transferring the risk means shifting the responsibility to the customer, subcontractor, or insurance company. The risk can be transferred through contracts or insurance policies, effectively transferring the potential consequences to another party.

Avoiding the risk entails finding alternative solutions that eliminate the risk entirely. While this approach may avoid the original risks, it introduces new risks associated with unfamiliar solutions.

Decreasing the risk involves implementing solutions to reduce the risk's probability or impact. This can be achieved through various procedures such as implementing safety measures, monitoring situations, and taking pre-emptive actions.

Since different kinds of product development approaches reduce different risks, the development approach itself can be considered a risk mitigation strategy (Josef Oehmen, Seering, Bassler, & Ben-Daya, 2013). In the following chapter, this perspective on risk management will be considered in greater detail.

2.2.1.4. Risk monitoring

Once risks have been identified, assessed, and mitigation actions have been implemented, it is essential to continuously monitor and evaluate the effectiveness of these actions. Risk monitoring involves ongoing surveillance and observation of identified risks to detect any changes in their likelihood, impact, or new emerging risks. It aims to ensure that risks are effectively managed and that any necessary adjustments or additional measures are taken promptly (Hopkin, 2018). The risk monitoring process consists of regular reassessment of the identified risks, evaluation of the effectiveness of risk mitigation actions, establishing of communication channels for informing stakeholders about identified risk status and keeping up-to-date documentation related to risk management.

2.2.2 Risk-Driven Design

As mentioned in the previous chapter, some product development approaches incorporate a risk management process during the product development process, which allows managing potential risks without implementing and establishing separate risk management processes. Consideration of risk management as an intrinsic part of the product development process is defined by the risk-driven design process, which follows the following design principles (Birkhofer, 2011):

Creating transparency regarding design risks: This principle involves exploring and identifying uncertainties in the design process and evaluating their impact on objectives.

Making risk-based decisions: This principle involves considering the level of risk when making decisions, which means prioritizing actions and allocating resources to address the most significant risks as early as possible.

Minimizing uncertainty in design is achieved through active risk management and reducing the underlying causes of uncertainty. However, uncertainties cannot be eliminated completely.

Creating resilience in the design system refers to the ability of the design process to be agile and robust to manage remaining uncertainties and unexpected events. Agility is achieved through the ability of the design process to quickly identify and efficiently manage these unexpected events. Robustness is established by the creation of risk buffers (financial, schedule, performance reserve) that absorb deviations in the development process and ensure that project outcomes remain within the desired range (Hubbard, 2009; Josef Oehmen et al., 2013).

Design for Six Sigma is one of the available product development approaches that shares risk-driven principles and could be considered a supportive methodology in addition to most common product development approaches such as waterfall and spiral development (Josef Oehmen et al., 2013).

Design for Six Sigma is chosen in this paper due to its proximity to the product development process. This structured methodology is widely used to develop new products due to its proven efficiency in working with customer requirements and specifications. DFSS targets minimizing defects and aims to reduce the number of variations, enabling proactive risk management for the product development process (Maass & McNair, 2010; Yang & El-Haik, 2009). DFSS is an extension of the traditional Six Sigma approach and especially focuses on creating new products. There are different methodologies to structure DFSS, but despite variations, they typically follow a series of predefined phases depending on the specific implementation. These phases are Define, Measure, Analyze, Design, and Optimize. Possible to list the following methodology for DFSS: DMADV (Define, Measure, Analyze, Design, Verify), DMADOV (Define, Measure, Analyze, Design, Optimize, Verify), DCCDI (Define Customer and Concept, Design, Implement), IDOV (Identify, Design, Optimize, Verify) and others.

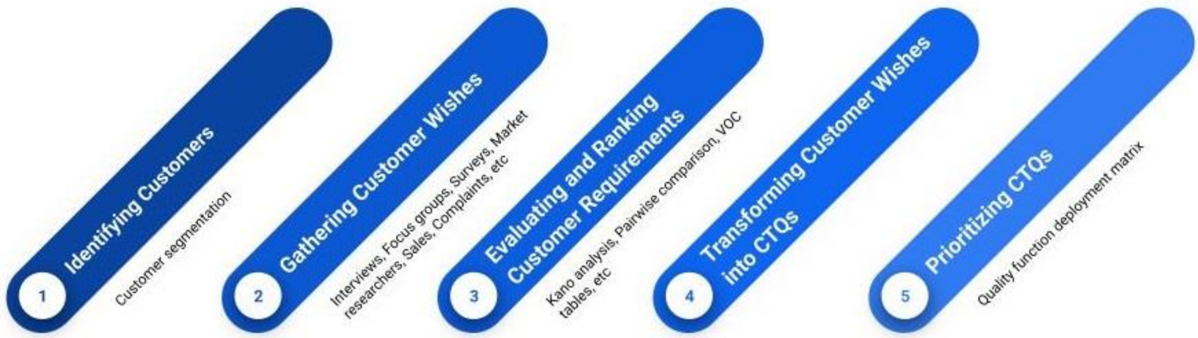
DFSS offers tools and methods to ensure that quality is incorporated into the design process from the beginning rather than relying on post-production revisions. The target is to create reliable, high-quality designs that satisfy customer expectations by integrating customer requirements, statistical analysis, risk assessment, and optimization techniques.

2.2.2.1. From customer wishes to Critical Design Parameters: The crucial role of the Identify stage in DFSS

The goal of DFSS is to fulfil customer requirements while minimizing product defects and variability. This target is achieved by applying Six Sigma principles starting from the beginning of a development process, which allows preventing defects instead of fixing them later (Yang & El-Haik, 2009). This approach leads to improved project outcomes.

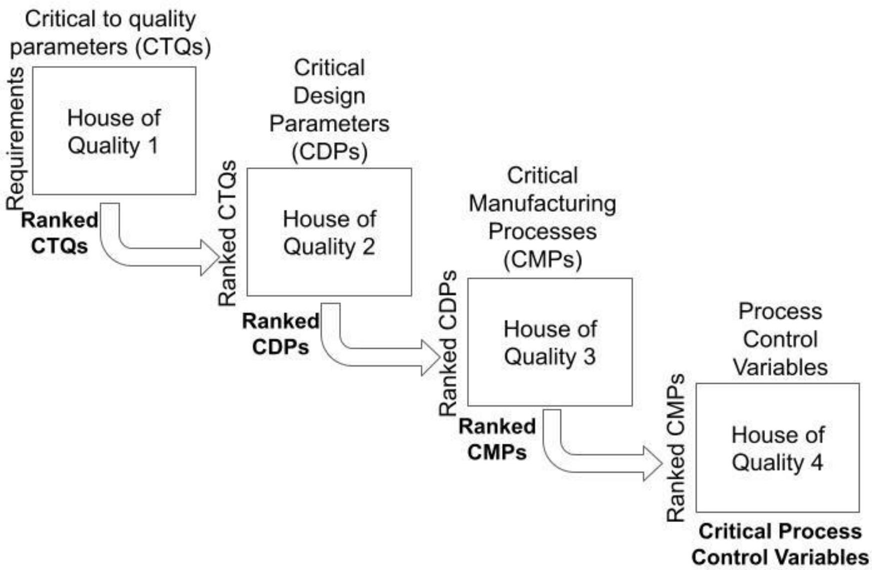
In the DFSS process, communication with customers and stakeholders is continuous and ensures persistent validation of the project's direction. For DFSS, working with customer requirements is one of the most important aspects that ensure alignment of the final product with initial customer needs (Maass & McNair, 2010). The work with customer requirements goes through all the DFSS stages listed in the previous chapter. Among these stages, the initial ones, namely Identify and Design in the IDOV methodology, hold particular significance in obtaining and clarifying customer needs. In the following, these two stages of DFSS will be briefly described, since the techniques and tools related to these stages were used in the case study.

For DFSS, the Identify stage is the first and most critical step in the product development process. The main target for this stage is clearly defined project objectives and customer needs. Properly defined customer requirements set the base for the project and allow to avoid rework. The project team should get input information and transform it into the Voice of Customer (VOC) and Voice of Business (VOB) (Ginn & Varner, 2004; Rowlands, 2001; Yang & El-Haik, 2009). Different methods are used to collect initial input, such as customer and market research, interviews, surveys, and focus groups. When initial input is collected and transformed into VOC, it is necessary to translate it into functional and measurable requirements, which should be prioritized. The next step is the identification of Critical to Quality parameters that directly impact customer satisfaction (Ginn & Varner, 2004; Maass & McNair, 2010; Yang & El-Haik, 2009). The Picture 5 presents a high-level representation of the stage. There are a lot of different tools available for each of the steps presented in the Picture 5; however Quality Function Deployment (QFD) is one of the most used. It facilitates the conversion of customer input into detailed technical requirements and precise product specifications.



Picture 5. Steps of Identify stage of DFSS (Maass & McNair, 2010).

QFD uses a special “House of Quality” matrix to link customer requirements with design elements, engineering characteristics, and other project components (Yang & El-Haik, 2009). The QFD cycle is presented in the Picture 6.



Picture 6. QFD cycle (Yang & El-Haik, 2009).

In the next chapter, during the Case study, the first two phases of QFD were executed, resulting in the identification and ranking of Critical Design Parameters. Applying QFD in the case study improved the comprehension of customer needs and enabled the prioritization of design requirements, fostering well-informed decisions throughout the product development process.

The Design stage of DFSS is centered on generating and evaluating various design concepts aimed at satisfying customer requirements and CTQs. The end target of this stage is to develop an optimal design and select a concept that should go for further optimization and validation (Ginn & Varner, 2004; Rowlands, 2001; Yang & El-Haik, 2009). The main tools usually used during this stage are the Functional Analysis system technique, Pugh Concept selection, Functional Partitioning, Failure Modes and Effects Analysis, etc.

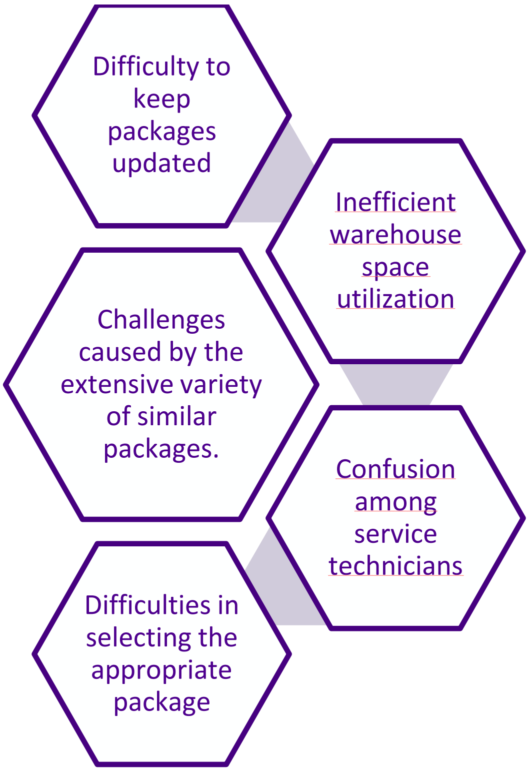
3 APPLYING RISK-DRIVEN DESIGN FOR CUSTOMER REQUIREMENT CLARIFICATION IN A REAL DEVELOPMENT PROJECT

3.1. Background for the project

Most of Company X's equipment is supplied with a specially designed device to monitor, protect, and operate its equipment. For now, Company X uses the 3rd generation of device A, which was introduced to the market 20 years ago. The currently available generation of device A is obsolete because most of its printed circuit board components have reached the end of their lifecycle. Moreover, this generation of device A does not comply with today's requirements from the market and customers. Additionally, the merger between company X and company Z has triggered the development process of a new generation of device A (A2) to harmonize the processes and equipment across both companies.

Since the stock for the 3rd generation of device A is finite, the Spare Part Department should start its project to utilize of device A2 for spare parts and modernization needs. The Spare Part Department has a wide variety of different modernization, retrofit, and spare part packages, where device A is a core component. These packages have different owners and serve different purposes. A large number of almost similar packages point out nonoptimal design and mistakes made during the case studies in the past. A new generation of the device provides optimization possibilities for this variety of disparate offerings.

The wide variety of retrofit and spare part packages with device A is not a result of a wide variety strategy but rather a consequence of badly managed and uncontrolled product line expansion. Device A is a key piece of many systems that serve different business areas of Company X business. Each of these business areas has stakeholders that considered device A's utilization within their responsible area. Moreover, device A has become widely used in the field as a spare part for its predecessors. These aspects have resulted in many modernization and retrofit packages with minimal differences.



Picture 7. The wide variety of similar packages causes the current challenges.

Maintaining this variety of products causes business complexity in sales, marketing, administrative, and supply chain processes. As a result, this leads to higher expenses for company X and difficulties for customers and employees. The Spare Part Department has recognized the importance of optimization for the product portfolio for a long time. In summary, there is a need for an optimal solution based on a better understanding of stakeholders' needs from different user groups. Throughout the case study, various tools from DFSS methodology were employed to identify clients, gather customer preferences, and prioritize technical requirements.

The following questions should be considered more specifically:

1. Who are the main internal customers for the packages?
2. What are the most important attributes of the packages for different user groups?
3. Is it possible to design optimal modernization/retrofit packages over different business areas?

