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DISSERTATION

SUSTAINABLE RISK MANAGEMENT IN NEW PRODUCT DEVELOPMENT

CASE STUDY: AUTOMOTIVE INDUSTRY

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ABSTRACT

The current market environment is increasingly competitive and dynamic, and each client's requirements are becoming more complex, influencing and impacting the cost, quality levels, and timings of all projects.

To achieve competitive advantage and overcome these levels of dynamism and complexity, analysing the risks involved is crucial at all stages of the project life cycle, a critical dimension for the project management process, which is gaining increasing relevance due to is ability to answer the inefficiencies generated by the various uncertainties and due to the help provided in the decision-making process throughout the different stages of a project or process.

On this basis, the main objective of this work is to identify and assess the influence of risk levels in the early stages of the new product development process, focusing on the sustainability dimensions in the automotive sector, since the balance in this dimension increases organisational value and is increasingly included in differentiation strategies.

To achieve the study's objective, a model was developed to support risk assessment in project management and decision-making. The model is based on fuzzy inference systems essential in risk management. These systems allow the subjectivity of the analysis associated with human perception to be mitigated based on Artificial Intelligence algorithms, known as Fuzzy Logic.

In summary, the presentation and application of this proposed model have reduced the uncertainty and ambiguity inherent in risk analysis. Therefore, the discussion of the problem under study was focused on identifying the development phase of a new program for a company in the automotive industry that presents the most significant risk regarding sustainability dimensions.

Keywords: Project management, Risk management, New Products Development, Industrial Sustainability, Automotive Industry, Fuzzy Logic

RESUMO

O atual ambiente de mercado é cada vez mais competitivo e dinâmico, com um aumento de complexidade presente nos requisitos de cada cliente, que influenciam e impactam o custo, os graus de qualidade e os *timings* de todos os projetos.

De forma a atingir a vantagem competitiva e superar estes níveis de dinamismo e complexidade, analisar os riscos envolvidos é crucial em todas as fases do ciclo de vida do projeto, dimensão crucial no processo de gestão de projetos, que tem ganho cada vez mais relevância pela sua capacidade de dar resposta às ineficiências geradas pelas diversas incertezas e no suporte ao processo de tomada de decisão ao longo das diferentes etapas de um projeto ou processo.

Com esta base, este trabalho tem como principal objetivo identificar e avaliar a influência dos níveis de risco nas fases iniciais do processo de desenvolvimento de novos produtos, com enfoque nas dimensões de sustentabilidade, no contexto do setor automóvel uma vez que o equilíbrio nesta dimensão impulsiona o aumento do valor organizacional e é cada vez mais incluído nas estratégias de diferenciação.

Para atingir o objetivo do estudo, foi desenvolvido um modelo que auxilia na avaliação de riscos na gestão de projetos e na tomada de decisão, baseado em sistemas de inferência difusa, que desempenham um papel importante na gestão de risco, permitido mitigar a subjetividade da análise associada da perceção humana com base algoritmos de Inteligência Artificial, conhecido como Lógica *Fuzzy*.

Em resumo, com a apresentação e aplicação deste modelo proposto foi possível reduzir a incerteza e ambiguidade inerente à análise de risco contribuindo para a discussão da problemática em estudo focada na identificação da fase de desenvolvimento de um novo programa, de uma empresa da indústria automóvel, que apresenta mais risco em termos das dimensões da sustentabilidade.

Palavras-chave: Gestão de projetos, Gestão de riscos, Desenvolvimento de novos produtos, Sustentabilidade industrial, Indústria automóvel, Lógica difusa

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AI	Artificial Intelligence
BOL	Beginning of Life
BOM	Bill of Materials
BPM	Business Process Management
CAPEX	Capital Expenditure
DFM	Design for Manufacturing
DMAIC	Define, Measure, Analyse, Improve, and Control
EOL	End of Life
ESG	Environmental, social, and governance
FIS	Fuzzy Inference System
HW	Hardware
IMDS	International Material Data System
ISO	International Organization of Standards
KPI	Key Performance Indicators
LCA	Life Cycle Assessment
LM	Lean Manufacturing
MOL	Middle of Life
NPD	New Product Development
OEM	Original Equipment Manufacturers
OPEX	Operational Expenditure
PCCC	Product Chemical Compliance Confirmation
PDCA	Plan, Do, Check, Act
PDMA	Product Development and Management Association
PLM	Product Lifecycle Management
PM	Project Management
PMBOK	Project Management Body of Knowledge
PMI	Project Management Institute
PPAP	Production Part Approval Process
RM	Risk Management
SA	Sustainability Assessment
SD	Sustainable Development
SDG	Sustainable Development Goals

SM	Sustainable manufacturing
SOP	Start of Production
SW	Software
TBL	Triple Bottom Line
Sc	System Component
RSc	Risk of system component
SR	System Risk
P_{UC}	Probability Unemployment control
I_{UC}	Impact Unemployment control
R_{UC}	Risk Unemployment control
W_{UC}	Weight Unemployment control
P_{PSS}	Probability Process Safety Standards
I_{PSS}	Impact Probability Process Safety Standards
R_{PSS}	Risk Process Safety Standards
W_{PSS}	Weight Process Safety Standards
P_{PSV}	Probability Product Safety Verification
I_{PSV}	Impact Product Safety Verification
R_{PSV}	Risk Product Safety Verification
W_{PSV}	Weight Product Safety Verification
P_{PT}	Probability People Training
I_{PT}	Impact People Training
R_{PT}	Risk People Training
W_{PT}	Weight People Training
P_{PE}	Probability Process Ergonomics
I_{PE}	Impact Process Ergonomics
R_{PE}	Risk Process Ergonomics
W_{PE}	Weight Process Ergonomics
P_{BC}	Probability Budget Control
I_{BC}	Impact Budget Control
R_{BC}	Risk Budget Control
W_{BC}	Weight Budget Control

P_{PP}	Probability Process Performance
I_{PP}	Impact Process Performance
R_{PP}	Risk Process Performance
W_{PP}	Weight Process Performance
P_{SC}	Probability Suppliers Control
I_{SC}	Impact Suppliers Control
R_{SC}	Risk Suppliers Control
W_{SC}	Weight Suppliers Control
P_{OT}	Probability Operations Timing
I_{OT}	Impact Operations Timing
R_{OT}	Risk Operations Timing
W_{OT}	Weight Operations Timing
P_{EI}	Probability Equipment Industrialization
I_{EI}	Impact Equipment Industrialization
R_{EI}	Risk Equipment Industrialization
W_{EI}	Weight Equipment Industrialization
P_{PAS}	Probability Product Architecture Specification
I_{PAS}	Impact Product Architecture Specification
R_{PAS}	Risk Product Architecture Specification
W_{PAS}	Weight Product Architecture Specification
P_{PMD}	Probability Product Material Definition
I_{PMD}	Impact Product Material Definition
R_{PMD}	Risk Product Material Definition
W_{PMD}	Weight Product Material Definition
P_{RP}	Probability Recycle Procedure
I_{RP}	Impact Recycle Procedure
R_{RP}	Risk Recycle Procedure
W_{RP}	Weight Recycle Procedure
P_{SL}	Probability Scrap Level
I_{SL}	Impact Scrap Level

R_{SL}	Risk Scrap Level
W_{SL}	Weight Scrap Level
P_{TV}	Probability Testing and Validation
I_{TV}	Impact Testing and Validation
R_{TV}	Risk Testing and Validation
W_{TV}	Weight Testing and Validation
R_{SOC}	Risk Social
R_{ECO}	Risk Economic
R_{ENV}	Risk Environmental
W_{SOC}	Weight Social
W_{ECO}	Weight Economic
W_{ENV}	Weight Environmental
R_{TS}	Risk Total system

1. INTRODUCTION

Introducing new programs is increasingly competitive in the current market environment (Bhogil, 2021), in which any inefficiency generates a significant impact and can compromise companies' objectives (Vargas *et al*., 2023).

There is a growing interest in developing and proving new management practices to avoid these situations. In these practices, the principles of sustainability and risk management (RM) dominate all contexts of business and organisational management, and the integration of these two fields represents the organisation's future (Villamil *et al*., 2023).

These principles, when correlated with the development of new products, are at the centre of the success of today's manufacturing companies, so learning more about how they interconnect each other is fundamental for future strategies to be dominant (Kunecová *et al*., 2024; Garrido *et al*., 2024**;** Villamil *et al*., 2023; Albert & Mickel, 2019).

Of these principles, sustainable development (SD) is increasingly relevant in supporting decision-making in the business context (Valdivia *et al.*, 2021), where, according to Sartal *et al.* (2020), assessing sustainable performance is essential for organisations as it can increase their value, reduce risks (El Khatib *et al*., 2020) and contribute to achieving competitive advantage (Saxena *et al*., 2020). To achieve sustainability, three dimensions must be included and have balanced relevance in the organisational strategy (Jayashree *et al*., 2021; Malek & Desai, 2021).

Concerning the second principle mentioned, RM is considered the most important of the different primary areas of management support (Barghi & Shadrokh sikari, 2020), and it recognises that all projects present risks and uncertainty that can affect objectives. To combat this reality, this area of knowledge includes all the activities that minimise these risks and their impact (Plattfaut, 2022).

Both of these principles should, as mentioned, be included in the development phases of new products or programs, as these phases are vital contributors to business profitability (Bhogil, 2021) and critical for product performance improvement throughout all is life cycle (Saxena *et al*., 2020; Parolin *et al.*, 2024) since these development phases present the high degrees of complexity and uncertainty that will influence the entire future (Bibaud-Alves *et al*., 2019).

In these phases of complexity, adopting increasingly viable RM techniques that generate accurate outputs is crucial. In this context, an Artificial Intelligence method based on fuzzy logic emerged. Based on observations and the integration of control techniques, this method allows imprecise and vague information to be expressed in mathematical terms by applying linguistic rules (R. Santos *et al.*, 2019).

Linking these concepts, this work proposes and studies the feasibility of implementing a risk analysis model using fuzzy logic in the automotive industry to analyse and measure the impact on NPD and launch phases. It will focus on the dimensions of sustainability alongside solving the problem of subjectivity inherent to human perception in risk analysis. To this end, the case study of developing a new program for a company that supplies electronic components to the automotive industry will be analysed.

The structure and organisation of this work is divided into five chapters, the first of which is this introduction. Then comes Chapter 2, which provides a framework based on a review of academic literature for the topic, describing the concepts, evolution and importance of sustainability, followed by a framework for PM and RM, with their respective models, and finally, the models for developing new products in the automotive sector context, from here an introduction to the problem is developed. In Chapter 3, the research methodology is explained, and the main issues associated with the problem are identified. The results of implementing the risk analysis model and their discussion are presented in Chapter 4. Finally, the conclusions and limitations of the work and recommendations for future research are in Chapter 5.

2. LITERATURE REVIEW

2.1. SUSTAINABILITY IN THE ORGANIZATIONS

2.1.1. SUSTAINABLE DEVELOPMENT

Sustainable development (SD) is increasingly relevant in supporting decision-making in the business context (Valdivia *et al.*, 2021). This challenges all organisations as it involves a complex management process (Kreiner *et al.*, 2023).

To support the implementation of SD, the 2030 Agenda for Sustainable Development Goals (SDGs) constitutes and describes the challenges faced, showing 17 primary goals and 169 sub-goals adopted by the United Nations General Assembly (Danish & Senjyu, 2023). These goals enable the development of a plan to drive sustainable measures and solutions to improve organisations' sustainability indicators.

Based on Jiang & Chen (2024), the SDGs, by the application of his plan, aim to create an increasingly sustainable world by improving people's lifestyles and values as well as the economy and the environment by promoting industrial restructuring to transform it into a more inclusive and sustainable concept. As mentioned by other authors in the literature, focusing on the conservation of resources through efficient use, recycling and implementing new tools and technologies in industrial processes makes them leaner, a way to achieve sustainability (Status & Trends, 2020).

To understand this plan clearly, the '17 SDGs' are characterised as a project of shared involvement to achieve prosperity, where sustainability is at the heart of all the objectives that support the continuous improvement of products and organisations. (Valdivia *et al.*, 2021).

In this way, the SDGs should provide direction for implementing sustainability at a national and global level and have been incorporated to highlight efforts and progress in SD. According to Barke *et al*. (2023), companies also use the SDGs to formulate and adapt business strategies. In particular, companies should focus on the SDGs that align with their missions and objectives so that their efforts create stronger links between users and organisations (Barta *et al*., 2023).

