Universidade do Minho
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Multi-objective optimization model for sustainable Robotic Process Automation technology implementation

october 2023

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Doctoral Thesis
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Work performed under the supervision of:
Professora Doutora Leonilde Varela
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october 2023

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STATEMENT OF INTEGRITY

I hereby declare having conducted this academic work with integrity. I confirm that I have not used plagiarism or any form of undue use of information or falsification of results along the process leading to its elaboration.

I further declare that I have fully acknowledged the Code of Ethical Conduct of the University of Minho.

MULTI-OBJECTIVE OPTIMIZATION MODEL FOR SUSTAINABLE ROBOTIC PROCESS AUTOMATION TECHNOLOGY IMPLEMENTATION

ABSTRACT

This work was conducted through a comprehensive investigation into the sustainable implementation of Robotic Process Automation, with a special focus on the needs of users and stakeholders involved in this technology. This study's main objective was to analyse the feasibility of sustainable Robotic Process Automation implementation, taking into account user requirements.

To achieve this objective, a multi-objective mathematical model was developed, and the weighted sum and Tchebycheff methods were applied to evaluate the efficiency of the implementation. Furthermore, a case study was carried out in a company to obtain data, using questionnaires and brainstorming sessions with the company's stakeholders.

The results obtained throughout this study highlight the importance of user needs in the context of Robotic Process Automation and demonstrate that the integration of these needs in the multi-objective model improves implementation evaluation. Practical guidance was also provided for Robotic Process Automation planning and management with a focus on sustainability. The analysis reveals a solution that reduces initial costs by 21.10% and enables an efficient and equitable allocation of available resources.

In conclusion, this study advances our knowledge about the interconnection between user needs and the feasibility of Robotic Process Automation, offering viable guidelines for the sustainable implementation of this technology. This work contributes to the development of more effective and sustainable strategies within the scope of Robotic Process Automation and has significant implications for the management of business processes and the improvement of operational efficiency.

Keywords: Sustainability; Robotic Process Automation; multi-objective optimization; mathematical model.

MODELO DE OTIMIZAÇÃO MULTIOBJETIVO PARA A IMPLEMENTAÇÃO SUSTENTÁVEL DA TECNOLOGIA DE AUTOMAÇÃO DE PROCESSOS ROBÓTICOS

RESUMO

Este trabalho foi conduzido através de uma investigação abrangente sobre a implementação sustentável de Automação de Processos Robóticos, com um foco especial nas necessidades dos utilizadores e nos *stakeholders* envolvidos nesta tecnologia. Este estudo teve como objetivo principal analisar a viabilidade da implementação sustentável da Automação de Processos Robóticos, tendo em consideração os requisitos dos utilizadores.

Para atingir este objetivo, foi desenvolvido um modelo matemático multiobjetivo, sendo que foram aplicados os métodos da soma ponderada e de Tchebycheff para avaliar a eficiência da implementação. Além disso, foi realizado um estudo de caso em uma empresa para obter os dados, recorrendo a questionários e sessões de *brainstorming* com os *stakeholders* da empresa. Os resultados obtidos ao longo deste estudo sublinham a importância das necessidades dos utilizadores no contexto da Automação de Processos Robóticos e demonstram que a integração destas necessidades no modelo multiobjetivo melhora a avaliação da implementação. Foram também fornecidas orientações práticas para o planeamento e gestão da Automação de Processos Robóticos com um enfoque na sustentabilidade. A análise revela uma solução que permite reduzir os custos iniciais em 21,10% e possibilita uma alocação eficiente e equitativa dos recursos disponíveis.

Em conclusão, este estudo avança o nosso conhecimento sobre a interligação entre as necessidades dos utilizadores e a viabilidade de Automação de Processos Robóticos, oferecendo diretrizes viáveis para a implementação sustentável desta tecnologia. Este trabalho contribui para o desenvolvimento de estratégias mais eficazes e sustentáveis no âmbito da Automação de Processos Robóticos e tem implicações significativas para a gestão de processos empresariais e a melhoria da eficiência operacional.

Palavras-Chave: Sustentabilidade; Automação de Processos Robóticos; otimização multiobjetivo; modelo matemático.