3.2. Challenges and targets for the project

The project's main goal is to create a new generation of retrofit packages for the new generation of monitoring device A2 that should improve the existing situation with a wide variety of similar retrofit products by combining the most feasible features in a smaller number of packages. A comprehensive review of existing products and sales volumes of old packages should be a part of the work to achieve the optimal design.

Especially the project team must focus on the following sub-tasks:

1. To identify the most important customers and analyze their needs by defining key attributes for groups of packages;
2. To collect and evaluate sales data for the last five years to understand which of the packages have potential on the market;
3. To formulate requirements of internal customers and interpret them into a list of technical requirements that will form technical specifications;
4. To consider that the new generation of the packages should be more robust to changes to avoid redesign cycles;
5. Transfer some of the obtained technical requirements to the development project of device A2;

The result of this study will be valuable to the Spare Part Department and other related departments.

3.3. Project execution

3.3.1 Customer Identification through Sales Data Collection and Structuring

A qualitative methodology was utilized to develop a comprehensive understanding of the opportunities for improving the product range. The analysis commenced with an examination of available sales data. To obtaining the necessary information, multiple systems of company X were reviewed and accessed to determine the quantity of packages delivered to customers for the previous five years. Appendix 1 provides a comprehensive and well-organized compilation of data regarding the packages where device A is present and their corresponding sales volumes.

Based on the data in Appendix 1, Table 1 was created to present better-grouped data. The packages were grouped based on the voltage of the package and the similarity of the additional equipment supplied with device A.

Table 1. Grouped sales data for the packages with device A.

Name of the package	Amount of sold pcs for last 5 years, pcs	Order number on the Figure 1
Device A, no preset parameters	2857	1
Modernization package without cubicle, with parametrized device A	739	2
Device A with preset parameters	457	3
Modernization package in a cubicle, with non-parameterized device A	428	4
Modernization package with cubicle, with non-parameterized device A, set of additional equipment #1	335	5
Modernization package without cubicle, with parametrized device A	153	6
Modernization package in a cubicle, with parametrized device A	105	7
Modernization packages for alpha brands 1,2,3 without cubicle and non-parameterized device A	68	8
Modernization package with cubicle, with parametrized device A, set of additional equipment #1	43	9
Modernization package with cubicle, with non-parameterized device A, set of additional equipment #2, version 1 and version 2	13	10
Retrofit packages	7	11

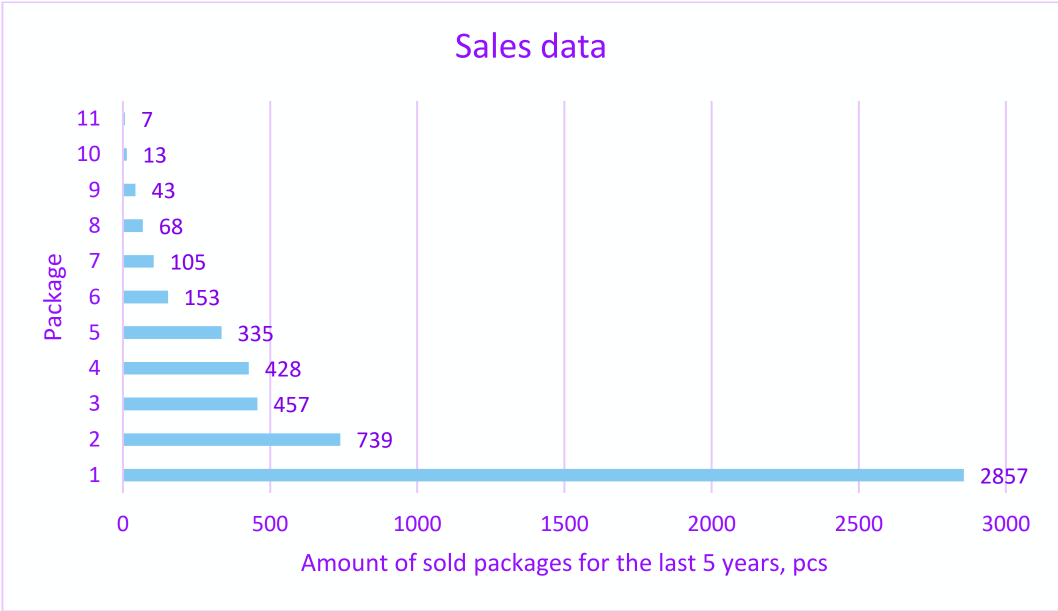
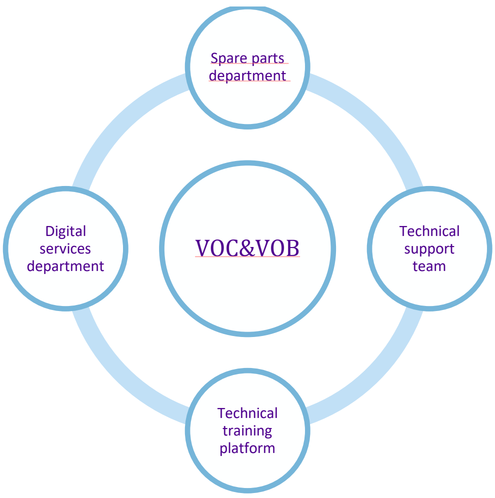


Figure 1. Grouped sales data for the packages with device A. Figure shows the number of packages sold for the last five years.

The initial process of data gathering and evaluation of sales data for all packages with device A for five years played an important role. This analytical step helped to identify the most demanded packages on the market and delineated the main internal user groups (customers) that engage with these packages. Based on the obtained data performed customer segmentation (Ginn & Varner, 2004; Yang & El-Haik, 2009), the following departments were defined as the most important customers: the spare parts department, the technical support team, the technical training platform, and the digital services department.



Picture 8. Key customers.

From each of the listed departments was selected a representative who presented the department's needs and was involved in the process. These selected representatives represent the combined voice of customers (VOC) and businesses (VOB) (Yang & El-Haik, 2009).

3.3.2 Gathering and Analyzing Customer Needs Data

After the customer's identification, the next step is collecting their wishes about the new package (Ginn & Varner, 2004; Maass & McNair, 2010; Yang & El-Haik, 2009). This step heavily relies on close cooperation with customers. Interaction with customers was done thru interviews, face-to-face meetings, group discussions, and surveys.

To facilitate the process, customers received an initial email, which included a concise pre-study presentation of the existing packages. The email also emphasized the difficulty of dealing with a wide variety of packages and the difficulties in classifying them due to the different available classification options, such as surrounding equipment, application, voltage, brand, etc. The mail also included a list of leading open-ended questions for customers (Appendix 2) to consider before our face-to-face meetings. This list of questions assisted customers in better expressing their preferences and requirements based on their previous experience with the existing packages (Rowlands, 2001).

Later, a separate face-to-face meeting was conducted with each customer to gather information about their usage of the existing packages and their preferences for the new generation of packages. After face-to-face meetings held a workshop with all groups of customers to share collected information between different departments. The outcome of these activities was a comprehensive register of high-level customer wishes, which, in some cases, were incompatible since different groups of customers used the existing packages for different purposes. The collected high-level wishes were translated into a set of customer requirements, listed in Table 2 (Maass & McNair, 2010; Rowlands, 2001; Yang & El-Haik, 2009).

Table 2. Translated Customer Wishes into Customer Requirements.

Requirement 1	Minimize the number of package variations
Requirement 2	Ensure simple data transfer when replacing device A with device A2
Requirement 3	Ensure universal compatibility across different applications (fits alfa brands and competitors)
Requirement 4	Ensure ease of mounting
Requirement 5	Avoid the need for additional cubicles
Requirement 6	Include equipment for internet connectivity in every package
Requirement 7	Provide the capability to track complete asset information
Requirement 8	Minimize or eliminate the need for manual adjustment of device A2 on site

Subsequently, it is necessary to prioritize these obtained customer requirements to identify and validate the most critical ones (Ginn & Varner, 2004).

3.3.3 Attempt 1

3.3.3.1. Analyzing and Prioritizing Customer Needs Data

The prioritization of customer requirements involved the use of a pairwise comparison approach. This approach implies comparing each requirement against every other requirement, which allows a thorough evaluation and comparison of alternatives. Execution of pairwise comparison should ensure that the final solution aligns with the desired objectives and criteria (Maass & McNair, 2010). A detailed overview of the process and completed pairwise comparison matrix is presented in Appendix 3. The resulting Pareto chart of customer requirements is shown in the Figure 2.

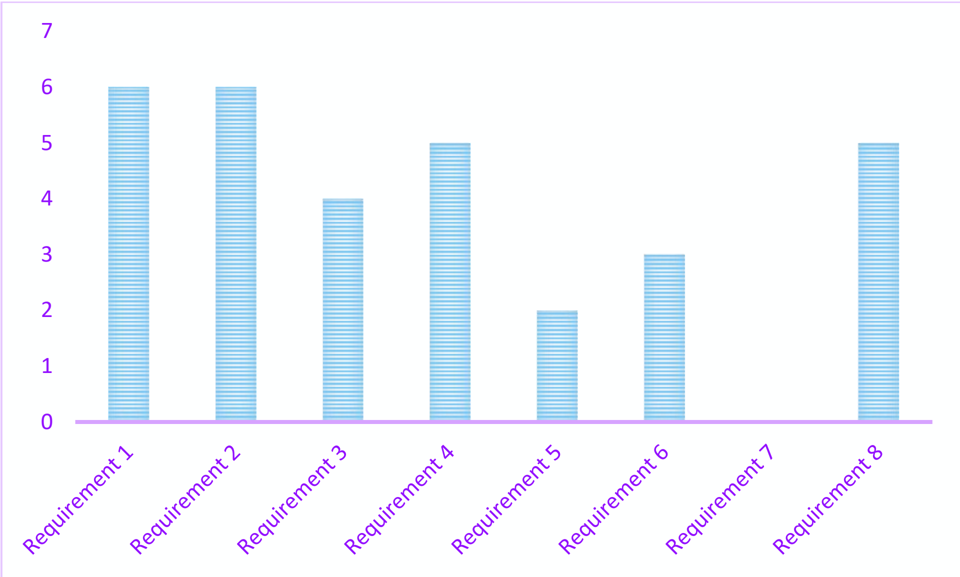


Figure 2. Pareto of customer requirements (Yang & El-Haik, 2009).

Table 3 presents the importance ranks of the requirements, which were determined through pairwise comparison.

Table 3. Requirements with assigned importance ranking.

Requirement #	Importance rank
Requirement 1	5
Requirement 2	5
Requirement 3	2
Requirement 4	4
Requirement 5	2
Requirement 6	3
Requirement 7	1
Requirement 8	4

The project team decided to use the Kano model for verification purposes to ensure the accuracy of the obtained importance ranks and eliminate potential mistakes in customer needs. The Kano questionnaire process was chosen as it allowed for gathering responses without requiring another round of in-person meetings. Through the Kano questionnaire process were created functional and dysfunctional questions for each requirement, a list of these questions is presented in Appendix 4 (Yang & El-Haik, 2009). These questions were then used to develop a questionnaire shared with the customers. The responses from customers to the questionnaire are presented in Appendix 4.

Based on the customers' responses to the functional and dysfunctional questions, each requirement was assigned a proper category (Ginn & Varner, 2004; Yang & El-Haik, 2009). The Table 4 presents the results, indicating how each customer categorized each requirement.

Table 4. Categorization of requirements based on customer answers (Ginn & Varner, 2004).

	Customer 1	Customer 2	Customer 3	Customer 4	Customer 5	Customer 6
Requirement 1	Indifferent	Indifferent	Reverse	Attractive	Indifferent	Must be
Requirement 2	One-Dimensional	Must be	Indifferent	Must be	Indifferent	Attractive
Requirement 3	Indifferent	Questionable	One-Dimensional	Attractive	One-Dimensional	Questionable
Requirement 4	Attractive	Must be	Attractive	Indifferent	Must be	Indifferent
Requirement 5	Must be	Attractive	Attractive	Attractive	Attractive	Attractive
Requirement 6	Must be	One-Dimensional	Must be	Attractive	Indifferent	Must be
Requirement 7	Indifferent	Attractive	Must be	One-Dimensional	Must be	Indifferent
Requirement 8	Attractive	Attractive	Attractive	Indifferent	Attractive	Attractive

Table 5 displays the categories assigned to each requirement (table cell marked with green colour) based on customer answers. It also highlights the highest result obtained for each requirement.

Table 5. Assigned category to each of requirements based on the highest score (Ginn & Varner, 2004).

	Attractive	Must be	One-Dimensional	Reverse	Questionable	Indifferent
Requirement 1	1	1	-	1	-	**3**
Requirement 2	1	**2**	1	-	-	2
Requirement 3	1	-	**2**	-	2	1
Requirement 4	2	**2**	-	-	-	2
Requirement 5	**5**	1	-	-	-	-
Requirement 6	1	**3**	1	-	-	1
Requirement 7	1	**2**	1	-	-	2
Requirement 8	**5**	-	-	-	-	1

Based on the analysis of the results in the Table 5, possible to determine the category for each requirement and establish the importance ranking, see Table 6.

Table 6. Requirements with identified category and assigned corresponding importance ranking.