This is recognised as one of the ways to answer one of the critical questions in this field, which is to understand how organisations will align their strategies to achieve the 17 SDGs, applying their efforts to what is known as the five Ps: Prosperity, People, Planet, Peace and Partnership (Sachs *et a*l., 2019).

2.1.2. DIMENSIONS AND CHALLENGES OF SUSTAINABILITY

Sustainable performance assessment is increasingly essential in the business context and must be guaranteed at the level of product, process, and organisation (Sartal *et al.*, 2020). As stated also by Jamwal *et al.* (2022), sustainable processes must create a relationship at the level of five main components and interconnect them, which are products, people, processes, equipment, and the environment. At each of these levels, Rauter *et al.* (2023) mentioned that sustainable key performance indicators (KPIs), for example, can be considered as a new sustainable product design, increased process efficiency, reduced environmental pollution, and improved results related to social responsibility.

To identify and evaluate these sustainable mentioned KPIs, Nowak *et al.* (2024) explained that it is necessary to follow an analysis flow consisting of sustainability verification, which involves mapping the value stream, then identifying and evaluating each project and the sustainability measures involved, and finally mapping each of these sustainability measures throughout the project.

The mapping of each sustainability measure should be done through the Triple Bottom Line (TBL) assessment, as previously mentioned, which requires the need to sustain and relate the environmental, social and economic requirements (Saxena e*t al.*, 2020) that must be implemented throughout all product life cycle (S. Wang *et al.*, 2021).

The TBL assessment aims to achieve highly self-sufficient operations in economic production processes and to develop prosperity in social processes while complying with the limits of the ecosystem (van Bueren *et al*., 2023), as explained below:

- ❖ Economic sustainability, to achieve sustainable production, focuses on optimising profits and achieving liquidity, something that can be achieved through lean manufacturing (LM) and Six Sigma practices, where DMAIC procedures play a crucial role by reducing process variation, improving performance, eliminating inefficiencies and increasing customer satisfaction, through structured data-driven decision-making methodology and a problem-centred approach (Hariyani *et al.*, 2022; Utama & Abirfatin, 2023).
- ❖ Environmental sustainability is based on controlling material consumption and preserving natural resources. This is achieved using the 6Rs for product, process, system, and supply chain design throughout the life cycle (Hariyani *et al.*, 2022).
- ❖ Social sustainability, achievable by ISO 26000, contributes to human and social capital development. It provides social benefits by incorporating organisational governance, human and labour rights and practices, community and consumer issues and a fair operating environment (Khan *et al*., 2021).

To achieve sustainability, the organisational strategy must include these three dimensions (Jayashree *et al*., 2021). Regarding the benefits of this inclusion, for Carvalho *et al*. (2018), developing strategies focused on sustainability will allow environmental and social benefits in organisation operations that open a door for a new value proposition and significantly reduce negative impacts on the environment and society. For Bashtannyk *et al.* (2020), this inclusion leads to economic development and growth, a crucial parameter since it provides the means to finance activities to eliminate environmental and social problems.

From another perspective, this triple-dimension inclusion and adoption can be a complicated process to achieve. Despite pressure from stakeholders, who are increasingly aware of sustainability and demand clarity, as shown by Sartal *et al.* (2020), and pressure from society for sustainable actions (Garrido *et al.*, 2024), which push companies to consider this inclusion, some companies do not have sufficient funds, present lack technological resources, have inherent organisational risks, are not able to afford the high costs of collecting and managing data and do not have a qualified workforce to achieve it (Malek & Desai, 2021; Abdullah *et al.*, 2023; Kassem & Trenz, 2020).

According to Valero-Gil *et al*. (2024), this difficulty generates the need to choose between different agendas where one side is investing in green technologies, which increase their environmental responsibility, or the other side focusing on digital platforms that increase efficiency and reduce costs, that lead to potential conflicts in the implementation of digitalisation and sustainability at the same time and generate barriers. This reality makes it challenging to formulate organisational strategies that can assimilate environmental and social benefits along with monetary. The imbalance between social, environmental and economic benefits will prevent organisations from adopting a sustainable approach (Malek & Desai, 2021).

2.1.3. INDUSTRIAL SUSTAINABILITY

According to Kunecová *et al*. (2024), sustainability is one of the industry's biggest challenges today, and it is becoming increasingly important as a decision-making attribute in the manufacturing environment (Saxena *et al*., 2020).

From an organisational perspective, sustainability is recently considered one of the most critical business issues accelerating business transformation (Buranasiri *et al*., 2024), something that goes hand in hand with the considerations of the ESG framework, which refers to environmental, social and governance factors (Babkin *et al*., 2023; Schramm *et al*., 2020) and which advocates sustainability as a top priority for companies, crucial for long-term financial success and numerous competitive advantages, that when implemented in their strategic development, provides benefits for building a relationship of trust with stakeholders and brand value (Rauter *et al*., 2023; Abdullah *et al*., 2023).

These are considered by Sartal *et al.* (2020) aspects that guide managers to constantly try to improve sustainability performance by identifying, managing and measuring the factors associated with this dimension, reviewed in the previous chapters, and developing support structures that make this possible. In this way, sustainable operations management concepts aim to integrate the dimensions and concerns of sustainability into all strategic and operational decisions (Garrido *et al.*, 2024).

According to Machado *et al.* (2020) and Hariyani *et al.* (2023) in terms of industrial sustainability perspective, sustainable manufacturing (SM) is the most relevant concept, defined as the integration of processes and systems that enable the production of high-quality products and services, using fewer and more sustainable resources, such as energy and materials, minimising negative environmental impacts, providing more safety for employees, customers and the surrounding communities in the sector, and economically prospering throughout their entire life cycle. These factors make it possible to achieve production that operates more flexibly, efficiently and sustainably with high quality and low cost.

The concept of SM is also seen by Sartal *et al.* (2020) and Parolin *et al.* (2024) as a properly planned process, designed and incorporated into the system, of collective thinking to integrate environmental, economic and social concerns in the medium to long term to achieve all the needs of society and the environment during the development of each product, as well as improving the company's social, market, environmental or ecological, economic and financial performance.

For Machado *et al.* (2020) and Kunecová *et al*. (2024), the main benefits of SM include cost reduction through resource efficiency and improved regulatory compliance, better brand reputation and more excellent customer value, something that drives the sale of new products and gives new market access that leads to better economic performance, lower staff turnover through the creation of more attractive workplaces and a long-term business approach through the creation of opportunities to access finance and capital. In this way, the typical qualities of production, which are quality, flexibility, time and cost, which are always crucial for the industry's well-being, are optimised with the demand for SM implementation (Saxena *et al*., 2020).

To assess these positive impacts and the sustainability performance of products, as well as to achieve and integrate sustainability into the organisation's core strategy, examples include the combination of life cycle assessment (LCA) and sustainability assessment (SA) used by manufacturing companies (Kassem & Trenz, 2020). They are considered mainstream business activities demonstrating the link between the organisation's strategy and commitment to a sustainable global economy through a set of often complex and multidisciplinary assessment methods that seek to support decision-making towards a more sustainable society (Parolin *et al.*, 2024).

2.2. RISK IN PROJECT MANAGEMENT

2.2.1. PROJECT MANAGEMENT

Projects are defined as activities and tools that aim to achieve the company's objectives and strategy through temporary efforts to drive beneficial changes and to gain a competitive advantage (Vrchota *et al.*, 2021; Khalifeh e*t al.*, 2020). In each project, many processes interact and overlap using different methods. Each method is defined using inputs, such as documentation, drawings, plans, tools and techniques, and then outputs, such as a product, service and others with a specific and unique objective defined by the company (Čabarkapa, 2020).

According to the PMBOK® Guide (2021) and as mentioned also by Marnewick & Marnewick (2022), there are various definitions for PM. However, the attributes are common and are characterised by the application of knowledge, skills, methods, tools and techniques to manage and lead activities, and must be applied according to the project's specific objectives and requirements, which are used in planning, execution, measurement, monitoring and operations coordination. As defined by ISO 21500, in PM, the application of the above attributes must be included and integrated into the various phases of the project life cycle (Čabarkapa, 2020; Saxena *et al*., 2020).

To achieve the competitive success of each project, PM aims to design and execute successful projects using the previous attributes, which, when well applied, are characterised as success factors, driving the completion of each project within the defined time, costs or budget defined on the scope and with the agreed quality or functionality, maximising the efficiency and effectiveness of the entire project life cycle and minimising the risk associated with PM by the best application of these attributes (Vrchota *et al.*, 2021; Plattfaut, 2022).

In the literature on PM, for a better understanding of how these attributes can be used for the competitive success of each project, and as mentioned above, the Project Management Body of Knowledge (PMBOK) guide, which is considered to be one of the leading international standards for PM, as well as one of the most cited references, published by the Project Management Institute (PMI) (Perspective, 2021), defines ten areas of knowledge that a project manager should take into account for their application.

The PMBOK, as a PM framework, also defines 49 project processes that are tasks and activities that a project manager has to carry out and include in their daily work, most notably risk analysis, with sophisticated approaches such as fuzzy decision-making methods, controlling the budget, or keeping stakeholders involved (Rosenberger & Tick, 2021).

The phases of the PM process, in which the tools, techniques and processes mentioned above are used and applied, consist of three main components, which are planning, execution and supervision (Barghi & Shadrokh sikari, 2020) or in more detail can be subdivided into five (Perspective, 2021):

- Initiate
- Planning
- Execute
- Monitoring and controlling
- Closing

Various methods are used throughout each phase, and specific steps must be carried out. Moreover, a milestone, such as a risk assessment sheet, is located after each phase to ensure the requirements and objectives have been created and achieved. This ensures that each milestone has been successfully passed, and the next phase can begin (Stechert, 2021).

From Kaufmann & Kock (2022), the results of their study show that efforts in the project's planning phase (initial development phase) are generally higher and that there is a higher level of risk, which is thus also associated with final success if this phase thrives, with great emphasis on the team's problem-solving capacity.

From another point of view, according to Elkhatib *et al*. (2022), agile values and principles are seen as a new form of PM, dividing each phase into small cycles where minor parts of the project scope are planned and executed, focusing on iterations, self-organisation, increments, closer interaction and collaboration with the client, involving many of the activities mentioned in PMBOK knowledge.

To validate each scenario from the previous authors, it is critical to measure the performance and success of projects and organisations across the sector from each PM phase. This can be assessed using KPIs, which measure the effectiveness of a task essential to a project's success. According to quantitative studies from Plattfaut (2022), PM capabilities have a direct positive impact on Business Process Management (BPM) performance, which can often be characterised in many dimensions as a critical success factor when well measured.

Regarding the way to properly measure the project´s performance, according to Clemente & Domingues (2023), eight performance domains are identified in PM, which include stakeholders, the team, the development approach and life cycle, planning, work throughout the project, delivery and uncertainty. For Miranda *et al.* (2023), the leading performance indicators are productivity, profitability, customer satisfaction, innovation initiatives, employee development, quality performance and customer delivery.

Based also on this author's study, the KPIs most frequently used in Portuguese organisations are customer satisfaction, time, and cost. Applying and controlling these performance domains more effectively leads to delivering higher-quality and more profitable products, shortening waiting times and reducing engineering changes (Bhogil, 2021).

2.2.2. RISK MANAGEMENT

Project risk refers to any uncertainty that could affect the project's objectives. To identify these uncertainties in today's complex and highly dynamic business environment, it is necessary to understand the specific requirements since they are the project's needs to be achieved. Managing these exact requirements is the process of understanding, formulating, and documenting all of them to increase reliability and generate value (Almarzooqi *et al.*, 2023; Testorelli & Verbano, 2022).

To realise the importance of RM and to consider it as one of the essential branches of management science, especially PM, according to the PMBOK, which defines standards for managing projects to be successful, RM among the various main areas of management, such as project scope, time, costs and quality, is considered the most crucial supporting area (Barghi & Shadrokh sikari, 2020). Project managers who follow the PMBOK know that RM is one of the ten areas of knowledge that must be applied to minimise these risks and their impact and to achieve project success (Vargas *et al*., 2023).

All projects present many types of risks associated with each product life phase, such as supply, operational, disruption, transport, financial, and demand risks, the reason why each company should control all activities, from supply to the end customer, to identify the risk associated throughout all the value chain (Chand, 2021).

In this way, the risk response is considered a critical process factor in the success of operations and one of the most significant challenges for many organisations, as it provides excellent support in developing strategies and making decisions throughout the project (Vargas *et al*., 2023; Plattfaut, 2022).

The main decision-making methods for this risk response strategy, throughout all these phases, mentioned that to eliminate risk effectively it is viable to implement risk strategies that interconnect project resources, time and budget constraints, acceptability by all stakeholders, project team, clients perspective and also sustainability, which refers to long-term viability and flexibility to adapt to changes in the project environment (Al-Mhdawi *et al.*, 2023).