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LIST OF ACRONYMS

3D Printing - 3-Dimensional Printing

3D - Three-Dimensional

ACOs - Ant Colony Algorithms

AGI - Artificial General Intelligence

AI- Artificial Intelligence

AIaaS - AI as a Service

AIoT- AI and IoT

AM- Additive Manufacturing

B2B - Business-to-Business

B2C - Business-to-Consumer

BCSDPortugal - Business Council for Sustainable Development Portugal

B-On - Biblioteca do Conhecimento Online

BPM - Business Process Automation

CAGR - Compound Annual Growth Rate

CEO - Chief Executive Officer

CFO - Chief Financial Officer

CIO - Chief Information Officer

CMO - Chief Marketing Officer

CO2 - Carbon Dioxide

COBIT - Control Objectives for Information and related Technology

COO - Chief Operating Officer

CSR - Corporate Social Responsibility

CSR - Customer Service Representative

CTO - Chief Technology Officer

DA - Data Analytics

Eq. - Equation

GAs - Genetic Algorithms

GDP - Gross Domestic Product

HR - Human Resources

I4.0- Industry 4.0

ICT- Information and Communication Technology

IoT- Internet of Things

ISI WOS - Institute for Scientific Information Web of Science

IT- Information Technology

ITIL - Information Technology Infrastructure Library

KPI - Key Performance Indicator

M&A - Mergers and Acquisitions

MCDM- Multi-Criteria Decision Making

MDPI- Multidisciplinary Digital Publishing Institute

ML- Machine Learning

MV- Machine Vision

NLP - Natural Language Processing

NP-hard- Nondeterministic polynomial-time hard

NSGA-II - Non-dominated Sorting Genetic Algorithm II

OCR - Optical Character Recognition

PDCA - Plan-Do-Check-Act cycle

PDF- Portable Document Format

PmBOK - Project Management Body of Knowledge

PMI- Project Management Institute

ROI - Return on Investment

RPA- Robotic Process Automation

SPEA2 - Strength Pareto Evolutionary Algorithm 2

SWOT - Strengths, Weaknesses, Opportunities, Threats

U.m.- Units monetary

1. INTRODUCTION

In this doctoral thesis, referring to the Industrial and Systems Engineering (Doctoral Program), the aim is to provide a significant contribution to the study of sustainable implementation of Robotic Process Automation (RPA) technology. This is achieved through the creation of a multi-objective optimization model, focusing on the perspective of user sustainability within the context of stakeholders. The current chapter encompasses the contextualization of the conducted work, the underlying motivation, the overarching and specific objectives of the thesis, the central research question, and the hypotheses underlying this inquiry. The selected research methodology is also addressed, along with the overall structure adopted for this dissertation.

1.1. Contextualization

> *Industry 4.0 (I4.0), and Sustainability are important concerns for companies and in a general way for the society. (...) The Industry 4.0 or I4.0 is starting to revolutionize communities requiring a significant upgrade not just in terms of technology. With the advent of exponential technology and high speed and big data processing capabilities, high levels of digitalization regarding all kind of processes in companies are also required. The concept of sustainability has received increasing global attention from the public, academic, and business sectors* (Varela, et al., 2019).

Industry 4.0, also known as the Fourth Industrial Revolution, pertains to the application of advanced technologies to automate and optimize industrial processes (Johnson, et al., 2018; Smith & Brown, 2019). This concept emerged in response to the growing need for companies to increase productivity, enhance efficiency, and reduce operational costs (Hermann, et al., 2016; Lee, et al., 2017). In this context, Robotic Process Automation (RPA) has emerged as a promising tool for automating tasks and business processes, contributing to the digital transformation of organizations (Chang & Lin, 2020; Gupta, et al., 2019).
According to Patrício,

> *Robotic Process Automation (RPA) aims to automate business processes or parts of them with software robots, (...) Despite being a tool that significantly contributes to improving the quality of life at work, a critical point related to this technology is the rejection by employees for fear*

> *of losing their jobs due to the implementation of robots. RPA is about using digital robots and artificial intelligence to eliminate/minimize human errors in repetitive processes and make them faster and more efficient* (Patrício, et al., 2023).