	Assigned category	Importance rank
Requirement 1	Indifferent	1
Requirement 2	Must be	5
Requirement 3	One-Dimensional	4
Requirement 4	Must be	5
Requirement 5	Attractive	3
Requirement 6	Must be	5
Requirement 7	Must be	5
Requirement 8	Attractive	3

Table 7 presents the importance ranking obtained through pairwise comparison and applying the Kano model.

Table 7. Importance ranking obtained with the Kano model and Pairwise comparison.

	Obtained importance ranking	
	Pairwise comparison	KANO model
Requirement 1	5	1
Requirement 2	5	5
Requirement 3	2	4
Requirement 4	4	5
Requirement 5	2	3
Requirement 6	3	5
Requirement 7	1	5
Requirement 8	4	3

From Table 7, can be observed that the obtained importance rankings are different, and in some cases, they are contradictory. To clarify the results obtained with the Kano model, was decided to further refine the results by conducting a detailed analysis using the continuous analysis approach for the Kano model (Ginn & Varner, 2004). For performing the continuous analysis, the averages of the answers need to be used (Wu & Wang, 2012).

Table 8 provides the assigned values to the answers based on their impact on satisfaction.

Table 8. Impact of answer on satisfaction levels (Ginn & Varner, 2004).

	I would dislike it	I could tolerate it	I would be neutral	I would expect it	I would like it
The score for functional answers	-2	-1	0	2	4
The score for dysfunctional answers	4	2	0	-1	-2

Table 9 presents assigned values for all answers from all the customers, a detailed presentation of questions, and assigned values for answers for each requirement from each customer, which could be seen in the Appendix 4.

Table 9. Assigned values for answers by requirements and customers.

		Customer 1	Customer 2	Customer 3	Customer 4	Customer 5	Customer 6
Requirement 1	Functional	2	-1	0	4	2	2
	Dysfunctional	2	-1	-2	2	2	4
Requirement 2	Functional	4	2	2	2	2	2
	Dysfunctional	4	4	2	4	2	2
Requirement 3	Functional	0	4	4	4	4	-1
	Dysfunctional	0	-2	4	0	4	2
Requirement 4	Functional	4	2	4	2	2	0
	Dysfunctional	2	4	2	0	4	0
Requirement 5	Functional	2	4	0	4	4	4
	Dysfunctional	4	2	0	2	2	2
Requirement 6	Functional	2	4	2	4	2	0
	Dysfunctional	4	4	4	2	2	4
Requirement 7	Functional	2	4	2	4	2	2
	Dysfunctional	0	2	4	4	4	0
Requirement 8	Functional	4	4	4	2	4	4
	Dysfunctional	2	2	-1	0	2	2

The next step involves calculating the average values of functional and dysfunctional responses for each requirement across all customers (Ginn & Varner, 2004; Wu & Wang, 2012; Yang & El-Haik, 2009). The calculated results are presented in the Table 10.

Table 10. Average values of functional and dysfunctional responses by requirements.

	Average value	
	Functional	Dysfunctional
Requirement 1	1,50	1,17
Requirement 2	2,33	3,00
Requirement 3	2,50	1,33
Requirement 4	2,33	2,00
Requirement 5	3,00	2,00
Requirement 6	2,33	3,33
Requirement 7	2,67	2,33
Requirement 8	3,67	1,17

Determination of importance ranking requires plotting a graph where pairs of functional and dysfunctional average values for each requirement are presented (Yang & El-Haik, 2009), see Figure 3.

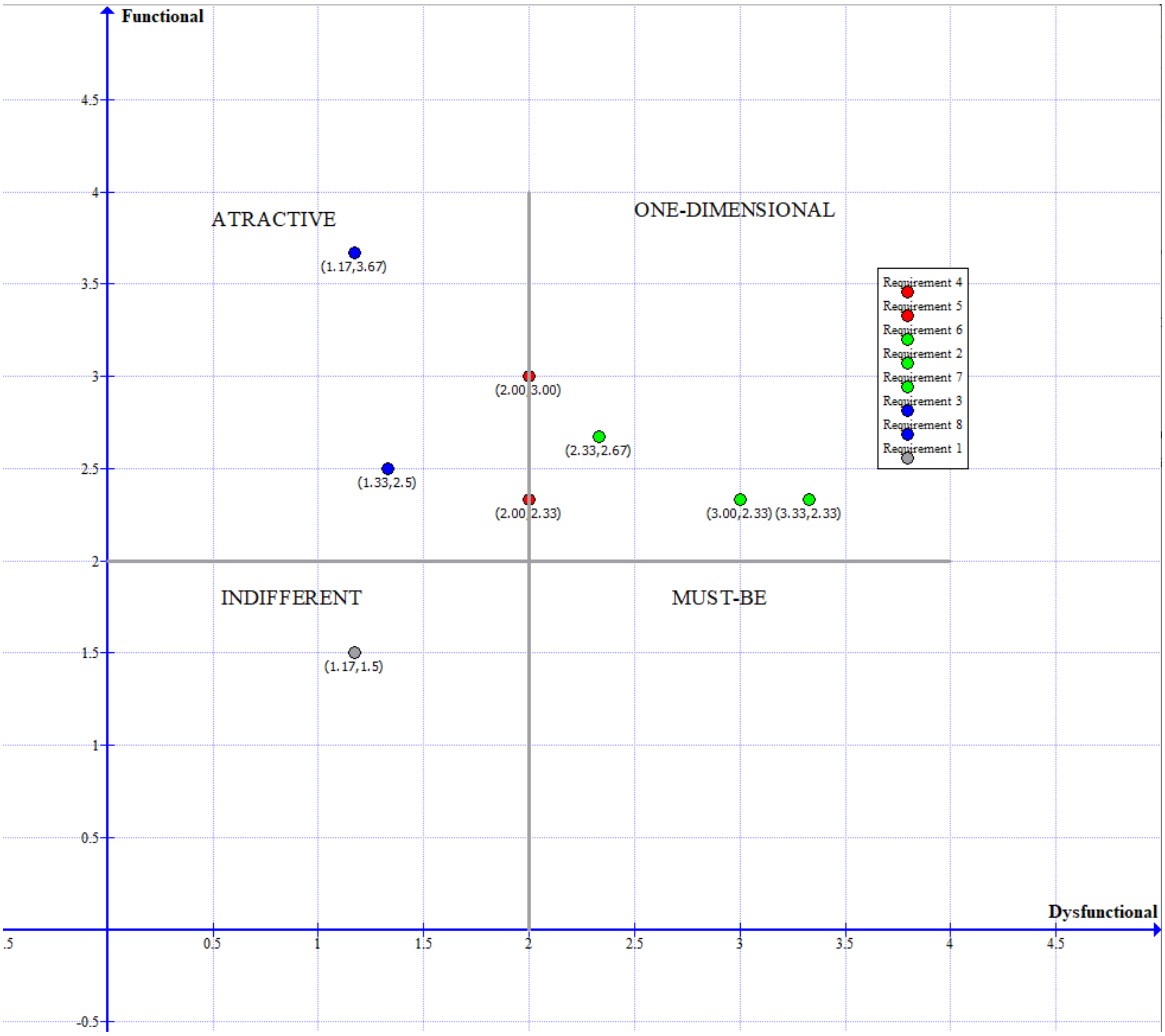


Figure 3. Categorization plane with plotted requirements (Yang & El-Haik, 2009).

Table 11 shows the importance ranking obtained with a continuous analysis approach for the Kano model (Ginn & Varner, 2004; Rowlands, 2001; Wu & Wang, 2012; Yang & El-Haik, 2009). The graph shows that requirements 4 and 5 stand on the border between one-dimensional and attractive categories. In further analysis, the category for these requirements will be defined as attractive.

Table 11. Requirements with assigned importance ranking obtained with the continuous analysis approach (Yang & El-Haik, 2009).

	Im-portance rank
Requirement 1	1
Requirement 2	4
Requirement 3	4
Requirement 4	3 or 4
Requirement 5	3 or 4
Requirement 6	4
Requirement 7	4
Requirement 8	3

Table 12 shows the obtained importance ranking with the help of used approaches.

Table 12. Importance ranking obtained with Pairwise comparison, the Kano model, and Continuous analysis.

	Importance ranking		
	Pairwise comparison	KANO model	Continuous Analysis
Requirement 1	5	1	1
Requirement 2	5	5	4
Requirement 3	2	4	4
Requirement 4	4	5	3
Requirement 5	2	3	3
Requirement 6	3	5	4
Requirement 7	1	5	4
Requirement 8	4	3	3

The project team decided to rely on the results obtained with continuous analysis and accept the importance rank obtained by this method. This decision was made based on the conclusion made by the project team that this method ensures equal opportunity for each client to assess the requirements by answering functional and dysfunctional questions. It is important to note that during group meetings and workshops, the most active clients betrayed the importance of requirements that were significant to them. This could affect other clients' decisions and impact the pairwise comparison result.

3.3.3.2. Translation of Customer Requirements into Critical-to-Quality Parameters

In the previous sub-chapter, the importance ranking for customer requirements was obtained. The next step involves converting these customer requirements into quantifiable elements. These elements should represent specific product characteristics defined by the customers and can be utilized by the design team. According to the methodology, these elements are named Critical to Quality parameters (CTQs) (Ginn & Varner, 2004; Yang & El-Haik, 2009).

The project team analyzed the customer requirements and generated critical parameters for each requirement. These critical parameters are presented in the Table 13.

Table 13. Generated Critical to quality parameters.

Requirements		Critical to quality parameters
Requirement 1	Minimize the number of package variations	- Package covers all voltages (CTQ1) - Package includes a modem (CTQ2) - Package fits alfa brands and competitors (CTQ3) - Package should replace device A and its predecessor (CTQ4)
Requirement 2	Ensure simple data transfer when replacing device A with device A2	- Preparametrized A2 device (CTQ5) - Step-by-step instructions (CTQ6) - A2 compatible with parameters of device A predecessor (CTQ7)
Requirement 3	Ensure universal compatibility across different applications (fits alfa brands and competitors)	- Package fits alfa brands and competitors (CTQ3) - Clear ordering instructions (CTQ11)
Requirement 4	Ensure ease of mounting	- Step-by-step instructions (CTQ6) - General wiring diagram (CTQ8)
Requirement 5	Avoid the need for additional cubicles	- Parts kit package (CTQ9)
Requirement 6	Include equipment for internet connectivity in every package	- Package includes a modem (CTQ2)
Requirement 7	Provide the capability to track complete asset information	- Free inputs of A2 to be adjusted for tracking complete asset (CTQ10)
Requirement 8	Minimize or eliminate the need for manual adjustment of device A2 on site	- Preparametrized A2 device (CTQ5)

After creating the critical to quality parameters according to the methodology, it is necessary to establish a correlation between each requirement and the corresponding critical to quality parameters (Maass & McNair, 2010; Yang & El-Haik, 2009). A detailed overview of the process and completed correlation matrix is presented in the Appendix 5. The resulting Pareto chart of evaluated critical to quality parameters is shown in the Figure 4.

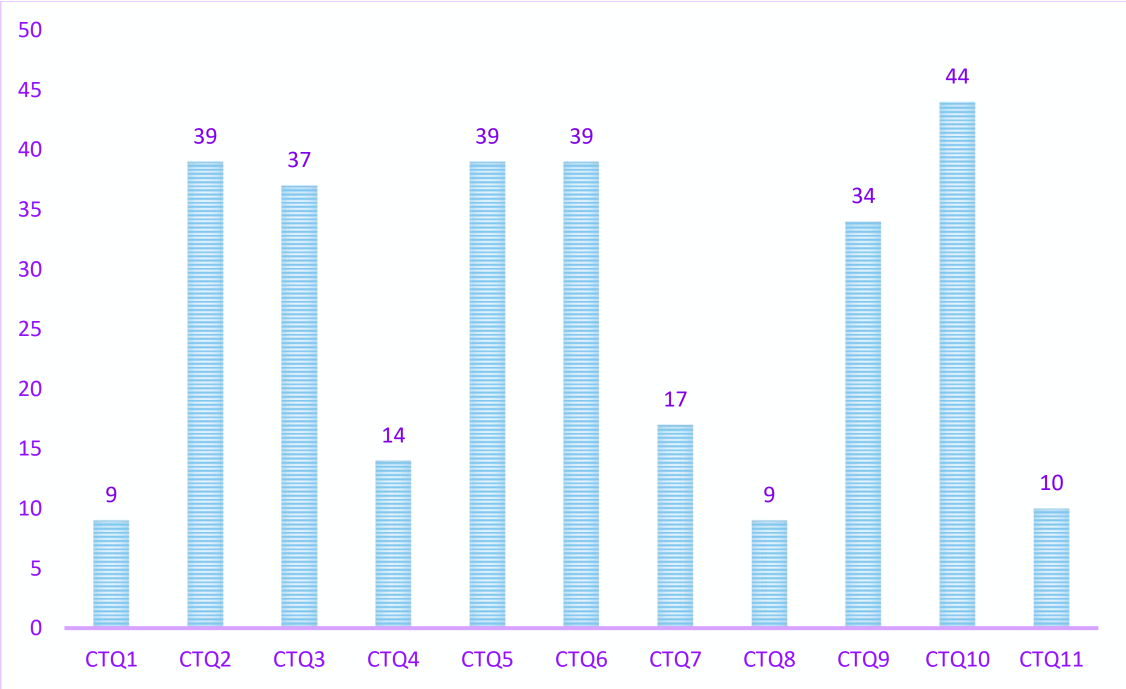


Figure 4. Pareto of raw scores for critical to quality parameters (Yang & El-Haik, 2009).