2.2.3. RISK MANAGEMENT PROCESS AND MODELS

According to the literature, various methodologies exist for managing risks and reducing their impact, depending on the variables determined for managing the risk and the application of the methods and strategies to deal with them.

According to various authors, from many methodologies, there are elements of coherence in the literature which define the processes and principles of this area that optimises the project's chances of success by reducing the impact of adverse risks (Al Mougher & Mahfuth, 2021; Almarzooqi *et al.*, 2023; Marle, 2020; Perspective, 2021; Barghi & Shadrokh sikari, 2020):

- Planning the RM strategy based on defining how to conduct RM activities.
- Identification of all possible project risks, both general and individual, based on communication and consultation according to their scope and characteristics.
- Evaluating or classifying risks by carrying out a qualitative analysis,
- Analyse or prioritise risks by carrying out a quantitative risk analysis on the combined effect of the probability and impact of the occurrence of general and individual risks, as well as the context and criteria based on the sources of uncertainty.
- Plan the response and treatment actions to the risk based on the risk precautions identified and implement them when necessary.
- Monitor and control or follow up on the risk according to the response or corrective action implemented, draw up reports, reassess the effectiveness of the actions, and finally, learn the lessons.

All the authors mentioned used two critical methodologies from the literature to define the phases of RM. The first is based on the processes defined by the ISO 31000:2018 standard, which establishes an understanding between all the activities of different types of organisations and dimensions that present risks, described as critical principles that must be identified, analysed and quantified before they can be treated. According to ISO 31000, these RM processes are essential to decision-making and are integrated into the organisation's structure, operations and processes (Ferreira de Araújo Lima *et al*., 2021).

The second methodology most referred to in the literature is defined based on the PMBOK guide, published by the PMI, in which RM is one of the ten areas of knowledge that must be applied to achieve success in projects and which identifies RM at various stages, providing control to reduce the severity of risks to objectives, focusing on the project's RM processes, in which each of the processes is simplified in the diagram by inputs and outputs (Leslie Appiah, 2020; Vargas *et al.*, 2023).

It is essential to realise that both methodologies (PDMBOK and ISO 3100) are based on the PDCA methodology and aim to continuously improve processes. Using each of the two methodologies for RM is sufficient to meet companies strategic objectives in controlling and treating risks. The only difference between the two approaches is that the ISO 3100 standard establishes risk treatment in the broadest sense of the company's activities, and the PDMBOK guide focuses on project risks (Vargas *et al.*, 2023).

2.3. NEW PRODUCTS DEVELOPMENT: AUTOMOTIVE INDUSTRY CASE

Over the years, NPD research and practice have changed a lot, as recent studies on best NPD practices sponsored by the Product Development & Management Association (PDMA) have shown (Xiao & Bharadwaj, 2023). The last ten years of research into NPD has been linked to studies into alliances, competition and dynamic capabilities, which recognise the NPD process as a critical success factor in defining the strategic positioning of companies (Marzi & Orcid, 2020) and an essential key element central to many companies achieving competitive advantage (Iqbal & Suzianti, 2021; Magnacca & Giannetti, 2024).

The NPD process influences the entire value chain and directly impacts all decisions on fundamental aspects such as quality, cost, and time. These are critical factors in high global competition, with a huge demand for innovation, shorter life cycles, shorter time to market, higher-quality products and product diversity (Wijewardhana *et al.*, 2021; Youssef & Webster, 2022).

At the base of the NPD process, which supports the development of models in this area, as previously reviewed, based also on Kaufmann & Kock (2022), is PM, which cuts across different areas and, in this case, plays a central role in NPD projects, as it is a method used to coordinate decisions regarding the project's objectives, planning and team organisation, which must integrate multiple cross-functional areas throughout the life cycle (Bhogil, 2021).

PM techniques and their integration into NPD focus on the stability of the relationship of three dimensions, which are duration, cost and the specification (quality) previously established in the objectives, preventing situations that ruin the schedule, budget or quality, measured by risk within each development project (Nagyová *et al.*, 2021). Furthermore, in addition to stability in these dimensions, NPD must include the dimension of sustainability in strategic thinking processes (Villamil *et al.*, 2023) since the economic, social and environmental objectives of sustainability can create challenges to the success of this development (Kunecová *et al.*, 2024).

2.3.1. NEW PRODUCT DEVELOPMENT MODELS

The importance of well-developed NPD models arises because, as mentioned by D. S. dos Santos *et al*. (2020) and according to product lifecycle management (PLM) principles, the initial phases are considered the most critical ones since is when the concept is defined for the complete product lifecycle that includes all the information and processes needed to plan, develop, manufacture and support the product, which integrates people, processes, business systems and information.

According to Bibaud-Alves *et al.* (2019), in many companies, 85% of the problems in the production process are related to decisions at the level of the NPD process due to the high degrees of complexity and uncertainty involved (Florén *et al.*, 2018), that affects this process and increases as development evolves (Magnacca & Giannetti, 2024)**,** and approximately 80% of production costs are also determined during the product design (Saxena *et al*., 2020). The literature also identifies the development phases as impacting up to 80% of a product's overall sustainability (Delaney & Liu, 2024).

Regarding the basis of NPD methods, this lies in the interconnection of engineering and manufacturing capabilities with customer needs, in which there must be simultaneous planning between the development of each product and the production system, with specific considerations for the interconnection of cross-functional teams from the initial development phase (May *et al.,* 2023), to eliminate inefficiencies and respond to process challenges that could lead to delays, high costs and misalignment with customer demands (C. Wang *et al.*, 2024; Falahat *et al.*, 2024).

According to PLM, this set of phases can be defined by three main phases, which are the beginning of life (BOL), recognised as the phase with the most significant added value, which includes the design and initial production of products, then the middle of life (MOL), which includes mass production, distribution and support or service, and the last phase is the end of life (EOL), in which products are taken off the market to be recycled or disposed of (Pinna *et al.*, 2018; Delaney & Liu, 2024; Ji & Abdoli, 2023).

In more detail, the literature describes various NPD versions, but academic convergence shows that the overall development process is defined as a process of six main phases which are (Delaney & Liu, 2024; C. Wang *et al.*, 2024; May *et al.,* 2023; Ji & Abdoli, 2023; Marzi & Orcid, 2020; Khannan *et al.*, 2021)**:**

- Gate 1 - Scoping or Order, where the products are planned and the concept designed and idealised.
- Gate 2 - Build a business case or a complete proposition concept, ensuring that the customer is involved early in this definition. Product concepts are generated and planned, and their requirements are defined based on product planning and the requirements portfolio to achieve concept freezing (customer-centred approach).
- Gate 3 - Development and materialisation of product design, wherein customer input is vital in product design, determining product requirements and specifications. It is also characterised by a sequence of detailed drawings generation, prototypes produced and tested, and rules for design engineering used to validate the system's architecture and archive of design freeze. In addition, the product and technology plan are involved (extensive NPD assessment (financial, market and technical) in the early stages of the development process).
- Gate 4 - Testing and validation in field trials, involving customer tests and trials, using an agreed methodology, with the involvement of process engineering and the start of process and resource planning for complete testing during product finalisation and detailed process development (cross-functional teams sharing knowledge effectively).
- Gate 5 – Launch or execution of a proficient, with the involvement of production engineering for production planning and start of production (SOP) (metrics, accountability and continuous improvement to track the performance of the NPD process). At this stage, the production system that includes the entire production operation, emphasising flexibility and adaptability built into this system during the planning phase, is reinforced during subsequent adaptations of the production system.
- Gate 6 - Post-launch review or operational realisation, after pilot testing, the product enters mass production and the ramp-up phase for customers, in which maintenance and repair begin to be validated (active portfolio management to integrate all the products developed into the company's strategy).

Each of these specific phases of NPD constitutes a set of tasks, activities and stages, which correlate with those reviewed in the previous chapter, that, when implemented correctly, have a positive impact on the profitability and long-term survival of an organisation (Magnacca & Giannetti, 2024**;** Y. Wang & Zhang, 2020).

To achieve these tasks positively, decision-making tools and management rules are used to bring efficiency through continuous improvement (Bibaud-Alves *et al.*, 2019) for the entire flow of projects in NPD with high variability, which require efforts in three categories that pass by reducing NPD cycle time, increase innovation in NPD and reuse the company's knowledge management assets using people, knowledge and systems to achieve success (Pinna *et al.*, 2018).

An example of a tool used in NPD, from Bersch *et al.* (2021), common in the automotive industry, to develop and produce a variety of products efficiently is standardised product platforms in which product portfolios are subdivided into various families. Standardisation is achieved using the LM principles to improve NPD efficiency (Marzi & Orcid, 2020; Wijewardhana *et al.*, 2021).

According to Salmen (2021), after implementing the various tools for each phase of the NPD, it is critical also to understand how to define the methods for measuring the launch success in a meaningful and comparable way based on the relationship between the contributions of the measures and the specific objective of the launch (Fabo *et al*., 2023).

In this way, product performance refers to defined measurement indicators as explained by Magnacca & Giannetti (2024)**,** such as the capabilities and efficiency of the NPD process, which aim to integrate the requirements of engineering and industrial processes to achieve a lower cost, higher quality and shorter development time (Wijewardhana *et al.*, 2021), considered to be internal aspects (Ahmadi-Gh & Bello-Pintado, 2021), and also to achieve external measures such as customer acceptance and financial performance (Rabea, 2022).

2.3.2. AUTOMOTIVE SECTOR

The global socioeconomic environment depends directly on the growth of the manufacturing industries, with great emphasis on the world's fastest-growing sector, contributing to the development of various other activities involved in the automotive ecosystem.

To represent this importance, as one of the largest economic sectors in the world in economic terms, in the EU represents more than 7 % of the total gross domestic product

(GDP) (Ostojic & Traverso, 2024) and 13.8 million people, which represents 6.1 % of the total workforce, directly or indirectly work in the automotive industry (Pichler *et al.*, 2021; Kanellou *et al.*, 2021). In this sector, purchases from suppliers account for more than 60% of overall revenues, which include raw materials, spare parts or subcontracted processing, which demonstrates the importance of suppliers in business operations, as shown by Ghosh *et* al. (2023).

More specifically, the Portuguese automotive components sector represents 5% of the country's gross domestic product, a significant weight in the Portuguese economy, with 85% of production sold to other countries, considered one of the largest exporting sectors (Azevedo *et al.*, 2022). According to the automotive business association ACEA, in Portugal, in 2021, in terms of the division of areas in the automotive sector, 70% represented component and accessory manufacturers, 25% focused on the manufacture of bodies, trailers and semi-trailers and 5% car manufacturing companies, with five large Original Equipment Manufacturers (OEM) production units (Moniz *et al.*, 2022).

In terms of the automotive industry's progress, based on Kolossváry *et al.* (2023), it increasingly includes innovation and technological advancement at is core, with an emphasis on digitalisation, autonomous systems, data-based functions and electrification, with large-scale mass production, implementation of stricter regulatory and legislative standards and various restructurings in response to constant changes in customer demands (Ghosh *et* al., 2023), due to multiple challenges and uncertainty in the sector, as a driver for improvement.

These challenges increase the complexity and dynamism of projects, such as growing competitive pressure from globalisation and expanding markets, increased outsourcing, and increased demands for mass customisation, which lead to individuality and specific complexities in production processes and systems (Schoch *et al.*, 2023), shorter product life cycles, which generate rapid depreciation (Soares *et al.*, 2022) and the continuous evolution of the relationship between organisation and customers (Hartoyo *et* al., 2023).

As Ostojic & Traverso (2024) mentioned, it is also essential to emphasise the pressure to improve climate, environmental, and social welfare impacts. This requires integrating sustainability into organisational strategies and transferring them to the operational level, a paradigm shift, and the conservative nature of the conventional vehicle design process (Schöggl *et al.*, 2024).

In response to the challenges, product and lifecycle management must respond to increasingly complex customer needs and requirements, the main criterion in NPD, without increasing costs, compromising quality or delaying deliveries (D. S. dos Santos *et al.*, 2020). This leads industries to consider designing, controlling, and optimising all product phases and improving their ability to operate in a dynamic global environment. These requirements are replicated in the relationship with automotive suppliers (Bastos *et al.*, 2021).

In terms of the future of the automotive industry, since customer requirements are the most critical point in the development of new projects, and since most companies are subject to requirements imposed by OEMs, there is a degree of dependency that will impact standards for quality, project timings and costs, with a higher restrictions levels on the automotive components suppliers, which as we have seen are the most significant percentage of this sector (Soares *et al.,* 2022).