The purpose of this section is to provide a suitable framework for the efficient implementation of RPA, addressing the user sustainability perspective within the stakeholder context. Industry 4.0 represents a new era of digital transformation, where the interconnection of systems and the use of intelligent technologies are pivotal in driving industrial efficiency and productivity (Schumacher & Sprott, 2020; Li, et al., 2018). This technological revolution has significant impacts on business processes and relationships between companies and their stakeholders (Kagermann, et al., 2013; Porter & Heppelmann, 2014). The adoption of RPA within this context enables the automation of repetitive and rule-based tasks, freeing up human resources for higher-value-added activities (Kumar & Sangwan, 2021; Raghavendra, et al., 2020).

The purpose of this section is to provide a suitable framework for the efficient implementation of RPA, addressing the user sustainability perspective within the stakeholder context. Industry 4.0 represents a new era of digital transformation, where the interconnection of systems and the use of intelligent technologies are pivotal in driving industrial efficiency and productivity (Schumacher & Sprott, 2020; Li, et al., 2018). This technological revolution has significant impacts on business processes and relationships between companies and their stakeholders (Kagermann, et al., 2013; Porter & Heppelmann, 2014). The adoption of RPA within this context enables the automation of repetitive and rule-based tasks, freeing up human resources for higher-value-added activities (Kumar & Sangwan, 2021; Raghavendra, et al., 2020).

Still according to Patrício,

> *The implementation of RPA reduces the manual burden within companies, in their various administrative or operational sectors. In this way, it guarantees greater autonomy to the teams, to focus on strategic issues that lead the company to fulfil its objectives* (Patrício, et al., 2023).

The effective implementation of Robotic Process Automation brings forth a range of benefits for organizations and their users. Firstly, robotic automation can reduce human errors, enhancing process accuracy and consistency, resulting in improved quality and compliance in operations (Goh & Gao, 2017). Moreover, RPA can enhance operational efficiency by accelerating task execution and reducing response times (Lacity & Willcocks, 2016).

Another significant advantage is the reduction of operational costs. By automating routine tasks, companies can decrease the need for human resources, yielding substantial long-term savings. Additionally, robotic automation allows for the strategic allocation of human resources to higher-value activities, thereby enhancing the overall productivity of the organization (Müller, et al., 2020; Ravichandran, et al., 2019).

However, beyond the intrinsic benefits of adopting RPA, it is critical to consider the user sustainability perspective when implementing this technology. Sustainability here refers to the ability to ensure positive and long-term outcomes for the involved stakeholders (Ren, et al., 2021). In this case, RPA users must ensure that the investment made in the implementation and operation of robotic automation is viable and generates sustainable value for the organization (Chandrasekaran, et al., 2019). In figure 1 we can analyse a diagram relating to the benefits of RPA technology.

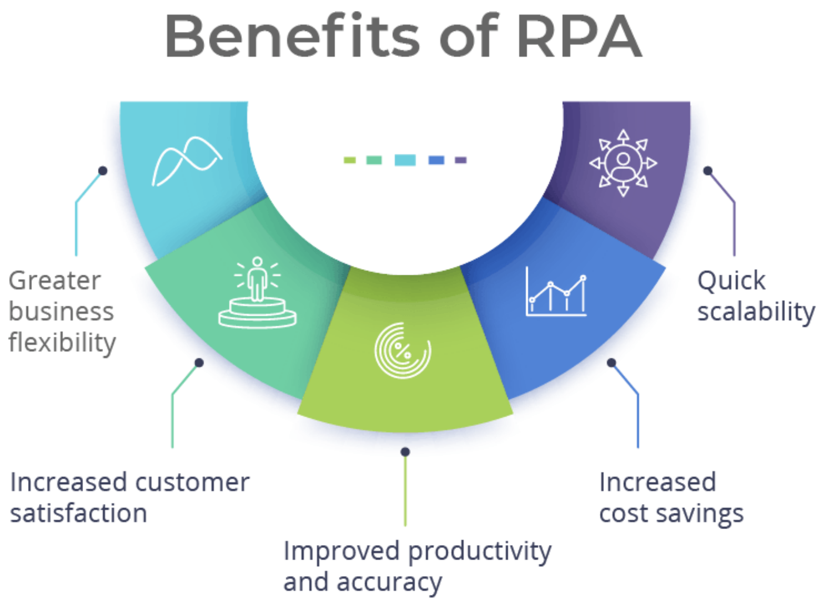

Figure 1 - Benefits of RPA

Souce: Nintex (2023)