Table 14 presents the importance rank for critical to quality parameters, which was determined through a completed correlation matrix (Ginn & Varner, 2004).

Table 14. Critical to quality parameters with assigned importance ranking.

CTQs	CTQ1	CTQ2	CTQ3	CTQ4	CTQ5	CTQ6	CTQ7	CTQ8	CTQ9	CTQ10	CTQ11
Obtained importance rank	1	4	4	2	4	4	2	1	4	5	1

Critical to quality parameters with assigned importance ranking were presented to the customers, and the project team met criticism from the customers; they stated that CTQs were incorrect and didn’t present their expectations of the package.

After presenting the customers with the critical to quality parameters with importance ranking, the project team received criticism from the customers. The customers expressed dissatisfaction, stating that the CTQs did not accurately reflect their expectations for the package. Furthermore, the project team encountered difficulties in identifying the variables that directly impact the defined critical quality parameters, also known as critical design parameters (CDPs). Since the identification of CDPs is an essential step to proceed further, the project team recognized the need to restart the process from the beginning.

After conducting a thorough analysis of the taken steps, the project team concluded several reasons for the failure, which can be summarized as follows:

- Proximity of critical to quality parameters to customer requirements: The CTQs identified did not sufficiently capture the nuanced aspects of the customer requirements, leading to a misalignment between the desired outcomes and the defined parameters.
- Inadequate division of customer requirements: The customer requirements were not effectively subdivided, which hindered the accurate translation of their expectations into measurable parameters.
- Desire to please everyone: There was a tendency to accommodate and incorporate the preferences of all customers, which resulted in an overly generalized approach that failed to address specific needs.
- Scepticism among some customers towards the new approach: Certain customers exhibited scepticism towards adopting the new methodology, which impacted their active participation and contributed to the overall failure.
- Overconfidence of the steering group regarding end customers' needs: The steering group displayed self-assurance regarding their understanding of the end customers' needs, which might have overlooked important nuances or evolving requirements.

3.3.4 Attempt 2

3.3.4.1. Reconsideration of customer wishes and redefining customer requirements

The project team acknowledged that the close alignment of customer requirements with critical to quality parameters contributed to the previous failure. In response, the team decided to keep the customer requirements at a higher level. This involved redefining certain requirements without specific details to facilitate a broader perspective. Furthermore, similar requirements were either combined or removed. The revised set of customer requirements is presented in Table 15.

Table 15. Redefined Customer Requirements.

Requirement 1	Commissioning simplicity
Requirement 2	Internet connectivity
Requirement 3	Complete asset monitoring
Requirement 4	Minimize package variety

As in the previous iteration, a new set of customer requirements must be prioritized to identify their relative importance.

3.3.4.2. Analyzing and Prioritizing Customer Needs Data

The project team decided to use the continuous analysis approach for the Kano model to prioritize customer requirements. Based on the previous attempt and gained experience, the project team concluded that the continuous analysis approach for the Kano model ensures equal consideration of input from all clients.

The Appendix 6 contains a list of functional and dysfunctional questions corresponding to each requirement. The questionnaire form, with these questions, was distributed to customers via email. The received responses from customers and the assigned values for answers for each requirement are provided in Appendix 6. Table 16 presents a consolidated summary.

Table 16. Assigned values for answers by requirements and customers.

		Customer 1	Customer 2	Customer 3	Customer 4	Customer 5	Customer 6
Requirement 1	Functional	2	2	-1	2	0	4
	Dysfunctional	4	2	2	2	0	4
Requirement 2	Functional	0	4	4	4	2	0
	Dysfunctional	0	4	4	2	2	2
Requirement 3	Functional	2	4	2	2	2	2
	Dysfunctional	0	2	2	4	2	0
Requirement 4	Functional	2	2	0	4	4	2
	Dysfunctional	2	-1	0	2	2	4

Table 17 lists the calculated average values of functional and dysfunctional responses for each requirement, considering all customers.

Table 17. Average values of functional and dysfunctional responses by requirements.

	Average value	
	Functional	Dysfunctional
Requirement 1	1.5	2.33
Requirement 2	2.33	2.33
Requirement 3	2.33	1.66
Requirement 4	2.33	1.5

To determine the importance ranking, a graph is plotted displaying the pairs of functional and dysfunctional average values for each requirement; see Figure 5 for visual representation.

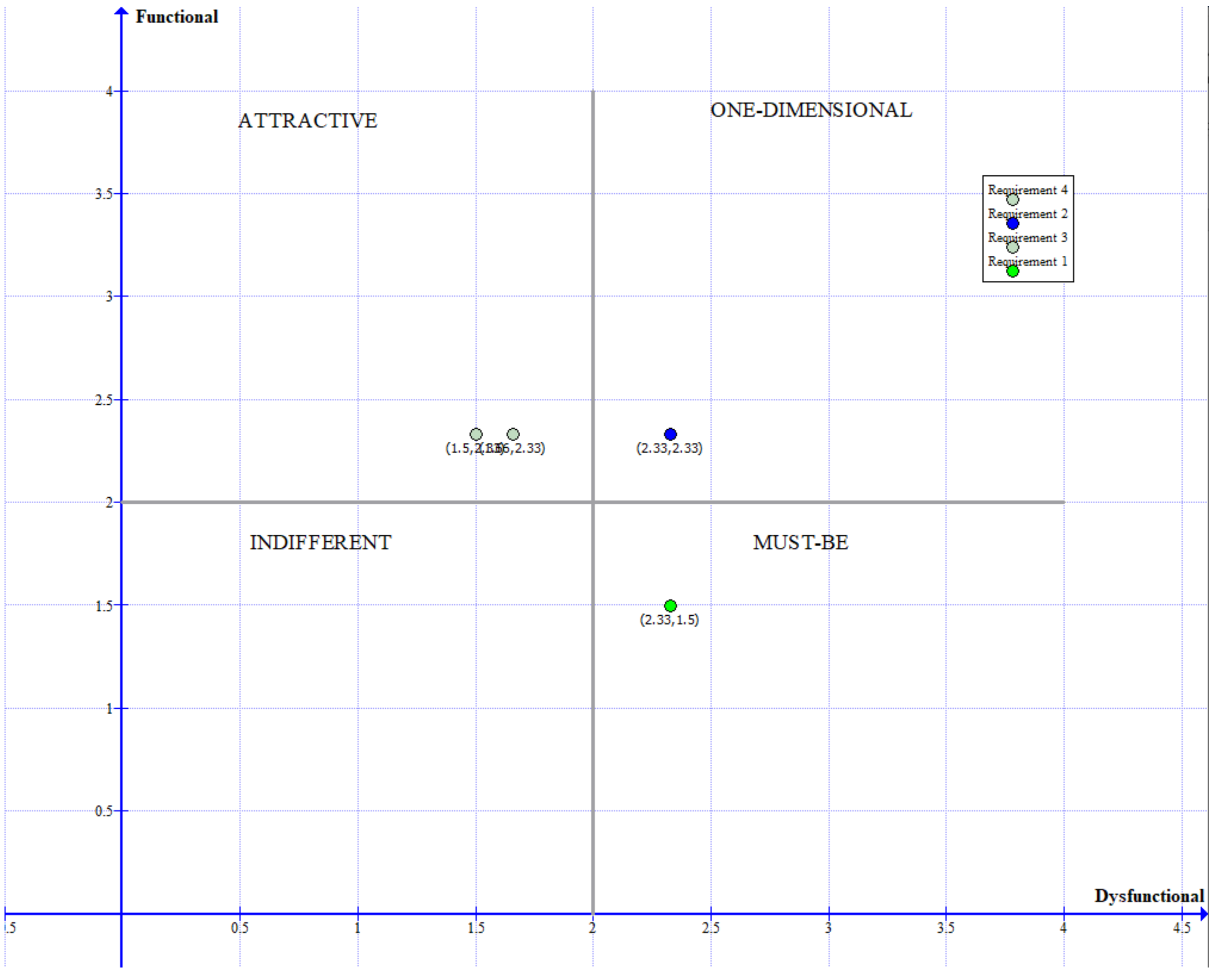


Figure 5. Categorization plane with plotted requirements (Yang & El-Haik, 2009).

Table 18 shows the importance ranking obtained with a continuous analysis approach for the Kano model (Ginn & Varner, 2004; Rowlands, 2001; Tarantino & Cernauskas, 2012; Wu & Wang, 2012; Yang & El-Haik, 2009).

Table 18. Requirements with assigned importance ranking obtained with the continuous analysis approach (Yang & El-Haik, 2009).

	Importance rank
Requirement 1	5
Requirement 2	4
Requirement 3	3
Requirement 4	3

3.3.4.3. Translation of Customer Requirements into Critical-to-Quality Parameters

After obtaining the importance ranks for customer requirements, the project team created critical to quality parameters. These parameters were generated based on the analysis and work with the customer requirements. The generated critical to quality parameters are presented in the Table 19.

Table 19. Generated Critical to quality parameters.

Requirements		Critical to quality parameters
Requirement 1	Commissioning simplicity	- Mounting simplicity (CTQ2) - Tuning simplicity (CTQ3) - General wiring diagram (CTQ6) - Step-by-step instructions (CTQ7) - Data transferring simplicity among devices (A, A2, etc) (CTQ8)
Requirement 2	Internet connectivity	- Package includes a modem (CTQ4)
Requirement 3	Complete asset monitoring	- Free inputs of A2 to be adjusted for tracking complete asset (CTQ5)
Requirement 4	Minimize package variety	- Package should be universal (CTQ1) - Package includes a modem (CTQ4)

The process of identifying the correlation between requirements and critical to quality parameters is done thru the correlation matrix; a detailed overview of the process and completed correlation matrix are presented in the Appendix 7. Based on the completed correlation matrix was plotted a Pareto chart displaying the evaluated critical to quality parameters, see Figure 6 (Ginn & Varner, 2004; Maass & McNair, 2010; Yang & El-Haik, 2009).

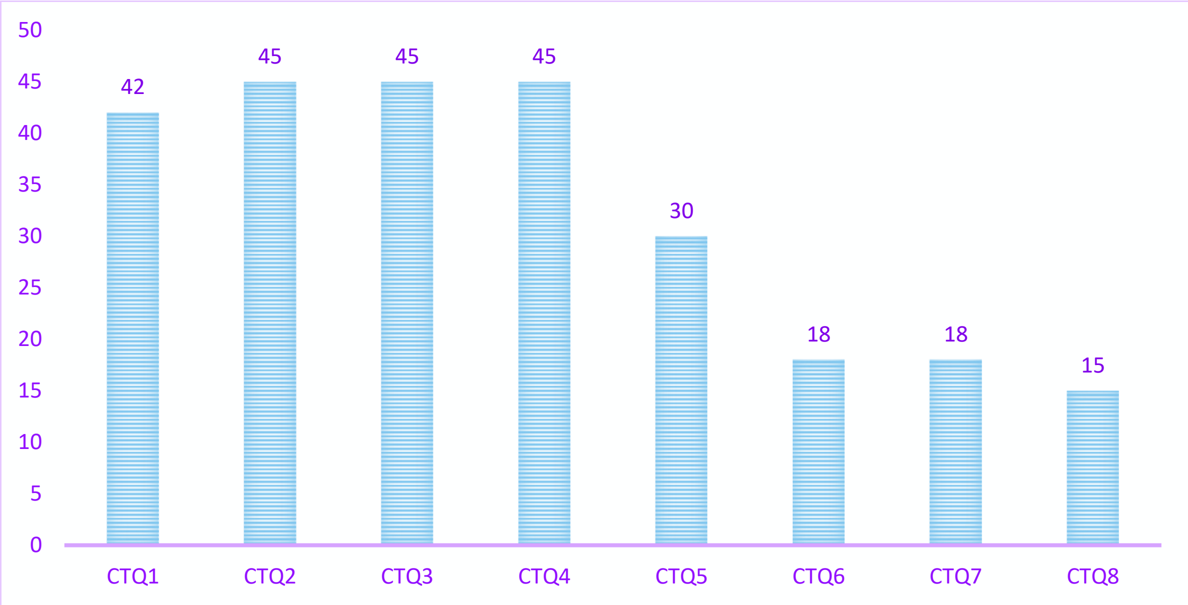


Figure 6. Pareto of raw scores for critical to quality parameters (Yang & El-Haik, 2009).

Table 20 shows the critical to quality parameters and their assigned importance ranks, which were determined based on the completed correlation matrix.

Table 20. Critical to quality parameters with assigned importance ranking.

CTQs	CTQ1	CTQ2	CTQ3	CTQ4	CTQ5	CTQ6	CTQ7	CTQ8
Obtained importance rank	5	5	5	5	3	1	1	1

The newly identified critical to quality parameters and their assigned importance rankings, were presented to the customers during the group meeting. The customers expressed positive feedback and approved the results, providing validation for the project team to proceed. With this approval, the team moved forward to the next step of identifying the variables that directly impact the defined critical quality parameters (Yang & El-Haik, 2009).