Other challenges for the sector's future include responding to the considerable changes in recent decades, such as the shift in leadership from European to Asian companies and the paradigm shift towards an ability to reduce costs and offer vehicles at competitive prices without compromising on quality. This is driving the relocation of part of production to these countries to capitalise on lower labour costs (Piepoli *et al.*, 2024).

Finally, according to Boavida & Candeias (2021), since this sector still has many tasks that depend on human hands and a shortage of workers to carry out physically intensive and repetitive tasks, the direction of investment in automation and AI is continually growing, intending to shift operators to carry out analysis, control and supervision tasks to increase process efficiency, without leading to substitution but instead to the reorganisation of work.

3. RESEARCH METODOLOGY

3.1. INVESTIGATION METHODOLOGY

3.1.1. INVESTIGATION PROBLEMATIC AND RESEARCH QUESTIONS

The main study objective is:

I. Identify and evaluate the risk levels that influence the initial project phases of the NPD process, focused on the sustainability dimensions of an organisation.

Additionally, with the research objective of improving the risk analysis process, seeking to reduce uncertainty and ambiguity always involved in the risk analysis, that product managers need to perform to enhance their decision-making efficiency in all product life cycles and improve the risk understanding involved in the development of new products, within the context of launching new products in the Automotive Industry, and considering what has been studied on the literature sources and review, the study questions that will guide this research and addressed in this study are the following:

I. Based on the risk analysis, how can the most critical NPD phase be selected from the initial product life cycle?
II. How can the subjectivity inherent in human perception be solved in risk analysis?
III. How to measure the impact associated with NPD in each sustainability domain of an organisation?

3.1.2. INVESTIGATION STRATEGY

The research design should be defined to characterise the investigation and explain how the data in this study was collected and presented. This one links the data to be collected to the study's initial questions by articulating a "theory" about what is to be learned. The aim is to increase knowledge and use it to solve problems, provide innovative solutions, establish or confirm facts, or develop new theories, as Yin (2018) mentioned.

This research is characterised as exploratory, following a deductive logic, since it will be based on existing literature explained earlier. Analysis was conducted to answer the questions of the presented study, and propositions and key concepts were deduced using a proposed model to answer the abovementioned problem and present the results.

Finally, the model was then validated using a case study methodology. The essence of a case study is to try to demonstrate in a detailed way the reason for a set of decisions, why they were taken, how they were implemented, and after that, with results analysed in a qualitative manner (Ebneyamini & Sadeghi Moghadam, 2018).

The data collection methods adopted were based on direct observation and document analysis. In terms of the research methodology adopted, a crucial decision to perform effective scientific research aligned with the objectives (Basias & Pollalis, 2018), the study is characterised as qualitative to examine the relationship and influence of sustainable risk in the NPD process, using qualitative and quantitative data.

3.2. MODEL DESCRIPTION

The automotive industry, one of the most structured and strategic sectors for economic development, is one of the most competitive sectors at a global level, constantly changing and innovating to meet the needs of all consumers. Products in the automotive sector, throughout the entire chain of Tier suppliers involved, are focused on quality, speed of response in adapting to the environment and meeting dates that are always aligned with the launches of each OEM.

To understand how companies respond to this constant requirement to adapt, the development and launch of each product are central to the competitive success of all companies. In this way, developing a model that makes it possible to assess and relate the risk present at various stages of the development of a new product, focusing on various risk categories associated with the requirements of each product, which makes it possible to assess their impact on the three dimensions of sustainability, is a contribution to understanding how a response to change is also developed.

The economic, social, and environmental dimensions will be used to assess risk's impact on sustainability because, based on many authors reviewed previously, all companies need to balance all three dimensions to succeed.

In terms of assessing the risk present in various stages of NPD, even though there are multiple methodologies and it is not standardised, as reviewed in previous chapters, the risk assessment process involves mainly:

- ❖ Risk identification: Identification of the potential sources of risk and associated context.
- ❖ Frequency estimation: The aim is to determine the probability of each risk context occurring and the estimated consequences associated with each one.
- ❖ Risk calculation: Risk calculation combines each context's estimated frequency and consequences. The results are then compared with previously defined acceptance criteria to determine the risk's acceptability.

Aligned with the objectives being studied, an increased need appears to develop a model that makes it possible to relate and quantify the risk between a given component of a system (n Sc) based on a set of risk categories, which in this study are represented as each phase in the development/launch of a new product, and the risk domains present in the sustainability of each phase, which will represent a total risk of the system/product phase to be developed (SR).

Thus, based on the methodology adopted and reviewed in the previous chapter, which consists of organising the different risks into two hierarchical levels, the system components (NPD phases) will be denominated as Sc and the system risk (NPD phases in the sustainability dimensions) as SR, as seen on Figure 1. Figure 2 describes the relationship between the risks mentioned, Scn and SR, and their categories or risk domains. In this way, the risk associated with each component of the system can influence the risk level of the system in the different sustainability domains, namely economic, social and environmental.

The figures below show that each system component's risk (Scn) can be analysed as an isolated process. In turn, the success or failure of this component can influence the system's level of risk (SR) and impact the different sustainability domains associated with the product phase.

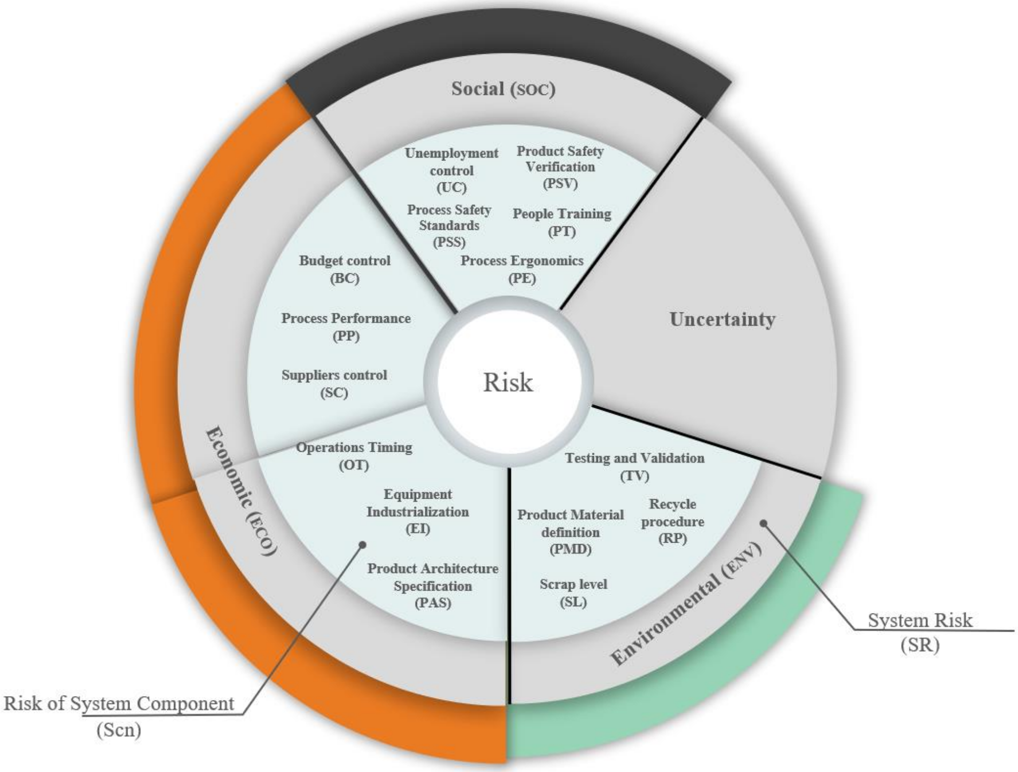

Figure 1 - Risk methodology adopted

Source: Adopted from R. Santos *et al.*, 2021

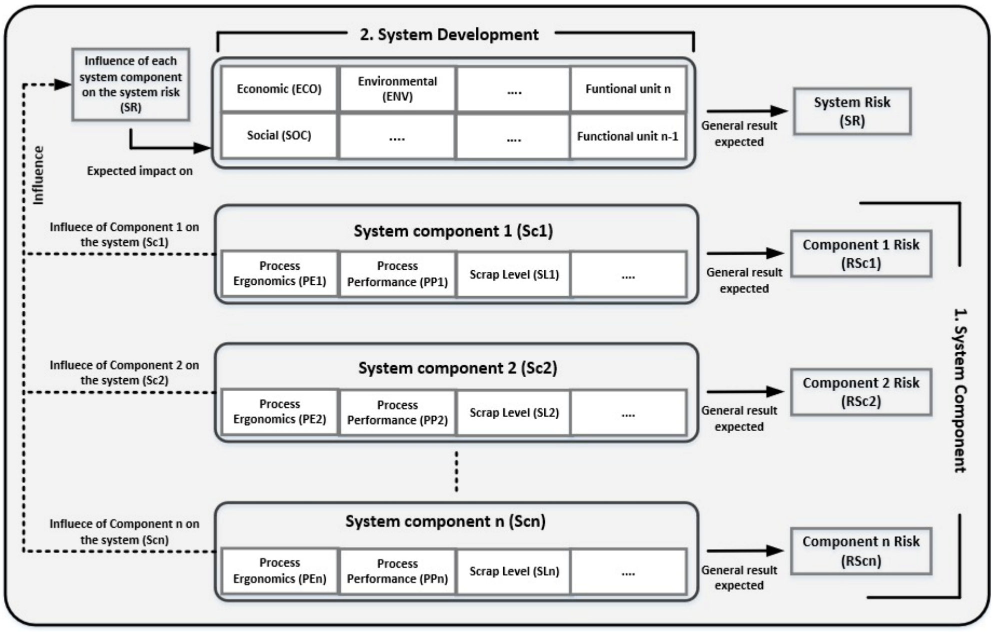

Figure 2 - Relationship between risks RScn and SR

Source: Adopted from R. Santos *et al.*, 2021

According to an interview with an industry professional, the risks present in each phase of NPD in a Tier 1 supplier from the automotive industry, the risk of each system component n (Scn), were categorised below and with the explained risk source:

- Unemployment control - Risk associated with wrong allocation management, fluctuation of volumes or, in the worst scenario, shutdown of working space or production lines due to early contract ending.
- Process Safety Standards - Risk associated with not following standards for the protection of all operators.
- Product Safety Verification - Risk associated with failing to validate the product's functionality will impact each consumer's use due to a wrong definition of requirements or incorrect verification plan and configuration.
- People Training - Risk associated with a lack of training for the professionals involved in operations.
- Process Ergonomics - Risk associated with developing processes that could impact the operator's health.
- Budget Control - Risk associated with incorrect management of the project's funding and initial quotes or assumptions during Capital Expenditure (CAPEX) development and application, which could lead to deviations from the investments.

- Process Performance - Risk associated with low KPIs or productivity in the product manufacturing process, failing Operational Expenditure (OPEX) objectives.
- Suppliers Control - Risk associated with a lack of components when required that could jeopardise validations, production, and each supplier's quality insurance.
- Operations Timing - Risk associated with non-compliance with the dates agreed by the client, Production Part Approval Process (PPAP) failure, impacting customer operations, or even stopping customer production at a high cost.
- Equipment Industrialisation - Risk associated with an incorrect manufacturing concept, equipment specification, development, installation, and configuration defined for the manufacturing process.
- Product Architecture Specification - Risk associated with Mechanical Design, hardware (HW) maturity and software (SW) maturity failures affecting product functionality.
- Product Material Definition - Risk associated with incorrectly defined Bill of Materials (BOM), not complying with Product Chemical Compliance Confirmation (PCCC) or not in the International Material Data System (IMDS), the repository for all material information used by the automotive industry.
- Recycle Procedure - Risk associated with high levels of waste that do not have a plan for how to be reused.
- Scrap Level - Risk associated with waste.
- Testing and Validation - Risk associated with failures in pollutant emissions due to an incorrect test strategy to ensure a quality environment.

Finally, the following risk domains inherent to the sustainability of the system (SR) were considered, which can be assessed in the following risk domains:

- Social - Based directly on a constant concern for people and their living conditions in the education, health, safety, and leisure sectors.
- Economic - Effectively integrates the entire network of business activity based on management principles, generating wealth and guaranteeing future economic sustainability.
- Environmental - Focused on environmental concerns, companies must balance natural resources management and sustainability over time through responsible production and consumption models.