In recent years, RPA technology has been widely adopted by organizations worldwide as an effective solution to improve operational efficiency and reduce costs (Lacity & Willcocks, 2019; Lu, et al., 2021). RPA involves the use of specialized software to automate repetitive and rule-based tasks, enabling companies to enhance productivity, reduce human errors, and expedite business

processes (Huang, et al., 2019; Soltani, et al., 2020).
However, as organizations seek to implement RPA technology and reap the associated benefits, it is crucial to consider not only the technical and operational aspects but also the sustainability of the involved users within the stakeholder context (Pereira, et al., 2021; Zhang, et al., 2022). Sustainability pertains to the ability to maintain and enhance the viability of organizational activities in the long term while meeting the needs of all involved stakeholders (Wu, et al., 2021).
According to BCSDPortugal,

> *Sustainability is the ability to meet our needs in the present without compromising the ability of future generations to meet their own needs. Historically, the concept of sustainability is linked to the fight for social justice, conservationism, internationalism and other movements of the past. At the end of the century. XX, these ideas culminated in the so-called "sustainable development". Today, it is a key topic for the competitiveness of companies, increasingly important for their short, medium and long-term strategies (BCSDPortugal, 2021).*

By addressing the user sustainability perspective, the aim is to comprehend how the efficient implementation of RPA technology can benefit the organization, the engaged employees, and other relevant stakeholders. When pondering sustainability, it is also essential to consider potential impacts on the roles and tasks of employees. However, the fact that RPA technology is designed to automate repetitive tasks does not necessarily imply replacing employees. Instead, automation can free up human resources to focus on more strategic and higher-value activities (Wu, et al., 2022). Consequently, it is crucial to analyse the effects of RPA within the stakeholder context, ensuring that sustainability is achieved without jeopardizing the existing workforce (Tang, et al., 2022).
Furthermore, within the stakeholder context, it is vital to consider the expectations and needs of the stakeholders involved in the RPA implementation. This encompasses not only the direct users of automation but also the managers, shareholders, and customers of the organization (Kusar, et al., 2021). By taking into account the diverse perspectives of stakeholders, it becomes possible to identify key concerns and focal points, aiming to strike a balance among the interests of all involved parties (Lacity, et al., 2020; Liu, et al., 2022).
The sustainability of RPA implementation is intricately linked with the organization's capacity for adaptation and innovation (Sawyer, et al., 2019; Zhang, et al., 2021). Robotic Process Automation is a technology in constant evolution, making it imperative for organizations to be equipped to keep

pace with changes and updates in the field of RPA (Pan, et al., 2019). This necessitates a flexible approach and a culture of continuous learning, enabling the organization to fully leverage the benefits of robotic automation in the long run (Chang, et al., 2021; Li, et al., 2022).

In this context, this study seeks to provide recommendations for the efficient implementation of RPA from the standpoint of user sustainability within the stakeholder framework (Wang, et al., 2019; Yu, et al., 2021). Through this study, it is anticipated that practical guidance will be offered to organizations aspiring to adopt RPA in a sustainable manner. Organizations will be poised to make well-informed decisions and to implement Robotic Process Automation efficiently, fostering both operational efficiency and sustainability (Chen, et al., 2020; Huang, et al., 2022).

We then move on to the motivation and presentation of the general objective of this work.

1.2. Motivation and General Objectives

My motivation to undertake this study stems from my passion for exploring new technological possibilities and seeking innovative solutions to business challenges. Upon encountering the topic of efficient implementation of Robotic Process Automation (RPA) from the perspective of user sustainability within the context of stakeholders, I recognized the relevance and potential positive impact that this approach could have on organizations.

RPA has been widely adopted by companies as a means to optimize operational efficiency, reduce costs, and enhance service quality. However, the concept of sustainability applied to RPA implementation is a critical aspect to ensure its long-term success. Understanding the factors that affect viability, identifying appropriate metrics, and considering the expectations and needs of stakeholders are fundamental elements for sustainable RPA implementation.

I believe that research in this field will contribute to advancing knowledge and developing best practices in RPA implementation. Through this study, I aim to provide valuable insights and practical recommendations for organizations wishing to adopt robotic process automation while considering sustainability.

The prospect of contributing to a more sustainable future, where technology and business can coexist harmoniously to drive growth, also motivates me. I believe that efficient RPA implementation, taking sustainability into account, is a significant step in this direction.