The project team conducted an in-depth analysis of the relationships between the critical to quality parameters and potential design variables. The target was to identify the specific variables that directly and significantly impact the critical to quality parameters. By examining these relationships, the team generated a set of critical design parameters. These parameters are important for the design and development process, as they play a crucial role in meeting and aligning with the desired criteria; quality parameters (Ginn & Varner, 2004; Rowlands, 2001; Yang & El-Haik, 2009).

Table 21. Generated critical design parameters.

CTQ1	Package should be universal	- Parts kit package (CDP13) - Package fits different generations of company X assets (CDP14) - Package can be used as a replacement for predecessors of device A (CDP15) - Package can be used as a replacement for device A (CDP16) - Package is suitable for situations where the asset did not have any existing monitoring or controlling device installed (CDP17)
CTQ2	Mounting simplicity	- Instructions on how to connect the free inputs of A2 (CDP1) - Avoid the need for additional cubicles (CDP3) - Instructions should provide a simplified installation procedure (CDP8) - Instructions should include a sketch illustrating the hardware configuration around devices A and A2 (CDP10) - The sketch should demonstrate the components that need to be added or removed in relation to the previous hardware set (CDP12) - Package fits different generations of company X assets (CDP14)
CTQ3	Tuning simplicity	- Instructions on how to tune the free inputs of A2 (CDP2) - Instructions on how to tune core parameters of A2 (CDP4) - Instructions on how to activate and tune the features of A2 (CDP5) - Instructions on how to adjust the condition parameters of A2 when the device is assembled into a used asset (CDP6) - Instructions on how to transfer the condition parameters from device A or its predecessors to A2 (CDP7) - Package is suitable for situations where the asset did not have any existing monitoring or controlling device installed (CDP17)
CTQ4	Package includes modem	- Parts kit package (CDP13)
CTQ5	Free inputs of A2 to be adjusted for tracking complete asset	- Instructions on how to connect the free inputs of A2 (CDP1) - Instructions on how to tune the free inputs of A2 (CDP2)
CTQ6	General wiring diagram	- Instructions on how to connect the free inputs of A2 (CDP1) - Instructions should provide a simplified installation procedure (CDP8) - Package covers all voltages (CDP9) - Instructions should include a sketch illustrating the hardware configuration around devices A and A2 (CDP10). - The sketch should illustrate which components from the old hardware set can be utilized (CDP11) - The sketch should demonstrate the components that need to be added or removed in relation to the previous hardware set (CDP12)
CTQ7	Step-by-step instructions	- Instructions on how to connect the free inputs of A2 (CDP1) - Instructions on how to tune the free inputs of A2 (CDP2) - Instructions on how to tune core parameters of A2 (CDP4) - Instructions on how to activate and tune the features of A2

		(CDP5) - Instructions on how to adjust the condition parameters of A2 when the device is assembled into a used asset (CDP6) - Instructions on how to transfer the condition parameters from device A or its predecessors to A2 (CDP7)
CTQ8	Data transferring simplicity among devices (A, A2, etc)	- Instructions on how to activate and tune the features of A2 (CDP5) - Instructions on how to adjust the condition parameters of A2 when the device is assembled into a used asset (CDP6) - Instructions on how to transfer the condition parameters from device A or its predecessors to A2 (CDP7)

After identifying CDPs, it is necessary to establish a correlation between each CTQ and the corresponding CDPs (Ginn & Varner, 2004; Maass & McNair, 2010; Rowlands, 2001; Yang & El-Haik, 2009). A detailed overview of the process and completed correlation matrix is presented in the Appendix 8. The resulting Pareto chart of evaluated CDS is shown in the Figure 7.

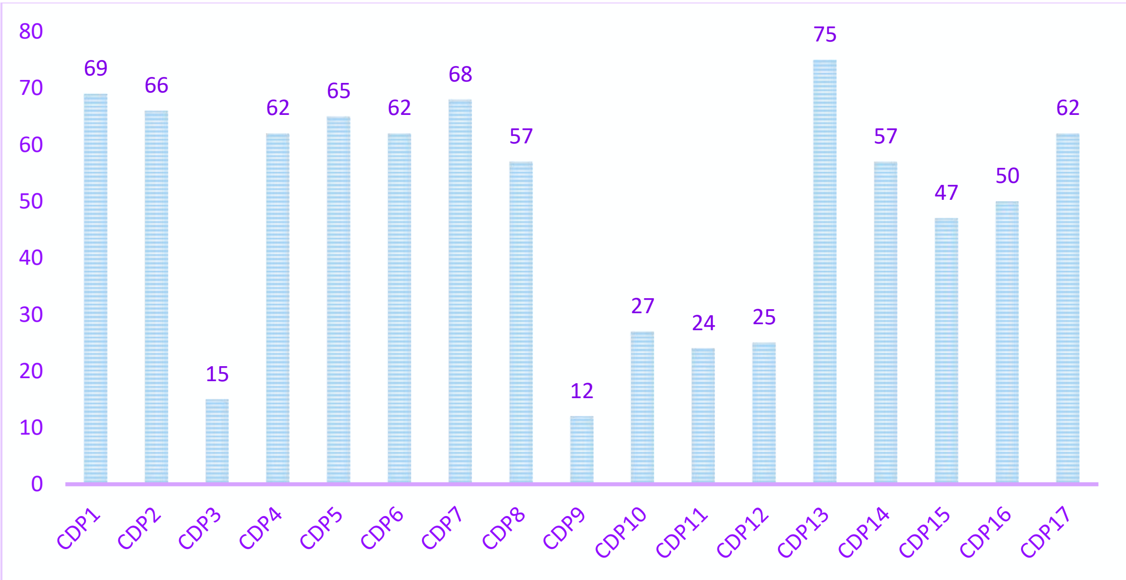


Figure 7. Pareto of raw scores for critical to design parameters.

Table 22 shows the critical to design parameters along with their assigned importance ranks, which were determined based on the completed correlation matrix.

Table 22. Critical to quality parameters with assigned importance ranking.

CDPs	Importance rank
CDP1	5
CDP2	4
CDP3	1
CDP4	4
CDP5	4
CDP6	4
CDP7	5
CDP8	4
CDP9	1
CDP10	2
CDP11	2
CDP12	2
CDP13	5
CDP14	4
CDP15	3
CDP16	3
CDP17	4

During the group meeting, the project team presented the critical design parameters and their assigned importance ranking to the customers. The objective of the meeting was to validate the accuracy and relevance of the generated critical design parameters. In addition, the project team proposed the exclusion of CDP3 and CDP9 from further consideration due to their relatively low importance ranking:

- CDP9: Avoid the need for additional cubicles
- CDP3: Package covers all voltages

After collaborative discussions, it was agreed to redirect CDP3 to the development project of the A2 device. This decision was made since the presence of packages with different voltage ranges was driven by the device A, which has different versions for different voltages. The new generation of the device (A2) should support different voltage ranges to increase its compatibility.

CDP9 is redundant and could be filtered out, as the customers clearly expressed their preference for the parts kit package, which is reflected in the highest-ranked CDP13.

Furthermore, the customers wanted to emphasize the high importance of the requirement related to internet connectivity. To address this requirement effectively, the project team applied the PUGH concept selection approach described in detail in the following chapter.

The updated list of CDPs and CTQ can serve as a foundation for ensuring the quality of the development process for creating a new package. By achieving higher customer satisfaction and minimizing the risk of misinterpreting customer expectations, the project team can proceed with confidence in the development process. The obtained result provides valuable guidance for the ongoing development efforts.

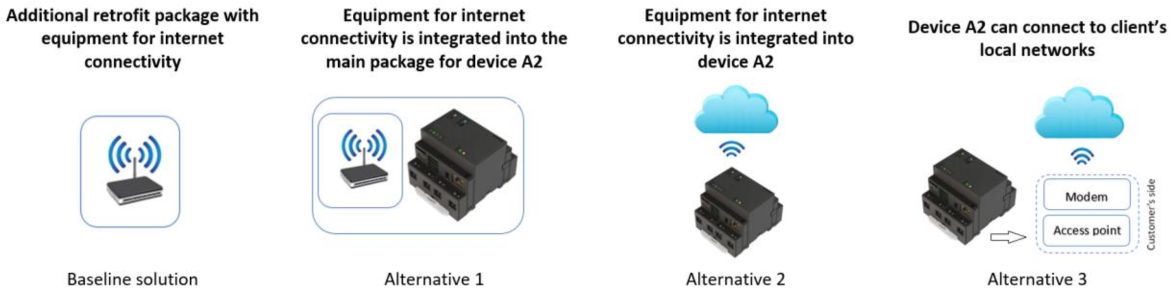
3.3.5 PUGH concept selection

Based on the previous design analysis and discussions with involved customers, it has become evident that the inclusion of equipment for internet connectivity is a critical and problematic aspect. This issue has contributed to the significant variation in package options in their previous generation. The project team has decided to employ the PUGH concept selection approach to address this challenge. This approach provides a systematic procedure to assess and compare several possible alternatives by evaluating their advantages and disadvantages (Ginn & Varner, 2004; Maass & McNair, 2010; Tarantino & Cernauskas, 2012; Yang & El-Haik, 2009).

The evaluation of other concepts involved comparing them to the baseline solution. In our case, the baseline solution is a retrofit package that includes additional equipment for internet connectivity. This package was offered and supplied as an additional package in addition to the main package with device A.

During the workshop with the customers were generated three alternatives:

- Alternative 1: The equipment for internet connectivity is integrated into the main package and always delivered together with the main package, irrespective of the end client's request.
- Alternative 2: The equipment for internet connectivity is integrated into device A2.
- Alternative 3: There is no dedicated internet connectivity equipment. Device A2 should be equipped with the functionality to connect to the client's local WIFI networks and transfer data through them.



Picture 9. Current implementation and alternatives.

Furthermore, the following list of key evaluation parameters and their respective weighting factors have been generated based on their importance.

Table 23. Evaluation criteria with their weighting factors (Ginn & Varner, 2004).

Evaluation Criteria	Weighting factor
Cost	
Manufacturing cost	2
Field installation cost	2
Implementation cost	2
Customer price	5
Design	
Design time	2
Solution simplicity	2
Handling/ordering simplicity	3
Assembling time on a field	3
Performance	
Frequency of data upload	2
Limitations by countries	1
Regulatory certifications	3

The next step is to compare each proposed alternative solution against the baseline solution (Maass & McNair, 2010; Tarantino, 2022). Each alternative is evaluated against the baseline solution for each criterion, and a score is assigned to indicate if it is better, worse, or the same. The scores are then summed to evaluate the overall performance of each concept (Ginn & Varner, 2004; Maass & McNair, 2010). The evaluation scale is presented in the Table 24.

Table 24. The evaluation scale for alternative solutions (Yang & El-Haik, 2009)

Score	Description
3	Far Better than Baseline
2	Much Better than Baseline
1	Better than Baseline
0	Same as Baseline
-1	Worse than Baseline
-2	Much Worse than Baseline
-3	Far Worse than Baseline

A detailed overview of the process and completed Decision matrix is presented in the Appendix 9. Summary result is presented in Table 25.

Table 25. Summary results of the compared alternatives (Yang & El-Haik, 2009).

		Alternative 1	Alternative 2	Alternative 3
Cost	Subtotal	-5	-5	-5
Design	Subtotal	-4	11	10
Perforamnce	Subtotal	0	4	8
Total result		**-9**	**10**	**13**

Based on the results analysis, alternative solutions #2 and #3 could be considered strong candidates for replacing existing baseline solution. Both alternatives have their pros and cons, but they offer the opportunity to address the current challenge regarding the inclusion of internet connectivity equipment. This will help decrease the variability in package options for the next generation of packages with device A2.

Should be noted that implementation of these alternative solutions cannot be carried out within the scope of the considered package development project. Since they are directly related to the functionality of device A2, the project team, in collaboration with stakeholders, concluded that these alternative solutions should be directed to the development project of Device A2. It is essential for the project team responsible for the development of Device A2 to thoroughly analyze them, select the most suitable option, and subsequently integrate it into the technical specifications for the functionality of Device A2.

4 DISCUSSION, CONCLUSION AND RECOMMENDATION

4.1. Analysis of Enhanced Practices for Customer Requirements Interpretation.

Utilization of the DFSS methodology in the project facilitated the efficient organization and structuring of the workflow concerning customer wishes to development of the new package. The decisions were based on concrete facts, real sales data, and valuable customer involvement in the process. Throughout the project, the team effectively transitioned broad, unstructured, and disorganized client requests into a well-structured and prioritized set of design-critical parameters. This set of parameters provides clear and concise input for the development team. Should be noted that the utilized process actively involves customers in the process of translating high-level wishes into particular and structured requirements. Customer involvement is crucial in minimizing uncertainties related to product requirements (Tarantino, 2022). Thus reducing the risks associated with misunderstanding customer wishes and, as a result, designing and delivering a product that does not meet expectations.

At company X, it is common for customers to have limited involvement in the process of creating a technical product specification, except for a brief period at the beginning of the development process. Creating the specification typically falls on the project team, who rely on their interpretation of the customer's wishes based on limited interactions with customers. Therefore, the implementation of the DFSS methodology and the active involvement of defined customers in the development of the product's technical specification are crucial steps toward the successful execution of the new package development project and the creation of a product that fully satisfies the needs and expectations.