3.2.1. FUZZY LOGIC THEORICAL FRAMEWORK

Fuzzy set theory and fuzzy logic play an essential role in RM (Barghi & Shadrokh sikari, 2020; Kabir & Papadopoulos, 2018) since they make it possible to assess the different risks involved and mitigate the subjectivity of analysis associated with imprecision, ambiguity, uncertainty, qualitative confusion or partial truth, which characterises risk assessment, given is dependence on human perception (Abreu *et al.*, 2018; R. Santos *et al.*, 2021)**.**

Through fuzzy control that successfully manages imprecision and ambiguity in decision-making, by fuzzy membership functions based on Artificial Intelligence (AI) algorithms, companies can improve their analysis capability and their effects of control (Jia & Wang, 2024; W. Wang *et al.*, 2024).

Fuzzy logic is thus characterised as a logical system based on partial falsity when the criteria that influence the choice are identified, as Palkova & Mašek (2024) explained.

The two aspects of risk assessment, quantitative and qualitative, are integrated into a single approach, aiming to be compatible with the uncertainty and ambiguity of human perception regarding risk assessment (R. Santos *et al.*, 2021) in project planning and control.

This allows easier use of these project processes, replacing statistical calculations with graphical demonstrations in interactive data visualisations to demonstrate the expression of non-precise linguistic variables with a characterisation not exact, as explained by Kambalimath & Deka (2020), improving them by the direct use of mental inference, experience and expert opinions that supports defining the influence present in each project, through their corresponding impacts.

The linguistic rules can be applied through conditional logic implications in the form IF...THEN, which represent a relationship between antecedent A and consequent B, $R_{A\rightarrow B}$.

Furthermore as Castro *et al.* (2024) explained, in the classical set theory, the concept of an element belonging to a set is well defined through the application of the characteristic function. For example, considering a set A within a universe X, the elements may or may not belong to the respective set, defined by the function $f_A(x)$.

$$f_A(x) = \begin{cases} 1 \; sse \; x \in A \\ 0 \; sse \; x \notin A \end{cases} \tag{1}$$

Based on Zhan *et al.* (2023), Ereiz *et al.* (2022) and Bhalla *et al.* (2022) study's, following on from the function presented, both authors mentioned the proposed Zadeh broader characterisation of this function to extend the set of values. This developed the characteristic function to take in the interval [0, 1] an infinite number of values, known as the fuzzy set. In this way, as mentioned, one $f(x)$, fuzzy set A belonging to a universe X, can be defined by the belonging function $\mu_A(x)$: X → [0,1] and is represented by the set of ordered pairs where μ_A (x) that represents the element x belonging degrees in the set A:

$$A = \left\{\frac{\mu_A(x)}{x}\right\} x \in X \tag{2}$$

Fuzzy sets can then be parameterised in continuous or discrete universes, also based on shown on each author´s study:

- ❖ In a universe X classified as discrete and finite, the fuzzy set A is usually characterised by a vector containing the degrees of pertinence in the set A of the corresponding elements of X.

$$\sum_{i=1}^{n} \frac{\mu_A(x_i)}{x_i} \tag{3}$$

- ❖ In a universe X classified as continuous, the fuzzy set A will be represented by an integral, which takes on the same notation as the sum of the universe classified as discrete.

$$\int \frac{\mu_A(x)}{x} dx \tag{4}$$

While variables take on numerical values in maths, linguistic terms and variables are often used to express rules in fuzzy logic. They can also be interpreted as fuzzy sets characterised by their belonging functions. The values of linguistic variables can correspond to primary terms, phrasal connectors, or verbal modifiers. Regardless of the terms used, the function of linguistic variables is to characterise complex or imprecise phenomena that allow data to be processed/analysed using traditional mathematical tools. Context should be considered when defining their membership function since, depending on the observer's perception and notion of belonging, a variable belonging to universe X may have different degrees of belonging in each universe.

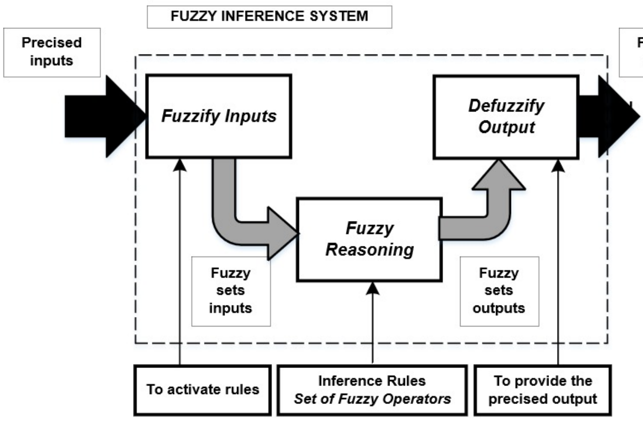

Figure 3 - Inference Fuzzy System

Source: Adopted from Abreu *et al.* (2018)

After defining the linguistic variables and their respective belonging functions, the fuzzy inference system (Figure 3) is generated. It is responsible for formulating and mapping a precise input into an output, using fuzzy logic for this purpose.

Based Palkova & Mašek (2024) and Kambalimath & Deka (2020), and according to Figure 3 shows that systems and models created using fuzzy logic consist of three main stages. They begin with fuzzification, which consists of converting actual variables into linguistic variables in the first stage, determining the degree of belonging of each precise input or set of values concerning each fuzzy set. The definition of the linguistic variables is based on an essential linguistic variable, such as low to extremely high risk.

The second foremost step is the inference engine, as mentioned by both authors. The rules of the type, at a language level, are used to define the system's behaviour. In other words, the previously defined rules of inference or control fuzzy logic are activated and combined, algorithms which are conditional sentences, resulting in fuzzy outputs, which are then grouped into a single fuzzy set, in which the correct determination of the meaning of the defined rules largely dictates the result of a fuzzy logic system.

The authors' final mentioned step is defuzzification, which, once the fuzzy output set has been obtained, converts the result of the fuzzy inference operation, based on the associated rules, into absolute values to be interpreted in the problem context.

Given the fuzzy nature of the decision-making process, the decision-maker judges based on specific values rather than those in the range. On the other hand, the results of the self-assessment are partially varied and dependent on various opinions, which means that the scores of the multiple consultants are sometimes very different. In this sense, Fuzzy Logic can be a valuable method for solving the above problems, given the flexibility and robustness of is outputs, which is necessary for decision-makers (R. Santos *et al.*, 2019).

3.3. MODEL ARQUITERTURE

The model presented in this work is based on developing and launching a new product in the automotive industry. It consists of a comprehensive approach that includes fuzzy logic to incorporate uncertainty and ambiguity related to human perception to assess NPD risk.

Based on the relationship shown in Figure 4, this work's approach uses fuzzy logic to conduct a qualitative and quantitative analysis of an NPD's risk assessment in a sustainability context. This analysis integrates two levels of risk: system component (Scn) and system development as a whole (SR), as shown in Figure 4.

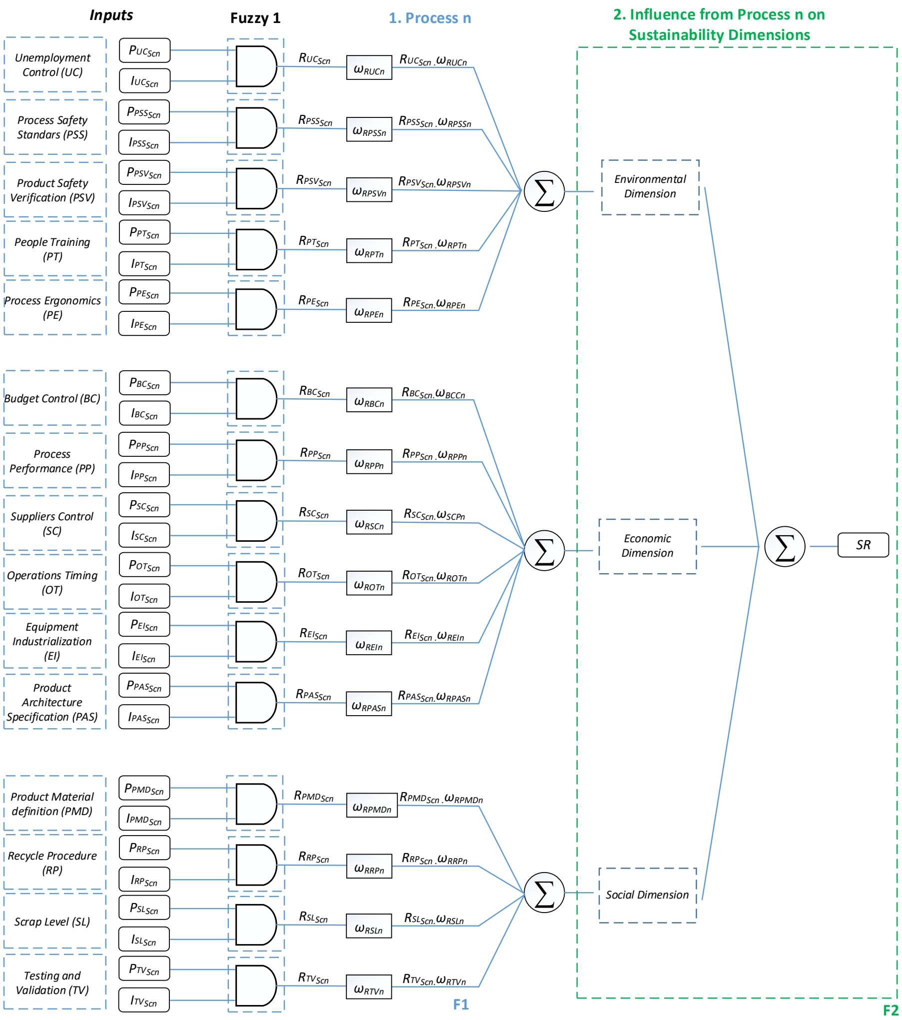

Figure 4 - Proposed model

Source: Own Elaboration

The first risk level aims to assess the risk associated with each system component, which in this study are the risk of a product's development phase. Each risk category of a launch phase is considered:

- Unemployment control (UC)
- Process Safety Standards (PSS)
- Product Safety Verification (PSV)
- People Training (PT)
- Process Ergonomics (PE)
- Budget Control (BC)
- Process Performance (PP)
- Suppliers Control (SC)
- Operations Timing (OT)
- Equipment Industrialization (EI)
- Product Architecture Specification (PAS)
- Product Material Definition (PMD)
- Recycle Procedure (RP)
- Scrap Level (SL)
- Testing and Validation (TV)

The risk of each NPD phase will be associated with a risk category, which in this study is the sustainability domain belonging to each system component. The individual risk level (R) of each will be calculated, resulting from the combination of the probability of occurrence (P) and the expected impact of the occurrence (I).

$$R_{UC} = P_{UC} \cdot \ I_{UC} \tag{5}$$

$$R_{PSS} = P_{PSS} \cdot \ I_{PSS} \tag{6}$$

$$R_{PSV} = P_{PSV} \cdot \ I_{PSV} \tag{7}$$

$$R_{PT} = P_{PT} \cdot \ I_{PT} \tag{8}$$

$$R_{PE} = P_{PE} \cdot \ I_{PE} \tag{9}$$

$$R_{BC} = P_{BC} \cdot \ I_{BC} \tag{10}$$

$$R_{PP} = P_{PP} \cdot \ I_{PP} \tag{11}$$

$$R_{SC} = P_{SC} \cdot \ I_{SC} \tag{12}$$

$$R_{OT} = P_{OT} \cdot I_{OT} \tag{13}$$

$$R_{EI} = P_{EI} \cdot I_{EI} \tag{14}$$

$$R_{PAS} = P_{PAS} \cdot I_{PAS} \tag{15}$$

$$R_{PMD} = P_{PMD} \cdot I_{PMD} \tag{16}$$

$$R_{RP} = P_{RP} \cdot I_{RP} \tag{17}$$

$$R_{SL} = P_{SL} \cdot I_{SL} \tag{18}$$

$$R_{TV} = P_{TV} \cdot I_{TV} \tag{19}$$

Since the risks of each phase have different weights and relevance and are associated with different sustainability dimensions, each risk of the sustainability dimension was calculated after the weights were applied to each risk category. The values obtained are added together to give the risk of each system component (Sc).

$$R_{SOC} = R_{UC} \cdot W_{UC} + R_{PSS} \cdot W_{PSS} + R_{PSV} \cdot W_{PSV} + R_{PT} \cdot W_{PT} + R_{PE} \cdot W_{PE} \tag{20}$$

$$R_{ECO} = R_{BC} \cdot W_{BC} + R_{PP} \cdot W_{PP} + R_{SC} \cdot W_{SC} + R_{OT} \cdot W_{OT} + R_{EI} \cdot W_{EI} + R_{PAS} \cdot W_{PAS} \tag{21}$$

$$R_{ENV} = R_{PMD} \cdot W_{PMD} + R_{RP} \cdot W_{RP} + R_{SL} \cdot W_{SL} + R_{TV} \cdot W_{TV} \tag{22}$$

After assigning weights to each sustainability dimension, we get the results in the second risk level and the total system risk of each phase (SR).

$$R_{TS} = R_{ENV} \cdot W_{ENV} + R_{ECO} \cdot W_{ECO} + R_{SOC} \cdot W_{SOC} \tag{23}$$

$$1 = W_{ENV} + W_{ECO} + W_{SOC} \tag{24}$$

The risk levels mentioned above were obtained through each Fuzzy Inference System based on conditional inference rules of the 'IF- AND - THEN' type.