Therefore, through this study, I aim to add value to the field of Robotic Process Automation by providing insights and guidance that can assist organizations in adopting RPA sustainably, thus promoting operational efficiency.

My motivation to conduct this study also arises from the need to fill a gap in academic and business literature regarding efficient RPA implementation. Despite the widespread adoption of this technology, there is a scarcity of studies that specifically address sustainable implementation aspects and stakeholder impacts.

Through this research, I endeavour to bridge this gap by offering a comprehensive and in-depth understanding of challenges and opportunities related to efficient RPA implementation. By exploring the user sustainability perspective, I aim to contribute to the comprehension of critical factors affecting the viability of robotic process automation and identifying recommended strategies and practices to maximize benefits.

I believe that this study can provide valuable perceptions for managers, decision-makers, and professionals involved in RPA implementation. By considering sustainability, organizations can make more informed and strategic decisions regarding robotic automation adoption, taking into account not only immediate benefits but also long-term impacts on outcomes and stakeholder relationships.

Furthermore, this research can have broader implications for society, as robotic automation becomes a reality across various sectors. Understanding how to implement RPA efficiently and sustainably can contribute to its development, the creation of skilled jobs, and the optimization of available resources.

Thus, my motivation to undertake this study lies in the opportunity to generate knowledge and practical perceptions that can contribute to the enhancement of RPA implementation processes, promoting user sustainability within the stakeholder context. I believe in the transformative potential of this technology and aspire to provide a solid foundation for organizations to make the most of the benefits of Robotic Process Automation, thereby driving efficiency and business competitiveness.

General Objectives:

The general objective of this doctoral study is to investigate the efficient implementation of RPA from a user sustainability perspective within the stakeholder context. To achieve this objective, we focus on two points, in which the intention **(1)** is to develop a multi-objective mathematical optimization model that takes into consideration the needs and interests of stakeholders, **(2)** providing guidelines for well-informed decision-making. Let us examine each of these points in more detail.

(1) Develop a multi-objective mathematical optimization model that takes into account the needs and interests of stakeholders:

- In this first objective, the primary aim is to create a mathematical model capable of optimizing multiple objectives simultaneously. Specifically, the model will focus on considering the needs and interests of stakeholders involved in a particular context, which, in the case of this study, is related to the efficient implementation of Robotic Process Automation (RPA). This means that the model will attempt to find solutions that meet multiple criteria or goals, taking into account the perspectives and demands of the parties involved. The expected outcome is a model that aids in making more informed and balanced decisions, considering the different priorities and interests of the stakeholders.

(2) Provide guidelines for well-founded decision-making:

- The second objective aims to produce guidelines or recommendations that assist in making decisions related to the efficient implementation of RPA. These guidelines will be based on the results and conclusions obtained from the mathematical optimization model mentioned in the first objective. The guidelines will be designed to help stakeholders make informed and strategic decisions that take into account the various factors involved in RPA implementation. This may include recommendations on how to balance the diverse needs of stakeholders, efficiently allocate resources, and maximize the positive impact of RPA on user sustainability.

In summary, the study's primary objective is to investigate the efficient implementation of RPA from the perspective of user sustainability within the context of stakeholders. To achieve this goal, the two highlighted objectives aim to develop a mathematical model that considers the needs of stakeholders and provide guidelines for informed decision-making. This should contribute to a more balanced and sustainable approach to RPA implementation.
After presenting the motivation and general objective of this work, we proceed to state the specific objectives of this investigation.

1.3. Specific Objectives

As specific objectives associated with the overarching goals mentioned in the preceding section, the following can be identified:

1. Framing Industry 4.0 and Sustainability:

- Conduct a comprehensive analysis of the context of Industry 4.0, understanding its challenges and opportunities, and integrating the concept of sustainability.

2. Framing Robotic Process Automation Technology:

- Explore the concept and relevance of RPA as a tool for process automation and optimization, considering potential benefits for organisations such as reduced human errors, increased precision and process consistency, improved operational efficiency, and cost reduction.

3. Developing a Literature Review on RPA-related Work:

- Investigate studies and research that address RPA application, identifying main contributions, benefits, and challenges in this area.
- Analyse academic and practical works exploring the integration of multi-objective techniques into planning and scheduling with RPA technology, investigating the approaches used, achieved results, and lessons learned.
- Summarise key findings from the literature review, providing a solid foundation for the development of the proposed research in this thesis.