Within the case study, the project team followed a sequential approach in applying the DFSS methodology to identify the requirements for the new package:

- Identification of customers: The team conducted a comprehensive sales data analysis to identify the main customers.

- Collection of initial customers' needs: Through face-to-face meetings, workshops, and email questionnaires, the team gathered the initial set of requirements for the new package based on customers' input.
- Analysis and prioritization of requirements: Various methods were employed, including pairwise comparison, the Kano questionnaire process, and a continuous analysis approach for the Kano model, to analyze and prioritize the collected requirements.
- Translation of requirements: The identified requirements were translated into critical to quality parameters, and a correlation matrix was used for the prioritization.
- Translation into critical design parameters: The critical to quality parameters were further translated into critical design parameters, and a correlation matrix was used to prioritize them based on their impact on the overall design.

These activities resulted in the creation of a prioritized list of critical design parameters that serve as a clear input for the design team. This input allows the design team to focus on the essential features of the package defined through close collaboration with the customers. It significantly reduces the risk of misinterpreting customers' requirements and ensures the development of a package that better aligns with needs and expectations (Q. Zhao et al., 2022). Furthermore, in collaboration with the customers, the project team identified additional technical requirements for device A2. Including these requirements in the technical specification of device A2 will significantly reduce the number of package variations in the future.

The schematic picture illustrates the transformation from high-level customer wishes at the beginning of the process to well-structured parameters crucial from the customer's perspective for the new package. It visually demonstrates the evolution and refinement of customer requirements throughout the project, highlighting the emphasis on capturing and addressing specific needs and preferences. This progression showcases the effective utilization of methodologies and practices to bridge the gap between initial customer aspirations and the final product that aligns closely with their expectations.

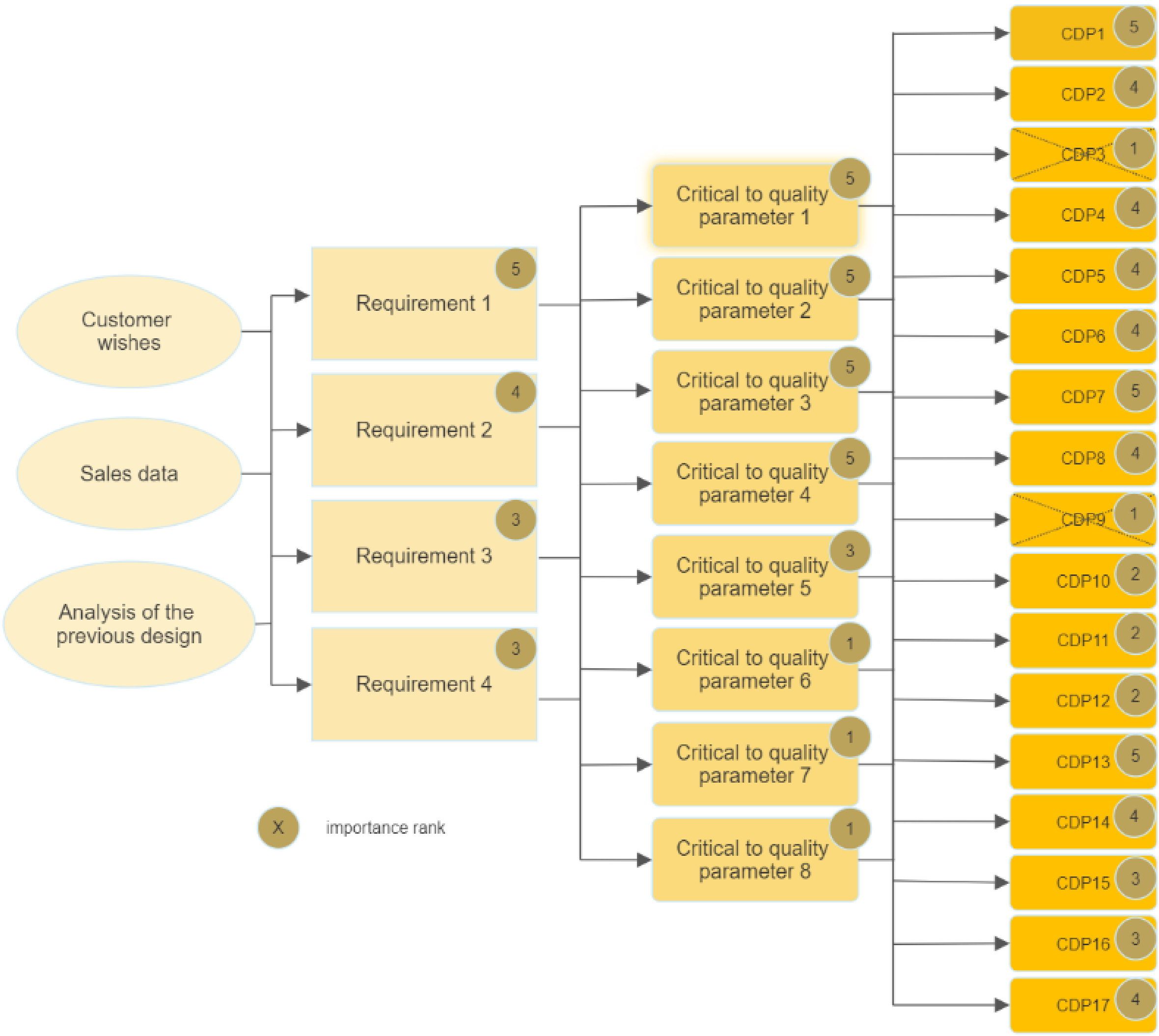


Figure 8. The evolution process of customer wishes.

Applying this approach to requirements management effectively mitigates uncertainty and associated risks using a structured, iterative, and methodical approach. By proactively addressing customer wishes, the likelihood of risks related to product development in the context of customer requirements is significantly reduced. Emphasizing the management of uncertainty during the early stages of the process is crucial to avoid the necessity of implementing separate risk management procedures for addressing risks arising from making decisions under uncertainty.

4.2. Mitigating Customer Requirement uncertainties through the application of DFSS.

In the examined case study, the application of DFSS indicated that risk-driven principles demonstrate good results and can effectively mitigate risks associated with uncertainties linked to customer requirements. From the obtained results could be seen that DFSS is designed in a way that minimizes the risks associated with early requirement phases by reducing the uncertainties associated with client requirements. The methodology aims to decrease these uncertainties through intensive work with clients using various tools and methods, such as conducting an exhaustive VOC gathering process, interviews, Kano Analysis, Conjoint Analysis, Customer Requirements Ranking, etc. DFSS aims to identify and quantify uncertainties, enabling a proactive risk management approach. The process places reasonable importance on converting customer expectations into measurable product requirements, which establishes a direct connection between customer needs and technical specifications for the product.

DFSS has a notable advantage in mitigating risks linked to customer requirement uncertainties due to a customer-centric focus compared to traditional methodologies of handling customer requirements. DFSS forces proactive actions toward these uncertainties and aims to systematically eliminate them through structured and systematic customer engagement. As a result, risks associated with requirements are either eliminated or reduced. This contrasts with the traditional risk management approach, which usually focuses on responding to undesired events rather than addressing their underlying reasons.

Applying DFSS during the customer requirements identification phase can strategically align with the larger project framework, improving overall risk management and product development process. DFSS can serve as a complementary framework within the broader organizational context, facilitating the systematic identification and management of uncertainties linked to customer requirements. Consequently, the development process strengthens against risks, leading to better results and higher customer satisfaction levels.

Despite all the advantages, the methodology has drawbacks as well. DFSS actively promotes clarity in the design process through intensive interaction with customers and data-driven decision-making. However, at the final stage of working with customer wishes, the methodology freezes customer requirements and establishes key indicators for later stages of the process.

4.3. Recommendation and implication for managers.

The research executed within the scope of the considered case study provides a valuable foundation for effective risk management integrated with the development process, focusing on the area of customer requirement clarification. The obtained results demonstrate the potential of proactive risk management methodology to effectively address uncertainties and, as a result, risks associated with customer needs. The methodology aims to reduce uncertainties by working with sources of potential risks, which positively impacts project success. Based on the results, possible to recommend integrating risk-driven design principles into development processes. This involves recognizing and measuring uncertainties and using tools or frameworks like DFSS to mitigate these uncertainties effectively. DFFS provides a structured approach that constructs a clear connection between customer expectations and a product's technical specifications, reducing the chances of misalignment of the result. Additionally, the methodology stimulates cross-functional collaboration between different departments within the organization (design team, internal customers, and customer-facing teams).

The thesis highlights the significance of managing uncertainties associated with customer requirements to achieve customer satisfaction and successful project outcomes. To attain this, possible to recommend the adaptation of a proactive and holistic approach to risk management that integrates robust methodologies, the agility to adapt to changes, and centers on the customer. In general, it is possible to conclude that it is a good practice to regularly inspect and adapt risk management strategies to handle risks generated by changing customer expectations and market conditions.

4.4. Limitations and Future Research Avenues.

The research has certain limitations that should be considered.

Firstly, it is based on a particular case study, which limits the applicability of the conclusions and findings to other industries or conditions. Additionally, in the study, a single DFSS methodology was chosen, leaving an opportunity to consider other frameworks and combinations with other risk management approaches in future research. Also, the research did not consider cultural, regional, and industry specific aspects that possibly can bring new insights into tailoring the chosen approaches to specific contexts.

Secondly, a long-term investigation of customer satisfaction and overall organization after integrating considered methodology for risk management in the phase of working with customer requirements in a development process would contribute to the subject.

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APPENDICES

Appendix 1. Collected sales data for packages with device A.

Retrofit, Spare part, Modernization package with device A	Main voltage	Unique internal identification	Amount of sold pieces per sales year					
			Year 1	Year 2	Year 3	Year 4	Year 5	Year 6
Modernization package in a cubicle, with parametrized device A	48V	XXXXXXX1	17	4	10	22	12	4
	230V	XXXXXXX2	6	5	2	5	11	7
Modernization package in a cubicle, with nonparameterized device A	48V	XXXXXXX3	25	25	13	15	34	10
	230V	XXXXXXX4	66	46	43	73	51	27
Modernization package without cubicle, with parametrized device A	48V	XXXXXXX5	3	16	18	13	30	3
	230V	XXXXXXX6	5	9	17	20	14	5
Modernization package without cubicle, with nonparameterized device A	48V	XXXXXXX7	47	75	79	77	122	18
	230V	XXXXXXX8	25	57	69	83	53	34
Modernization package for alfa brand 1 without cubicle, with nonparameterized device A	48V	XXXXXXX9	0					
	230V	XXXXXX10	0					
Modernization package for alfa brand 2 without cubicle, with nonparameterized device A	48V	XXXXXX11	20					
	230V	XXXXXX12	15					
Modernization package for alfa brand 3 without cubicle, with nonparameterized device A	48V	XXXXXX13	7					
	230V	XXXXXX14	26					
Modernization package with cubicle, with parametrized device A, set of additional equipment #1	48V	XXXXXX15	4	1	0	7	1	1
	230V	XXXXXX16	17	3	8	1	0	0
Modernization package with cubicle, with nonparameterized device A,	48V	XXXXXX17	19	8	4	4	14	6

set of additional equipment #1	230V	XXXXXX18	54	13	70	82	35	26
Modernization package with cubicle, with nonparameterized device A, set of additional equipment #2	48V	XXXXXX19	3					
	230V	XXXXXX20	0					
Modernization package with cubicle, with nonparameterized device A, set of additional equipment #2	48V	XXXXXX21	0					
	230V	XXXXXX22	0	0	0	1	0	10
Retrofit package without a set of additional equipment	48V	XXXXXX23	0					
	230V	XXXXXX24	0	0	0	1	0	0
Retrofit package with a set of additional equipment #3	48V	XXXXXX25	0	0	0	1	0	0
	230V	XXXXXX26	4					
Retrofit package with a set of additional equipment #3	48V	XXXXXX27	0					
	230V	XXXXXX28	0	0	0	1	0	0
Device A, no preset parameters	48V	XXXXXX29	157	191	220	281	320	93
	230V	XXXXXX30	312	219	205	243	457	159
Device A, preset parameters	48V	XXXXXX31	11	19	58	80	59	13
	230V	XXXXXX32	11	27	37	60	66	16

Appendix 2. List of leading questions for customers.

1. What problems do you face with the previous generation of packages?
2. What annoys you in the packages the most?
3. What is most important for you?
4. What should we do to make the packages better for you?
5. What are your expectations about the new generation of packages?

Appendix 3. Process of pairwise comparison (Attempt #1).

Initial pairwise comparison matrix.

		A	B	C	D	E	F	G	H	
		Minimize the number of package variations	Ensure simple data transfer when replacing device A with device A2	Ensure universal compatibility across different applications	Ensure ease of mounting	Avoid the need for additional cubi-cles	Include equipment for internet con-nectivity in every package	Provide the capability to track com-plete asset information	Minimize or eliminate the need for manual adjustment of device A2 on site	Total
A	Minimize the number of package variations									0
B	Ensure simple data transfer when replacing device A with device A2									0
C	Ensure universal compatibility across different applications									0
D	Ensure ease of mounting									0
E	Avoid the need for additional cubicles									0
F	Include equipment for internet connectivity in every package									0
G	Provide the capability to track complete asset information									0
H	Minimize or eliminate the need for manual adjustment of device A2 on site									0
	Total	0	0	0	0	0	0	0	0	
	Importance Rating	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	

Pairwise comparison matrix, step 1.