Table I - Linguistic variables regarding the probability of occurrence (P) and membership functions

Linguistic Variables	Description	Triangular fuzzy number [a,b,c]
Rare	It is estimated that the event will occur only in exceptional circumstances	(0,0,0.2)
Unlikely	The event is not likely, but it can occur	(0,0.2,0.4)
Likely	Probable occurence event	(0.2,0.4,0.6)
Very Likely	The event will likely occur	(0.4,0.6,0.8)
Expected	The event is expected to occur	(0.6,0.8,1)

Source: Own Elaboration

Table II - Linguistic variables regarding the expected impact of the occurrence (I). and membership functions

Linguistic Variables	Description	Triangular fuzzy number [a,b,c]
Insignificant	Insignificant impact on the processes for product launch	(0,0,2)
Low	Prevents the fulfillment f one or more activities established for each product task	(0,2,4)
Moderate	Prevents the fulfillment of one or more tasks. No requirement changes	(2,4,6)
High	Prevents the fulfillment of one or more requirements. Product change required	(4,6,8)
Severe	It prevents the fulfillment of the product objective (s), and it´s not possible to achive it even with product changes.	(6,8,10)

Source: Own Elaboration

Table III - Linguistic variables regarding the individual risk level (R) and membership functions

Linguistic Variables	Description	Triangular fuzzy number [a,b,c]
Very Low	Risk can be accepted as it does not pose a threat to the project/organization, it must be monitored to ensure that it´s level does not change	(0,0,2)
Low	Risk can be accepted. Risk control must be carried out based on a cost-benefit analysis	(0,2,4)
Moderate	Risk must be mitigated; the effectiveness of controls must be monitored	(2,4,6)
High	Efforts should be made to mitigate risk as soon as possible	(4,6,8)
Very High	Immediate action must be taken to mitigate the risk	(6,8,10)

Source: Own Elaboration

In addition to the risk shown in Tables I-III, from the set of ranges shown in Table IV, it will be possible to match the linguistic values with numerical ones, which will drive a result quantitative analysis relating to the risks in the system components and the overall risk of the system.

Table IV - Type of variable used: linguistic values and corresponding numerical values

Variable Type					
Occurrence Impact (I)		Occurrence Probability (P)		Occurrence Risk (R)	
Linguistic Level	Numerical correspondence	Linguistic Level	Numerical correspondence	Linguistic Level	Numerical correspondence
Insignificant	[0,2]	Rare	[0,0.2]	Very Low	[0,2]
Low	]2,4]	Unlikely	]0.2,0.4]	Low	]2,4]
Moderate	]4,6]	Likely	]0.4,0.6]	Moderate	]4,6]
High	]6,8]	Very Likely	]0.6,0.8]	High	]6,8]
Severe	]8,10]	Expected	]0.8,1]	Very High	]8,10]

Source: Own Elaboration

3.3.1. IMPLEMENTATION IN SOFTWARE MATLAB

After the architecture of the model demonstrated previously, and to develop the inference rules set, the definition of the membership functions, and to analyse the fuzzy inference system (FIS) behaviour, it was possible to simulate the Fuzzy Inference model using the MATLAB® program and specifically is tool, Fuzzy Logic ToolboxTM (called Fuzzy Logic Designer in version R2024a).

This software will be used to process the FIS, entering as linguistic variables the associated inputs, the probability of occurrence (P) and the expected impact of occurrence (I), and collecting the considered output, the risk level (R) of the component, as seen in Figure 5.

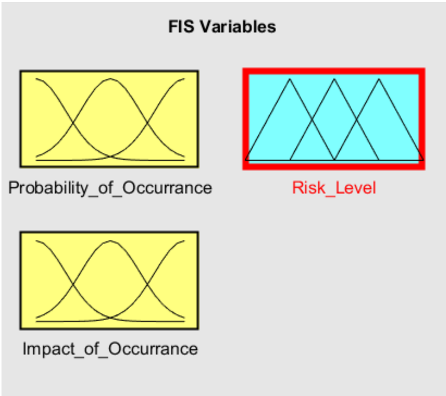

Figure 5 - FIS Variables

Source: Own Elaboration

Then, triangular functions whose risk corresponds to those shown in the 'Model Architecture' subchapter in Tables I-IV were used in the membership function editor to introduce and generate the membership function plots in Figures 6-8.

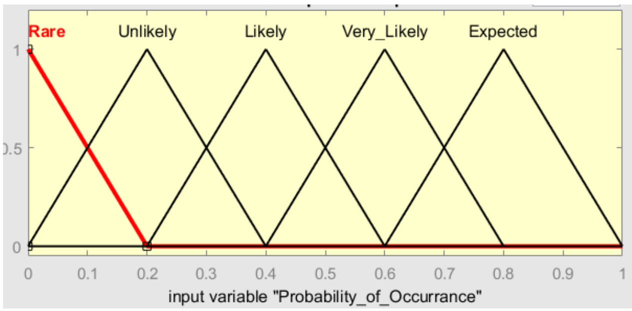

Figure 6 - Triangular Function for Probability

Source: Own Elaboration

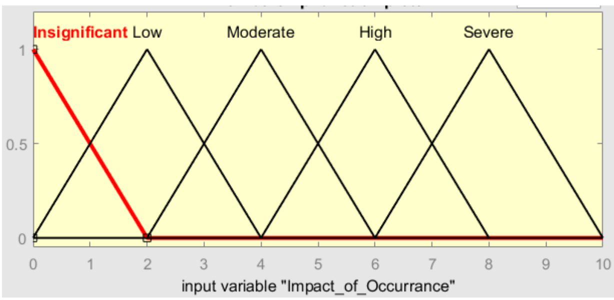

Figure 7 - Triangular Function for Impact

Source: Own Elaboration

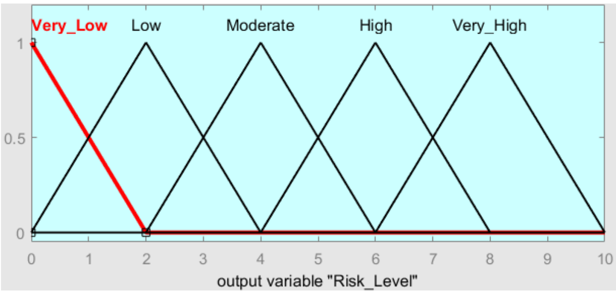

Figure 8 - Triangular Function for Risk Level

Source: Own Elaboration

This software presents two inference systems methods to implement fuzzy inference: *Mamdani* and *Sugeno*, where the *Mandani* method is characterised by being intuitive and better adapted to inputs from human perception and is the most referenced in the literature (R. Santos *et al.*, 2020), reason why was the one used to implement fuzzy inference as seen on Figure 9.

For the defuzzification method, the centroid method was considered as it is the most referred to be used for this type of application (Abreu *et al.*, 2018).

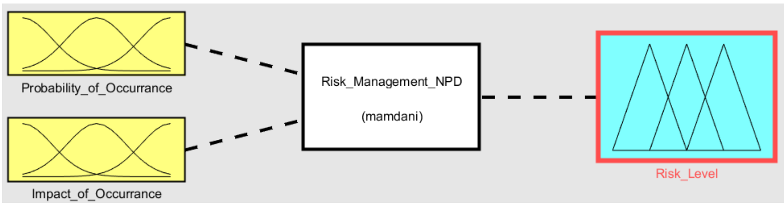

Figure 9 - MATLAB implementation

Source: Own Elaboration

After selecting the inference system, Rule Editor was used to establish the inference rules in the software to characterise the fuzzy inference.

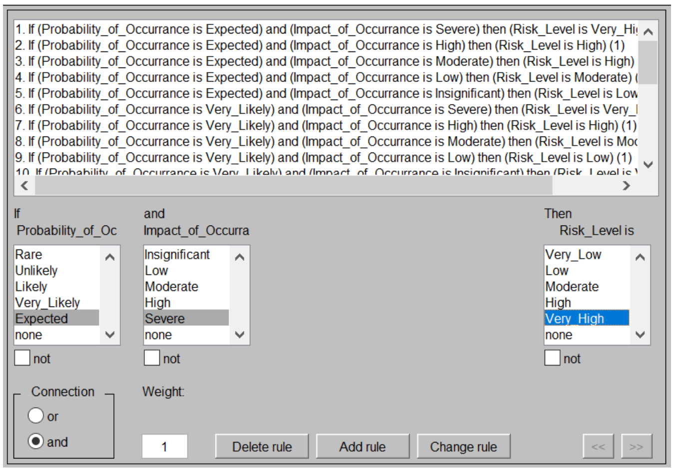

Figure 10 - Operation in the Rule Editor of Fuzzy Logic Designer

Source: Own Elaboration

Once the system characterisation has been completed, using the Surface Viewer tool, it is possible to analyse the results graphically using surfaces. This allows the visualisation of various outputs resulting from the probability of occurrence and their impact to be measured.

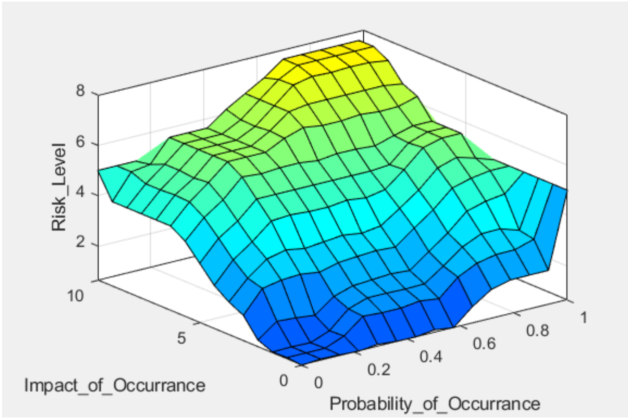

Figure 11 - Operation in the Fuzzy Logic Designer Surface Viewer

Source: Own Elaboration

The surfaces also allow obtaining the specific results of the outputs, in this case, resulting from the component's behaviour, by entering the selected inputs, which are the probability and impact of occurrence, in the Rule Viewer interface.

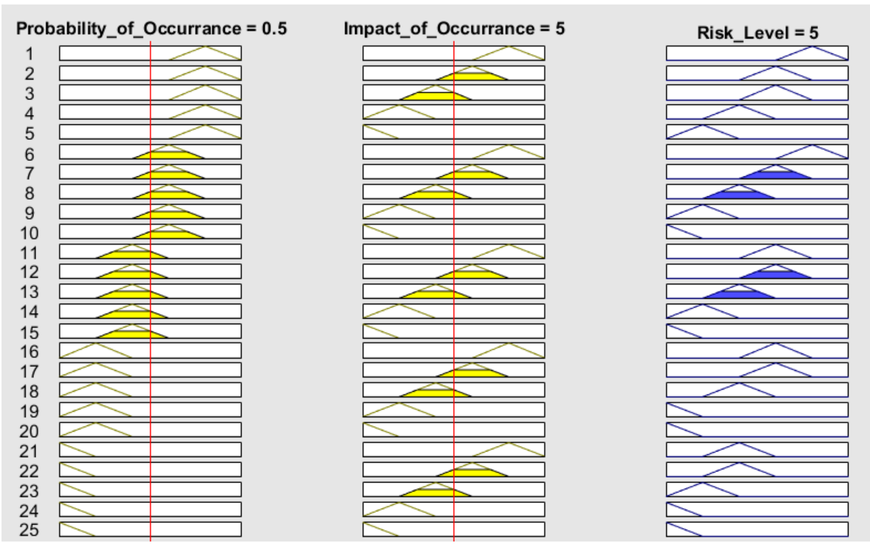

Figure 12 - Operation in the Rule Viewer of Fuzzy Logic Designer

Source: Own Elaboration

4. DATA ANALYSIS AND RESULTS

This dissertation summarises the importance of RM when launching new products in the automotive industry, with the objective being the applicability presented above, which allows the best decisions to be made. It assesses the potential risk of six development phases for the launch of a new product and the impact that this risk has on the three dimensions of sustainability considered.