		A	B	C	D	E	F	G	H	Total
		Minimize the number of package variations	Ensure simple data transfer when replacing device A with device A2	Ensure universal compatibility across different applications	Ensure ease of mounting	Avoid the need for additional cubicles	Include equipment for internet connectivity in every package	Provide the capability to track complete asset information	Minimize or eliminate the need for manual ad-justment of device A2 on site	
A	Minimize the number of package variations									6
B	Ensure simple data transfer when replacing device A with device A2	A								6
C	Ensure universal compatibility across different applications	A	B							2
D	Ensure ease of mounting	D	B	C						5
E	Avoid the need for additional cubicles	A	B	E	D					2
F	Include equipment for internet connectivity in every package	A	B	F	D	F				3
G	Provide the capability to track complete asset information	A	B	C	D	E	F			0
H	Minimize or eliminate the need for manual adjustment of device A2 on site	A	B	H	D	H	H	H		4
	Total	6	6	2	5	2	3	0	4	
	Importance Rating	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	

Completed pairwise comparison matrix, step 2.

		A	B	C	D	E	F	G	H	Total
		Minimize the number of package variations	Ensure simple data transfer when replacing device A with device A2	Ensure universal compatibility across different applications	Ensure ease of mounting	Avoid the need for additional cubicles	Include equipment for internet connectivity in every package	Provide the capability to track complete asset information	Minimize or eliminate the need for manual adjustment of device A2 on site	
A	Minimize the number of package variations									6
B	Ensure simple data transfer when replacing device A with device A2	A								6
C	Ensure universal compatibility across different applications	A	B							2
D	Ensure ease of mounting	D	B	C						5
E	Avoid the need for additional cubicles	A	B	E	D					2
F	Include equipment for internet connectivity in every package	A	B	F	D	F				3
G	Provide the capability to track complete asset information	A	B	C	D	E	F			0
H	Minimize or eliminate the need for manual adjustment of device A2 on site	A	B	H	D	H	H	H		4
	Total	6	6	2	5	2	3	0	4	
	Importance Rating	**5**	**5**	**2**	**4**	**2**	**3**	**1**	**4**	

Appendix 4. List of functional and dysfunctional questions for requirements (Attempt #1).

Functional question	Dysfunctional question
Requirement 1	
If a package would be available in a minimum number of variations, how would you feel?	If a package would be available in multiple variations, how would you feel?
Requirement 2	
If data transferring from device A to A2 would be simple and easy, how would you feel?	If data transferring from device A to A2 wouldn't be simple and easy, how would you feel?
Requirement 3	
If a package would be universal across different applications, how would you feel?	If a package wouldn't be universal across different applications, how would you feel?
Requirement 4	
If a package would be easy to mount, how would you feel?	If a package wouldn't be easy to mount, how would you feel?
Requirement 5	
If a package wouldn't require a separate cubicle for installation, how would you feel?	If a package would require a separate cubicle for installation, how would you feel?
Requirement 6	
If a package would have equipment for internet connectivity, how would you feel?	If a package wouldn't have equipment for internet connectivity, how would you feel?
Requirement 7	
If a package would be able to provide the capability to track complete asset information, how would you feel?	If a package wouldn't be able to provide the capability to track complete asset information, how would you feel?
Requirement 8	
If A2 device as a part of a package wouldn't require manual adjustment on-site, how would you feel?	If A2 device as a part of a package would require manual adjustment on-site, how would you feel?

All questions have identical answering options; the respondent could choose only one answer. List of available answering options:

1. I would like it
2. I would expect it
3. I would be neutral
4. I could tolerate it
5. I would dislike it

Answers from the customers.

Requirement 1		
If a package would be available in a minimum number of variations, how would you feel?	Customer 1	I would expect it
	Customer 2	I could tolerate it
	Customer 3	I would be neutral
	Customer 4	I would like it
	Customer 5	I would expect it
	Customer 6	I would expect it
If a package would be available in multiple variations, how would you feel?	Customer 1	I could tolerate it
	Customer 2	I would expect it
	Customer 3	I would like it
	Customer 4	I could tolerate it
	Customer 5	I could tolerate it
	Customer 6	I would dislike it
Requirement 2		
If data transferring from device A to A2 would be simple and easy, how would you feel?	Customer 1	I would like it
	Customer 2	I would expect it
	Customer 3	I would expect it
	Customer 4	I would expect it
	Customer 5	I would expect it
	Customer 6	I would like it
If data transferring from device A to A2 wouldn't be simple and easy, how would you feel?	Customer 1	I would dislike it
	Customer 2	I would dislike it
	Customer 3	I could tolerate it
	Customer 4	I would dislike it
	Customer 5	I could tolerate it
	Customer 6	I could tolerate it
Requirement 3		
If a package would be universal across different applications, how would you feel?	Customer 1	I would be neutral
	Customer 2	I would like it
	Customer 3	I would like it
	Customer 4	I would like it
	Customer 5	I would like it
	Customer 6	I could tolerate it
If a package wouldn't be universal across different applications, how would you feel?	Customer 1	I would be neutral
	Customer 2	I would like it
	Customer 3	I would dislike it
	Customer 4	I would be neutral
	Customer 5	I would dislike it
	Customer 6	I could tolerate it

Requirement 4		
If a package would be easy to mount, how would you feel?	Customer 1	I would like it
	Customer 2	I would expect it
	Customer 3	I would like it
	Customer 4	I would expect it
	Customer 5	I would expect it
	Customer 6	I would be neutral
If a package wouldn't be easy to mount, how would you feel?	Customer 1	I could tolerate it
	Customer 2	I would dislike it
	Customer 3	I could tolerate it
	Customer 4	I would be neutral
	Customer 5	I would dislike it
	Customer 6	I would be neutral
Requirement 5		
If a package would require a separate cubicle for installation, how would you feel?	Customer 1	I would dislike it
	Customer 2	I could tolerate it
	Customer 3	I would be neutral
	Customer 4	I could tolerate it
	Customer 5	I could tolerate it
	Customer 6	I could tolerate it
If a package wouldn't require a separate cubicle for installation, how would you feel?	Customer 1	I would expect it
	Customer 2	I would like it
	Customer 3	I would be neutral
	Customer 4	I would like it
	Customer 5	I would like it
	Customer 6	I would like it
Requirement 6		
If a package would have equipment for internet connectivity, how would you feel?	Customer 1	I would expect it
	Customer 2	I would like it
	Customer 3	I would expect it
	Customer 4	I would like it
	Customer 5	I would expect it
	Customer 6	I would be neutral
If a package wouldn't have equipment for internet connectivity, how would you feel?	Customer 1	I would dislike it
	Customer 2	I would dislike it
	Customer 3	I would dislike it
	Customer 4	I could tolerate it
	Customer 5	I could tolerate it
	Customer 6	I would dislike it
Requirement 7		

If a package would be able to provide the capability to track complete asset information, how would you feel?	Customer 1	I would expect it
	Customer 2	I would like it
	Customer 3	I would expect it
	Customer 4	I would like it
	Customer 5	I would expect it
	Customer 6	I would expect it
If a package wouldn't be able to provide the capability to track complete asset information, how would you feel?	Customer 1	I would be neutral
	Customer 2	I could tolerate it
	Customer 3	I would dislike it
	Customer 4	I would dislike it
	Customer 5	I would dislike it
	Customer 6	I would be neutral
Requirement 8		
If A2 device as a part of a package wouldn't require manual adjustment on-site, how would you feel?	Customer 1	I would like it
	Customer 2	I would like it
	Customer 3	I would like it
	Customer 4	I would expect it
	Customer 5	I would like it
	Customer 6	I would like it
If A2 device as a part of a package would require manual adjustment on-site, how would you feel?	Customer 1	I could tolerate it
	Customer 2	I could tolerate it
	Customer 3	I would expect it
	Customer 4	I would be neutral
	Customer 5	I could tolerate it
	Customer 6	I could tolerate it

Answers with assigned values from the customers for each requirement.

Requirement 1			
If a package would be available in a minimum number of variations, how would you feel?	Customer 1	I would expect it	2
	Customer 2	I could tolerate it	-1
	Customer 3	I would be neutral	0
	Customer 4	I would like it	4
	Customer 5	I would expect it	2
	Customer 6	I would expect it	2
If a package would be available in multiple variations, how would you feel?	Customer 1	I could tolerate it	2
	Customer 2	I would expect it	-1
	Customer 3	I would like it	-2
	Customer 4	I could tolerate it	2
	Customer 5	I could tolerate it	2

	Customer 6	I would dislike it	4
Requirement 2			
If data transferring from device A to A2 would be simple and easy, how would you feel?	Customer 1	I would like it	4
	Customer 2	I would expect it	2
	Customer 3	I would expect it	2
	Customer 4	I would expect it	2
	Customer 5	I would expect it	2
	Customer 6	I would like it	4
If data transferring from device A to A2 wouldn't be simple and easy, how would you feel?	Customer 1	I would dislike it	4
	Customer 2	I would dislike it	4
	Customer 3	I could tolerate it	2
	Customer 4	I would dislike it	4
	Customer 5	I could tolerate it	2
	Customer 6	I could tolerate it	2
Requirement 3			
If a package would be universal across different applications, how would you feel?	Customer 1	I would be neutral	0
	Customer 2	I would like it	4
	Customer 3	I would like it	4
	Customer 4	I would like it	4
	Customer 5	I would like it	4
	Customer 6	I could tolerate it	-1
If a package wouldn't be universal across different applications, how would you feel?	Customer 1	I would be neutral	0
	Customer 2	I would like it	-2
	Customer 3	I would dislike it	4
	Customer 4	I would be neutral	0
	Customer 5	I would dislike it	4
	Customer 6	I could tolerate it	2
Requirement 4			
If a package would be easy to mount, how would you feel?	Customer 1	I would like it	4
	Customer 2	I would expect it	2
	Customer 3	I would like it	4
	Customer 4	I would expect it	2
	Customer 5	I would expect it	2
	Customer 6	I would be neutral	0
If a package wouldn't be easy to mount, how would you feel?	Customer 1	I could tolerate it	2
	Customer 2	I would dislike it	4
	Customer 3	I could tolerate it	2
	Customer 4	I would be neutral	0
	Customer 5	I would dislike it	4
	Customer 6	I would be neutral	0

Requirement 5			
If a package would require a separate cubicle for installation, how would you feel?	Customer 1	I would dislike it	-2
	Customer 2	I could tolerate it	-1
	Customer 3	I would be neutral	0
	Customer 4	I could tolerate it	-1
	Customer 5	I could tolerate it	-1
	Customer 6	I could tolerate it	-1
If a package wouldn't require a separate cubicle for installation, how would you feel?	Customer 1	I would expect it	4
	Customer 2	I would like it	2
	Customer 3	I would be neutral	0
	Customer 4	I would like it	2
	Customer 5	I would like it	2
	Customer 6	I would like it	2
Requirement 6			
If a package would have equipment for internet connectivity, how would you feel?	Customer 1	I would expect it	2
	Customer 2	I would like it	4
	Customer 3	I would expect it	2
	Customer 4	I would like it	4
	Customer 5	I would expect it	2
	Customer 6	I would be neutral	0
If a package wouldn't have equipment for internet connectivity, how would you feel?	Customer 1	I would dislike it	4
	Customer 2	I would dislike it	4
	Customer 3	I would dislike it	4
	Customer 4	I could tolerate it	2
	Customer 5	I could tolerate it	2
	Customer 6	I would dislike it	2
Requirement 7			
If a package would be able to provide the capability to track complete asset information, how would you feel?	Customer 1	I would expect it	2
	Customer 2	I would like it	4
	Customer 3	I would expect it	2
	Customer 4	I would like it	4
	Customer 5	I would expect it	2
	Customer 6	I would expect it	2
If a package wouldn't be able to provide the capability to track complete asset information, how would you feel?	Customer 1	I would be neutral	0
	Customer 2	I could tolerate it	2
	Customer 3	I would dislike it	4
	Customer 4	I would dislike it	4
	Customer 5	I would dislike it	4
	Customer 6	I would be neutral	0
Requirement 8			

If A2 device as a part of a package wouldn't require manual adjustment on-site, how would you feel?	Customer 1	I would like it	4
	Customer 2	I would like it	4
	Customer 3	I would like it	4
	Customer 4	I would expect it	2
	Customer 5	I would like it	4
	Customer 6	I would like it	4
If A2 device as a part of a package would require manual adjustment on-site, how would you feel?	Customer 1	I could tolerate it	2
	Customer 2	I could tolerate it	2
	Customer 3	I would expect it	-1
	Customer 4	I would be neutral	0
	Customer 5	I could tolerate it	2
	Customer 6	I could tolerate it	2

Appendix 5. Completion process of the correlation matrix (Attempt #1).

Initial correlation matrix between requirements and critical to quality parameters.

Relationships: 9 = Strong 3 = Moderate 1 = Weak 0 or Blank = No Rela-	**Importance Rating**	Package covers all voltages	Package includes modem	Package fits alfa brands and competitors	Package should replace device A and its predecessor	Preparametrized A2 device	Step by step instructions	A2 compatible with parameters of device A	General wiring diagram	Parts kit package	Free inputs of A2 to be adjusted for tracking	Clear ordering instructions
Requirement 1	1	0	0	0	0	0	0	0	0	0	0	0
Requirement 2	4	0	0	0	0	0	0	0	0	0	0	0
Requirement 3	4	0	0	0	0	0	0	0	0	0	0	0
Requirement 4	3	0	0	0	0	0	0	0	0	0	0	0
Requirement 5	3	0	0	0	0	0	0	0	0	0	0	0
Requirement 6	4	0	0	0	0	0	0	0	0	0	0	0
Requirement 7	4	0	0	0	0	0	0	0	0	0	0	0
Requirement 8	3	0	0	0	0	0	0	0	0	0	0	0
Raw score		0	0	0	0	0	0	0	0	0	0	0
Relative %		12%	12%	12%	11%	11%	11%	9%	9%	5%	5%	3%
Importance Rank		1	1	1	1	1	1	1	1	1	1	1

Completed correlation matrix.

Relationships: 9 = Strong 3 = Moderate 1 = Weak 0 or Blank = No Rela-	**Importance Rating**	Package covers all voltages	Package includes modem	Package fits alfa brands and competitors	Package should replace device A and its predecessor	Preparametrized A2 device	Step by step instructions	A2 compatible with parameters of device A	General wiring diagram	Parts kit package	Free inputs of A2 to be adjusted for tracking	Clear ordering instructions
Requirement 1	1	9	3	1	3	0	0	0	0	0	1	0
Requirement 2	4	0	0	0	1	3	9	1	0	0	0	0
Requirement 3	4	0	0	9	1	0	0	1	0	0	0	0
Requirement 4	3	0	0	0	0	0	1	0	3	1	1	1
Requirement 5	3	0	0	0	0	0	0	0	0	9	0	0
Requirement 6	4	0	9	0	0	0	0	0	0	1	1	1
Requirement 7	4	0	0	0	0	0	0	0	0	0	9	0
Requirement 8	3	0	0	0	1	9	0	3	0	0	0	1
Raw score		9	39	37	14	39	39	17	9	34	44	10
Relative %		12%	12%	12%	11%	11%	11%	9%	9%	5%	5%	3%
Importance Rank		1	4	4	2	4	4	2	1	4	5	1

Appendix 6. List of functional and dysfunctional questions for requirements (Attempt #2).

Functional question	Dysfunctional question
Requirement 1	
If a package would have commissioning simplicity, how would you feel?	If a package wouldn't have commissioning simplicity, how would you feel?
Requirement 2	
If a package would provide internet connectivity, how would you feel?	If a package wouldn't provide internet connectivity, how would you feel?
Requirement 3	
If a package would be able to provide complete asset monitoring, how would you feel?	If a package wouldn't be able to provide complete asset monitoring, how would you feel?
Requirement 4	
If a package would be available in a minimum number of variations, how would you feel?	If a package would be available in multiple variations, how would you feel?

All questions have identical answering options; the respondent could choose only one answer. List of available answering options:

1. I would like it
2. I would expect it
3. I would be neutral
4. I could tolerate it
5. I would dislike it

Customer responses, along with the assigned values for answers for each requirement.

Requirement 1			
If a package would have commissioning simplicity, how would you feel?	Customer 1	I would expect it	2
	Customer 2	I would expect it	2
	Customer 3	I could tolerate it	-1
	Customer 4	I would expect it	2
	Customer 5	I would be neutral	0
	Customer 6	I would like it	4
If a package wouldn't have commissioning simplicity, how would you feel?	Customer 1	I would dislike it	4
	Customer 2	I could tolerate it	2
	Customer 3	I could tolerate it	2
	Customer 4	I could tolerate it	2

	Customer 5	I would be neutral	0
	Customer 6	I would dislike it	4
Requirement 2			
If a package would provide internet connectivity, how would you feel?	Customer 1	I would be neutral	0
	Customer 2	I would like it	4
	Customer 3	I would like it	4
	Customer 4	I would like it	4
	Customer 5	I would expect it	2
	Customer 6	I would be neutral	0
If a package wouldn't provide internet connectivity, how would you feel?	Customer 1	I would be neutral	0
	Customer 2	I would dislike it	4
	Customer 3	I would dislike it	4
	Customer 4	I could tolerate it	2
	Customer 5	I could tolerate it	2
	Customer 6	I would dislike it	2
Requirement 3			
If a package would be able to provide complete asset monitoring, how would you feel?	Customer 1	I would expect it	2
	Customer 2	I would like it	4
	Customer 3	I would expect it	2
	Customer 4	I would expect it	2
	Customer 5	I would expect it	2
	Customer 6	I would expect it	2
If a package wouldn't be able to provide complete asset monitoring, how would you feel?	Customer 1	I would be neutral	0
	Customer 2	I could tolerate it	2
	Customer 3	I could tolerate it	2
	Customer 4	I would dislike it	4
	Customer 5	I could tolerate it	2
	Customer 6	I would be neutral	0
Requirement 4			
If a package would be available in a minimum number of variations, how would you feel?	Customer 1	I would expect it	2
	Customer 2	I would expect it	2
	Customer 3	I would be neutral	0
	Customer 4	I would like it	4
	Customer 5	I would like it	4

	Customer 6	I would expect it	2
If a package would be available in multiple variations, how would you feel?	Customer 1	I could tolerate it	2
	Customer 2	I would expect it	-1
	Customer 3	I would be neutral	0
	Customer 4	I could tolerate it	2
	Customer 5	I could tolerate it	2
	Customer 6	I would dislike it	4

Appendix 7. Completion process of the correlation matrix (Attempt #2).

Initial correlation matrix between requirements and critical to quality parameters.

Relationships: 9 = Strong 3 = Moderate 1 = Weak 0 or Blank = No Relationship	Importance Rating	Package should be universal	Mounting simplicity	Tuning simplicity	Package includes	Free inputs of A2 to be adjusted for tracking	General wiring diagram	Step by step instructions	Data transferring simplicity among devices
Commissioning simplicity	5	0	0	0	0	0	0	0	0
Internet connectivity	4	0	0	0	0	0	0	0	0
Complete asset monitoring	3	0	0	0	0	0	0	0	0
Minimize package variety	3	0	0	0	0	0	0	0	0
Raw score		0	0	0	0	0	0	0	0
Relative %		19%	17%	17%	15%	11%	7%	7%	6%
Importance Rank		1	1	1	1	1	1	1	1

Completed correlation matrix.

Relationships: 9 = Strong 3 = Moderate 1 = Weak 0 or Blank = No Relationship	Importance Rating	Package should be universal	Mounting simplicity	Tuning simplicity	Package includes modem	Free inputs of A2 to be adjusted for tracking	General wiring diagram	Step by step instructions	Data transferring simplicity among devices
Commissioning simplicity	5	0	9	9	0	0	3	3	3
Internet connectivity	4	3	0	0	9	0	0	0	0
Complete asset monitoring	3	1	0	0	0	9	1	1	0
Minimize package variety	3	9	0	0	3	1	0	0	0
Raw score		42	45	45	45	30	18	18	15
Relative %		19%	17%	17%	15%	11%	7%	7%	6%
Importance Rank		5	5	5	5	3	1	1	1

Appendix 8. Completion process of correlation matrix between critical to quality and design parameters.

Initial correlation matrix between critical to quality and design parameters

Relationships:
9 = Strong
3 = Moderate
1 = Weak
0 or Blank = No Relationship

	Importance Rating	Instructions on how to connect the free inputs of A2	Instructions on how to tune the free inputs of A2	Avoid the need for additional cubicles	Instructions on how to tune core parameters of A2	Instructions on how to activate and tune the features of A2	Instructions on how to adjust the condition parameters of A2 when the device is assembled into a used asset	Instructions on how to transfer the condition parameters from device A or its predecessors to A2	Instructions should provide a simplified installation procedure	Package covers all voltages	Instructions should include a sketch illustrating the hardware configuration around device A and A2	The sketch should illustrate which components from the old hardware set can be utilized	The sketch should demonstrate the components that need to be added or removed in relation to the previous hardware set	Parts kit package	Package fits different generation of company X assets	Package can be used as a replacement for predecessors of device A	Package can be used as a replacement for device A	Package is suitable for situations where the asset did not have any existing monitoring or controlling device installed
Package should be universal	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mounting simplicity	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tuning simplicity	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Package includes modem	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Free inputs of A2 to be adjusted for tracking complete asset	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
General wiring diagram	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Step by step instructions	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Data transferring simplicity	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Raw score		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Relative %																		
Importance Rank		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Completed correlation matrix between critical to quality and design parameters.

Relationships:
9 = Strong
3 = Moderate
1 = Weak
0 or Blank = No Relationship

	Importance Rating	Instructions on how to connect the free inputs of A2	Instructions on how to tune the free inputs of A2	Avoid the need for additional cubicles	Instructions on how to tune core parameters of A2	Instructions on how to activate and tune the features of A2	Instructions on how to adjust the condition parameters of A2 when the device is assembled into a used asset	Instructions on how to transfer the condition parameters from device A or its predecessors to A2	Instructions should provide a simplified installation procedure	Package covers all voltages	Instructions should include a sketch illustrating the hardware configuration around device A and A2	The sketch should illustrate which components from the old hardware set can be utilized	The sketch should demonstrate the components that need to be added or removed in relation to the previous hardware set	Parts kit package	Package fits different generation of company X assets	Package can be used as a replacement for predecessors of device A	Package can be used as a replacement for device A	Package is suitable for situations where the asset did not have any existing monitoring or controlling device installed
Package should be universal	5	3	3	0	1	1	1	1	0	0	0	0	0	9	9	9	9	9
Mounting simplicity	5	3	0	3	0	0	0	0	9	0	3	3	3	3	1	0	0	0
Tuning simplicity	5	0	3	0	9	9	9	9	0	0	0	0	0	0	0	0	0	3
Package includes modem	5	0	0	0	0	0	0	0	0	0	0	0	0	3	1	0	0	0
Free inputs of A2 to be adjusted for tracking complete asset	3	9	9	0	0	1	0	0	1	0	1	0	0	0	0	0	1	0
General wiring diagram	1	3	0	0	0	0	0	0	9	9	9	9	9	0	0	1	1	1
Step by step instructions	1	9	9	0	9	9	9	9	0	3	0	0	1	0	1	0	0	0
Data transferring simplicity	1	0	0	0	3	3	3	9	0	0	0	0	0	0	1	1	1	1
Raw score		69	66	15	62	65	62	68	57	12	27	24	25	75	57	47	50	62
Relative %		8%	8%	2%	7%	8%	7%	8%	7%	1%	3%	3%	3%	9%	7%	6%	6%	7%
Importance Rank		5	4	1	4	4	4	5	4	1	2	2	2	5	4	3	3	4

Appendix 9. Completion process of the decision matrix.

Initial Decision matrix

		Weight	Baseline solution	Alterna-tive 1	Alterna-tive 2	Alterna-tive 3
Cost	Manufacturing cost	2	0	0	0	0
	Field installation cost	2	0	0	0	0
	Implementation cost	2	0	0	0	0
	Customer proce	5	0	0	0	0
	Subtotal		**0**	**0**	**0**	**0**
Design	Design time	2	0	0	0	0
	Solution simplicity	2	0	0	0	0
	Handling/ordering simplicity	3	0	0	0	0
	Assembling time on a field	3	0	0	0	0
	Manufacturing comp-lexity	2	0	0	0	0
	Subtotal		**0**	**0**	**0**	**0**
Perfor-mance	Frequency of data upload	2	0	0	0	**0**
	Limitations by count-ries	1	0	0	0	**0**
	Regulatory certificati-ons	3	0	0	0	**0**
	Subtotal		**0**	**0**	**0**	**0**
Total	**Sum**		**0**	**0**	**0**	**0**
	# of positive values		0	0	0	0
	# of negative values		0	0	0	0

Completed Decision matrix.

		Weight	**Baseline solution**	**Alterna-tive 1**	**Alterna-tive 2**	**Alterna-tive 3**
Cost	Manufacturing cost	2	0	0	**-1**	**-1**
	Field installation cost	2	0	0	**3**	**2**
	Implementation cost	2	0	0	**-2**	**-1**
	Customer proce	5	0	**-1**	**-1**	**-1**
	Subtotal		**0**	**-5**	**-5**	**-5**
Design	Design time	2	0	**-1**	**-2**	**-1**
	Solution simplicity	2	0	0	**2**	**1**
	Handling/ordering simpli-city	3	0	0	**3**	**3**
	Assembling time on a field	3	0	0	**2**	**1**
	Manufacturing complexity	2	0	**-1**	**-2**	**-1**
	Subtotal		**0**	**-4**	**11**	**10**
Perfor-mance	Frequency of data upload	2	0	0	**2**	**1**
	Limitations by countries	1	0	0	0	**3**
	Regulatory certifications	3	0	0	0	**1**
	Subtotal		**0**	**0**	**4**	**8**
Total	**Sum**		**0**	**-9**	**10**	**13**
	# of positive values		0	0	5	7
	# of negative values		0	3	5	5