The model presented above aims to be a risk assessment tool that allows the product manager and others involved to have information characterised by numerical and linguistic variables, with data that can be integrated into management and decision-making processes.

Risk assessment is a human process that supports the use of fuzzy logic. Decisions with different degrees of importance are directly interconnected and dependent on human subjectivity, and they are characterised by uncertainty and ambiguity.

Based on a case study of a Multinational Tier 1 Supplier of electronic components and modules for OEMs in the automotive industry, NPD is central to success throughout the product life cycle, and these phases are shown in Table V. From this table, the study will focus on the first stages of NPD since, based on the literature and by the interview with an industry professional, they are the most critical for the success of the programs.

Table V - Electronic Components Launch Phases

<table>
<tr><th>Nº</th><th>Stage</th><th>Launch Phase</th></tr>
<tr><td>NA</td><td>Business Identification</td><td>Gate 0: Opportunity Identification</td></tr>
<tr><td>1</td><td>Business Pursuit
(Customer Quote)</td><td>Gate 1: Proposal</td></tr>
<tr><td>2</td><td rowspan="5">Forward Models Phases (Development of Parts for Manufacturing Prove Out)</td><td>Gate 2: Award and Planning</td></tr>
<tr><td>3</td><td>Gate 3: Development</td></tr>
<tr><td>4</td><td>Gate 4: Pilot</td></tr>
<tr><td>5</td><td>Gate 5: Launch</td></tr>
<tr><td>6</td><td>Gate 6: Post-Launch</td></tr>
<tr><td>NA</td><td>Current Model Phase
(Parts in Production)</td><td>Gate 7: Current Model</td></tr>
<tr><td>NA</td><td>Past Model Service
(Parts in Service only)</td><td>Gate 8: Past Model Service</td></tr>
</table>

Source: Own Elaboration

The model to be developed consists of fifteen risks present in all the development phases of a new product, which are incorporated into the respective sustainability areas shown in Table VI.

Table VI - Risk present on each Launch Phase

Nº	Phase Requirement	Sustainablility Area
1	Unemployment Control (UC)	Social
2	Process Safety Standards (PSS)	Social
3	Product Safety Verification (PSV)	Social
4	People Training (PT)	Social
5	Process Ergonomics (PE)	Social
6	Budget Control (BC)	Economic
7	Process performance (PP)	Economic
8	Suppliers Control (SC)	Economic
9	Operations Timing (OT)	Economic
10	Equipment Industrialization (EI)	Economic
11	Product Architecture Specification (PAS)	Economic
12	Product Material Definition (PMD)	Environmental
13	Recycle Procedure (RP)	Environmental
14	Scrap Level (SL)	Environmental
15	Testing and Validation (TV)	Environmental

Source: Own Elaboration

To carry out a precise risk analysis of the system, a risk manager will be allocated who will be responsible for evaluating 30 input variables of the model (P and Impact of each risk present in the development and launch of a new program) based on the two levels of risk identified, which are the risk associated with each risk of the launch of a new program and the total risk of each component of the system in the system's domain.

To start applying the model, using the previously proposed model shown in Figure 4, the inference system was applied using the Fuzzy Logic ToolboxTM tool available in the Matlab program. To aid this analysis, the different risk levels obtained were presented in a table using a matrix of colours and corresponding linguistic variables, established previously in Table IV, in which the intensity of the colour increases as the risk level increases.

The first risk level aims to assess each new program's launch risk in each system component, that is, each launch phase. To do this, the probability of occurrence and respective impact were calculated for each risk category for each system component, the qualitative values of which are shown in Table VII. The risk of each component was calculated from the combination of the expected impact and the corresponding probability of occurrence, as shown in Table VIII.

Table VII - Qualitative values applied to the Fuzzy Inference

Source: Own Elaboration

Table VIII - Risks obtained from the application of the Fuzzy Inference

Outputs	Project Phase / Gate	R_{UC}	R_{PSS}	R_{PSV}	R_{PT}	R_{PE}	R_{BC}	R_{PP}	R_{SC}	R_{OT}	R_{EI}	R_{PAS}	R_{PMD}	R_{RP}	R_{SL}	R_{TV}
1	Proposal	0,752	0,752	0,752	0,752	0,752	5	0,752	0,752	2,73	3	3	1,74	0,752	0,752	1,74
2	Award and Planning	0,752	0,752	1,74	0,752	1,74	8	0,752	0,752	2,73	7	5	1,74	1,74	0,752	2,73
3	Development	0,752	0,752	5	1,74	6	8	0,752	7	6	7	7	7	2,73	0,752	7
4	Pilot	2,73	5	7	5	6	4	5	7	8	8	7	7	2,73	6	4
5	Launch	5	5	5	5	5	2,73	7	7	6	5	4	5	4	7	2,73
6	Post-Launch	5	5	5	4	5	2,73	7	5	5	4	4	5	4	6	2,73

Source: Own Elaboration

Analysing the results obtained, it was found that, in terms of risk, the Unemployment risk has a 'Moderate' level of risk in the Launch and Post Launch phases, with a value of 5, due to Launch being a ramp-up phase where there is significant variation in volumes and allocation that can remove occupancy from the lines, and in Post-Launch with a Rare probability. The Process Safety Standards risk has a moderate risk level in the last 3 phases of the program launch, with a value of 5, as these are the phases where the manufacturing process begins, and failures in these standards have a severe impact. Product Safety Verification has a high-risk level in the Pilot phase, with a value of 7, since in this phase and the Development phase, the probability of failure is higher, as these are the phases where tests are being developed and validated, and in the Pilot phase any failure can impact the validations also in the OEMs and failures in the PPAP timing. The People Training risk has a moderate or low-risk level in the last phases of the program launch, with a value of 5 in Pilot and Launch, since this is the start of the production process and where training begins. The Process Ergonomics risk has a moderate level of risk in the final 4 phases of the program launch, where in development, where the concept is defined, and in the pilot, where the concept is materialised, it has the highest value of

6 since failures in these phases can have an impact on all working conditions on the production lines.

About the Budget Control risk, the risk level is high, with a value of 8, in the Award and Planning and Development phases, since it is in these phases that investments are defined and materialised with the purchase of equipment and where deviations are more likely to occur with a severe impact on the launch financials. The Process Performance risk has a high-risk level in the launch and post-launch phases, with a value of 7, since it is in these phases that the SOP begins, and performance is analysed throughout the ramp-up. Regarding the Supplier's Control risk, the risk is high in the Development, Pilot and Launch phases, with a value of 7 in all three, since in development, the quality of the components is critical for design verification, and in pilot and launch the stability of supply is still stabilising. The risk of shortage is higher, which could compromise availability in Pilot for process verification validations and entry into SOP. Regarding the Operations Timing risk, the risk Equipment Industrialisation has a high risk in the Award and Planning and Development phases, with a value of 7, and in the Pilot, with a value of 8, since it is in these phases that the PPAP submissions are made with the design verification completed and with the process verification, and which has a high probability of timing failures with a severe impact since it can compromise OEM validations and entry into SOP. The Equipment Industrialisation has a high risk in the Award and Planning and Development phases, with a value of 7, and in the Pilot, with a value of 8, since it is in these phases that the manufacturing concept is defined, the specifications and purchase of the equipment are developed and materialised in the installation, configuration and validation, something that has a high probability of failure and a high and severe impact that can compromise the three critical metrics for the launch of the program, which is cost, quality and timing. Regarding the Product Architecture Specification risk, the risk is high, with a value of 7, in the Development and Pilot phases since it is in these phases that the critical validations of the design and process are made.

The Product Material Definition risk presents the most significant risk in the Development and Pilot phases, with a value of 7, because it is in these phases that the checks, validations and submissions of the reports for each material involving the product to be manufactured and assembled by each OEM are made. The Recycle Procedure risk has a low risk, with the highest value of 4 in the Launch and Post-Launch phases, because these are the phases where the most production and failures in the recycling plan have the most significant impact. The Scrap Level risk has a high risk in the launch phase, with a value of 7, since this is the ramp-up of production and the probability of scrap is higher due to the oscillations and initial stability of production. Finally, the testing and validation risk is higher in the Development phase, with a value of 7, since this is the phase where design verification is carried out and the probability and impact of failures are higher.

In addition to the information gathered, the risk manager was asked to define a level of relative importance for each launch risk, referring to each sustainability domain, by assigning weights (W) to each.

In the social dimension, the risks that directly affect people's health and safety were considered to have the most significant weight of relevance to the dimension, which was Process Safety Standards and Product Safety Verification, with 25%, then Process Ergonomics with 20%, which has no immediate impact on health and safety, but can jeopardise it in the medium to long term, and with 15% the factors that influence the quality, development and well-being of people, Unemployment control and People Training.

In the economic dimension, the risk that directly affects the cost, timing and requirements defined with the client was considered the most relevant, with 20% for Budget Control, Operations Timing, and Product Architecture Specification, then 15% for what impacts the materialisation of these metrics in production, which is the Process Performance and Equipment Industrialisation risk, and finally 10% for Suppliers Control, which has a parallel impact in all the risk.

In the environmental dimension, the risk that directly impacts waste, the Scrap level risk, was considered the most relevant with 30%, followed by the Product Material Definition and Testing and Validation risk with 25%, which impact the development and launch of a program within the standards and requirements, and with 20% Recycle Procedure.

Table IX - Risks of system dimensions obtained from the Fuzzy Inference

		R_{SOC}					R_{ECO}						R_{ENV}						
	W_R	15%	25%	25%	15%	20%	20%	15%	10%	20%	15%	20%	25%	20%	30%	25%			
Sc	Project Phase / Gate	R_{UC}	R_{PSS}	R_{PSV}	R_{PT}	R_{PE}	R_{BC}	R_{PP}	R_{SC}	R_{OT}	R_{EI}	R_{PAS}	R_{PMD}	R_{RP}	R_{SL}	R_{TV}	R_{SOC}	R_{ECO}	R_{ENV}
1	**Proposal**	0,752	0,752	0,752	0,752	0,752	5	0,752	0,752	2,73	3	3	1,74	0,752	0,752	1,74	0,752	2,784	1,246
2	**Award and Planning**	0,752	0,752	1,74	0,752	1,74	8	0,752	0,752	2,73	7	5	1,74	1,74	0,752	2,73	1,197	4,384	1,691
3	**Development**	0,752	0,752	5	1,74	6	8	0,752	7	6	7	7	7	2,73	0,752	7	3,012	6,063	4,272
4	**Pilot**	2,73	5	7	5	6	4	5	7	8	8	7	7	2,73	6	4	5,360	6,450	5,096
5	**Launch**	5	5	5	5	5	2,73	7	7	6	5	4	5	4	7	2,73	5,000	5,046	4,833
6	**Post-Launch**	5	5	5	4	5	2,73	7	5	5	4	4	5	4	6	2,73	4,850	4,496	4,533

Source: Own Elaboration

This resulted in the level of risk for each phase of the development and launch of a new program segmented by sustainability dimensions, as seen in Table IX. In social and environmental terms, the pilot phase, followed by the launch and post-launch phases, have the highest risk values in descending order since these are the phases in which the production process begins. In economic terms, the Pilot phase, followed by the Development and Launch phases, have the highest risk values, in descending order, since these are the phases where all the cost-intensive tests and validations are carried out, and the production process begins, still with oscillations.

Following the information requested from the risk manager, he was asked to assign relative importance to each sustainability dimension to enable the total risk of each component and each launch phase to be calculated as accurately as possible. This request resulted in the composition of the project's total risk, with a relative importance of 70 % in the economic dimension, 20 % in the social dimension, and 10 % in the environmental dimension.

Table X - Total Risk of the system obtained from the Fuzzy Inference

	WR	20%	70%	10%		
Sc	Project Phase / Gate	**RSOC**	**RECO**	**RENV**	**SR**	**RISK THRESHOLD (5≤)**
1	**Proposal**	0,752	2,784	1,246	2,224	-
2	**Award and Planning**	1,197	4,384	1,691	3,477	-
3	**Development**	3,012	6,063	4,272	5,273	ACTION REQUIRED
4	**Pilot**	5,360	6,450	5,096	6,097	ACTION REQUIRED
5	**Launch**	5,000	5,046	4,833	5,015	ACTION REQUIRED
6	**Post-Launch**	4,850	4,496	4,533	4,570	-

Source: Own Elaboration

This allocation led to the results shown in Table X, which show that the phases of the launch of a new program with the most significant risk based on the three dimensions of the system are, in descending order, firstly, the Pilot phase, with the highest SR of 6.097, due to being the phase with the higher risk on the Economic dimension, as seen on previous Sc analysis, with the value of 6.45, due to the risk involved on the Operation Timing and Equipment Industrialization with the value of 8, since, as previously explained, this is the phase that involves equipment acceptance and commissioning, process and production verification and maturity analysis for PPAP 1-3 submission and approval to SOP, critical also for OEM validation to the market. Then, the Development phase, also defined as the Design verification and maturity prototype, with an SR of 5.273, due to the higher risk on the Economic dimension, with a value of 6.06, since the risk involved in the Budget Control, with a value of 8, and involved in the Supplier Control and Product Architecture Specification, with the value of 7, as previously explained, are considered high because this is the phase where the product should be validated against the requirements and also when the manufacturing concept is defined, equipment ordered based on design and industrialisation kick-off, with high uncertainty involved, leading to high probability and impact of occurrence. This phase is then followed by the Launch phase when SOP starts (JOB1), with an SR of 5.015 and the Post-Launch phase, 90 days after the previous phase, with an SR of 4.570, phase where is confirmed that the process runs at an average production rate. After this comes the Award and Planning phases, in which the design and process plan are based on the requirements and assumptions of the proposal, which consists of Design for Manufacturing (DFM), product architecture analysis and industrialisation and equipment spec bullet points with a lower SR of 3.477. Finally, with the lowest of all SRs of 2.224, the Proposal phase goes through requirements, initial assumptions, and approval to quote pricing strategy and response to the customer.

To analyse the total risk of each phase, a maximum risk threshold was established to begin the process of developing risk mitigation actions. This threshold was set at level 5, as it is the average value considering the risk calculation range, which goes from 0 to 10.

Based on Table X, the Pilot phase, which has the highest total risk, SR value, above the defined risk threshold of 5, and considering the sources of risk previously identified, should have implemented actions to reduce and mitigate them. These actions could pass from implementing lessons learned (organisational knowledge application) and standardisation during the design and implementation of the manufacturing concept to avoid uncertainty in these operations, reducing the probability of occurrence. They could also involve closer relations with the customer for more accurate management of client expectations and a more detailed alignment regarding the requirements definition for each PPAP milestone.

5. CONCLUSIONS, LIMITATIONS, AND FUTURE RESEARCH

This dissertation emphasises the relevance of RM in the context of managing the launch of new programs in the automotive industry, which, according to the literature, is one of the fastest-growing sectors in the world and contributes to the growth of various other activities involved in the automotive ecosystem, with significant impacts in socio-economic terms and with various challenges and uncertainties that lead to advances in various areas. This reality emphasises making the best decisions in various risk situations.

To answer the first and third questions posed in the initial problem, '*Based on the risk analysis, how can the most critical NPD phase be selected from the initial product life cycle?*' and '*How to measure the impact associated with NPD in each sustainability domain of an organisation?* ', a model was developed that made it possible to carry out a quantitative and qualitative risk analysis, risks inherent to each risk present in the launch and development of a new program in the context of a company supplying electronic components to the automotive industry, and to understand the identification of the most critical phase with the highest level of risk, by estimating the corresponding risk in the three dimensions of sustainability.

In response to the second question in the methodology, '*How can the subjectivity inherent in human perception be solved in risk analysis?*', we used techniques and methods based on fuzzy logic and artificial intelligence, an advanced method for dealing with the complexity of the variables involved and which allows us to minimise the subjectivity intrinsic to human perception present in conventional risk assessment methods, which involve analysing the probability of occurrence and the impact associated with the product under development, using data generally obtained through research, surveys and by an interview.

A limitation of this study is that it was carried out for the specific reality and characteristics of one company through a case study, where the results and conclusions obtained refer to the specific company context.

This leads to suggestions for future work, given that each new product depends on the company and the operations sector and has a specific strategy and lifecycle management, representing a unique study environment. Since this study only focused on a specific case, it is worth highlighting the need to analyse other program developments that reflect different phases and risks in different contexts to diversify the model's applicability.

In a second direction, the model developed needs to incorporate not only the risks inherent in the threats but also the possibility of significant opportunities arising. This would enable organisations to be prepared not only to face challenges but also to capitalise on new and promising possibilities that may arise during the project's execution.

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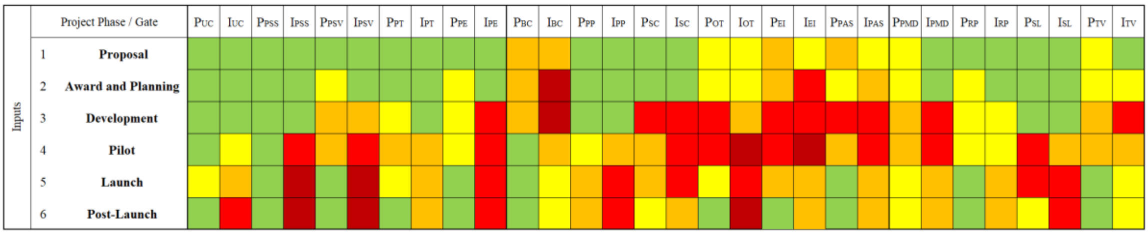
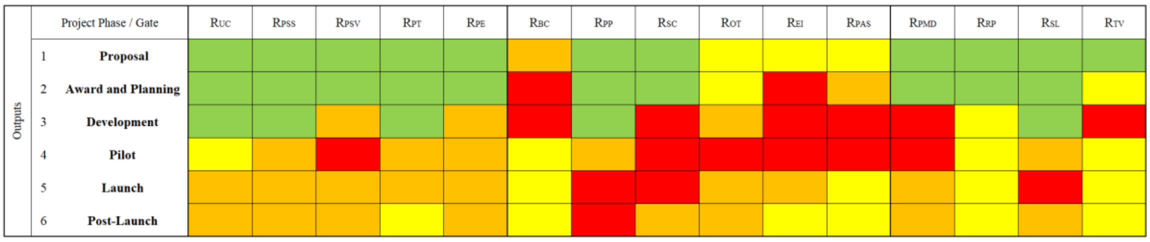
7. APPENDIXES

7.1. APPENDIX 1 - Results obtained from the application of the Fuzzy Inference





7.2. APPENDIX 2 - Risks obtained from the application of the Fuzzy Inference

	Project Phase / Gate	R_{UC}	R_{PSS}	R_{PSV}	R_{PT}	R_{PE}	R_{BC}	R_{PP}	R_{SC}	R_{OT}	R_{EI}	R_{PAS}	R_{PMD}	R_{RP}	R_{SL}	R_{TV}
Outputs	1 **Proposal**	0,752	0,752	0,752	0,752	0,752	5	0,752	0,752	2,73	3	3	1,74	0,752	0,752	1,74
	2 **Award and Planning**	0,752	0,752	1,74	0,752	1,74	8	0,752	0,752	2,73	7	5	1,74	1,74	0,752	2,73
	3 **Development**	0,752	0,752	5	1,74	6	8	0,752	7	6	7	7	7	2,73	0,752	7
	4 **Pilot**	2,73	5	7	5	6	4	5	7	8	8	7	7	2,73	6	4
	5 **Launch**	5	5	5	5	5	2,73	7	7	6	5	4	5	4	7	2,73
	6 **Post-Launch**	5	5	5	4	5	2,73	7	5	5	4	4	5	4	6	2,73

		R_{SOC}					R_{ECO}						R_{ENV}			
	W_R	15%	25%	25%	15%	20%	20%	15%	10%	20%	15%	20%	25%	20%	30%	25%
Sc	Project Phase / Gate	R_{UC}	R_{PSS}	R_{PSV}	R_{PT}	R_{PE}	R_{BC}	R_{PP}	R_{SC}	R_{OT}	R_{EI}	R_{PAS}	R_{PMD}	R_{RP}	R_{SL}	R_{TV}
1	**Proposal**	0,752	0,752	0,752	0,752	0,752	5	0,752	0,752	2,73	3	3	1,74	0,752	0,752	1,74
2	**Award and Planning**	0,752	0,752	1,74	0,752	1,74	8	0,752	0,752	2,73	7	5	1,74	1,74	0,752	2,73
3	**Development**	0,752	0,752	5	1,74	6	8	0,752	7	6	7	7	7	2,73	0,752	7
4	**Pilot**	2,73	5	7	5	6	4	5	7	8	8	7	7	2,73	6	4
5	**Launch**	5	5	5	5	5	2,73	7	7	6	5	4	5	4	7	2,73
6	**Post-Launch**	5	5	5	4	5	2,73	7	5	5	4	4	5	4	6	2,73

		20%	70%	10%	
Sc	Project Phase / Gate	**R_{SOC}**	**R_{ECO}**	**R_{ENV}**	**R_{Sc}**
1	**Proposal**	0,752	2,784	1,246	2,224
2	**Award and Planning**	1,197	4,384	1,691	3,477
3	**Development**	3,012	6,063	4,272	5,273
4	**Pilot**	5,360	6,450	5,096	6,097
5	**Launch**	5,000	5,046	4,833	5,015
6	**Post-Launch**	4,850	4,496	4,533	4,570

	W_R	20%	70%	10%		
Sc	Project Phase / Gate	**RSOC**	**RECO**	**RENV**	**SR**	**RISK THRESHOLD (5≤)**
1	**Proposal**	0,752	2,784	1,246	2,224	-
2	**Award and Planning**	1,197	4,384	1,691	3,477	-
3	**Development**	3,012	6,063	4,272	5,273	ACTION REQUIRED
4	**Pilot**	5,360	6,450	5,096	6,097	ACTION REQUIRED
5	**Launch**	5,000	5,046	4,833	5,015	ACTION REQUIRED
6	**Post-Launch**	4,850	4,496	4,533	4,570	-

7.3. APPENDIX 3 – Inference Rules

1. If (Probability of occurrence is Expected) and (Impact of Occurrence is Severe) then (Risk Level is Very High)
2. If (Probability of occurrence is Expected) and (Impact of Occurrence is High) then (Risk Level is High)
3. If (Probability of occurrence is Expected) and (Impact of Occurrence is Moderate) then (Risk Level is High)
4. If (Probability of occurrence is Expected) and (Impact of Occurrence is Low) then (Risk Level is Moderate)
5. If (Probability of occurrence is Expected) and (Impact of Occurrence is Insignificant) then (Risk Level is Low)
6. If (Probability of occurrence is Very Likely) and (Impact of Occurrence is Severe) then (Risk Level is Very High)
7. If (Probability of occurrence is Very Likely) and (Impact of Occurrence is High) then (Risk Level is High)
8. If (Probability of occurrence is Very Likely) and (Impact of Occurrence is Moderate) then (Risk Level is Moderate)

9. If (Probability of occurrence is Very Likely) and (Impact of Occurrence is Low) then (Risk Level is Low)
10. If (Probability of occurrence is Very Likely) and (Impact of Occurrence is Insignificant) then (Risk Level is Very Low)
11. If (Probability of occurrence is Likely) and (Impact of Occurrence is Severe) then (Risk Level is High)
12. If (Probability of occurrence is Likely) and (Impact of Occurrence is High) then (Risk Level is High)
13. If (Probability of occurrence is Likely) and (Impact of Occurrence is Moderate) then (Risk Level is Moderate)
14. If (Probability of occurrence is Likely) and (Impact of Occurrence is Low) then (Risk Level is Low)
15. If (Probability of occurrence is Likely) and (Impact of Occurrence is Insignificant) then (Risk Level is Very Low)
16. If (Probability of occurrence is Unlikely) and (Impact of Occurrence is Severe) then (Risk Level is High)
17. If (Probability of occurrence is Unlikely) and (Impact of Occurrence is High) then (Risk Level is High)
18. If (Probability of occurrence is Unlikely) and (Impact of Occurrence is Moderate) then (Risk Level is Moderate)
19. If (Probability of occurrence is Unlikely) and (Impact of Occurrence is Low) then (Risk Level is Very Low)
20. If (Probability of occurrence is Unlikely) and (Impact of Occurrence is Insignificant) then (Risk Level is Very Low)
21. If (Probability of occurrence is Rare) and (Impact of Occurrence is Severe) then (Risk Level is Moderate)
22. If (Probability of occurrence is Rare) and (Impact of Occurrence is High) then (Risk Level is Moderate)
23. If (Probability of occurrence is Rare) and (Impact of Occurrence is Moderate) then (Risk Level is Low)
24. If (Probability of occurrence is Rare) and (Impact of Occurrence is Low) then (Risk Level is Very Low)
25. If (Probability of occurrence is Rare) and (Impact of Occurrence is Insignificant) then (Risk Level is Very Low)