4. Framing the Planning and Scheduling Problem:

- Analyse key issues and challenges related to planning and scheduling.
- Explore existing approaches and methods to address the planning and scheduling problem.

5. Framing the Concept of Multi-objective Problems:

- Understand the concept of multi-objective problems and their relevance in decision-making.

- Analyse the characteristics and challenges of multi-objective problems.
- Explore techniques and methods used to solve multi-objective problems.

6. Problem Description and Case Study Presentation:

- Specification and contextualization of the problem to be addressed.
- Presentation of the case study and identification of the characteristics that make the case study relevant to the research.

7. Data Collection:

- Identification and description of data sources to be used in the case study.
- Presentation of the results of the data collected for the case study.

8. Developing a Mathematical Model for Multi-objective Optimization:

- Create a mathematical model enabling efficient implementation of RPA, considering the sustainability perspective of the user.

9. Application of the Model in Two Scenarios:

- Execute an implementation in two scenarios, Scenario 1 using the weighted sum method, and Scenario 2 using the Tchebyshev method.
- Assign weights to each requirement, considering user preferences, to enable precise evaluation of their relevance in the optimization process.

10. Analysis and Statistical Study of Results:

- Analyse obtained results and conduct a statistical analysis to compare which of the applied scenarios may yield more favourable outcomes.

11. Conclusions and Final Considerations:

- Presentation of the answer to the central research question and the respective answers to the research hypotheses.
- Concise summary of the main conclusions and results obtained throughout the research.
- Discussions are the practical implications of this work in the area of RPA.

- Identification of research limitations, recognizing areas that can be improved or extended.
- Suggestions for future research that can build on the work carried out.

Table 1 illustrates the mapping of the proposed objectives with the chapters of this thesis.

Table 1 - Mapping between specific objectives and thesis chapters.

Objective	**Chapter 2**	**Chapter 3**	**Chapter 4**	**Chapter 5**	**Chapter 6**	**Chapter 7**	**Chapter 8**
1	x						
2		x					
3		x					
4			x				
5			x				
6				x			
7				x			
8				x			
9					X		
10						x	
11							x

Next, we present the central research question and the research hypotheses that guided this work.

1.4. Research Question and Research Hypotheses

The creation of the research theme marks the inception of the investigative project (Ghauri & Grønhaug, 2005). Scientific inquiry commences with defining the problem, aiming to resolve it. For the present study, the problem can be articulated with the following research question.

Central Research Question:

- **How do user needs, within the context of stakeholders, influence decisions regarding the sustainable viability of Robotic Process Automation (RPA), and how can this relationship be incorporated into a multi-objective optimization model to assess the effectiveness of sustainable RPA implementation?**

Alongside this research question, the following hypotheses are presented.

Investigation Hypotheses:

1. What are the user requirements within the context of stakeholders that impact decisions concerning the sustainable viability of RPA systems?

2. Considering user requirements within the context of stakeholders significantly affects the decision about the sustainable viability of RPA systems?

3. Identifying and analysing user requirements within the context of stakeholders enables a more precise evaluation of the sustainable viability of RPA systems?

4. Incorporating the relationship between user requirements and stakeholders in a multi-objective model permits a comprehensive assessment of the efficiency of sustainable RPA system implementation?

5. Identifying and analysing the primary challenges and obstacles users encounter when adopting RPA enables the development of tailored solutions to meet their needs?

6. Will the proposed guidelines for sustainable and efficient RPA implementation, based on the case study results and data analysis, prove beneficial for organizations seeking to adopt RPA in an economical and sustainable manner?

7. Will the research findings and contributions to the scientific community and industry professionals yield significant benefits in advancing the field of RPA?

These hypotheses will be explored throughout the research, with the aim of comprehending how user requirements and their interaction with stakeholder's impact decisions regarding the sustainable viability of RPA systems, as well as delving into the utility of a multi-objective model in efficiently and sustainably evaluating its implementation.

1.5. Research Methodology

Scientific methodology is linked to the method and to science. The method, which literally means "path to achieving an objective" (from the Greek "methodos"), defines a path to reach a goal and involves a series of activities, techniques, and sequential actions. The methodology comprises rules and procedures based on logical principles, crafted to achieve a set of objectives. The method, therefore, is the procedure or set of systematic and rational activities used to achieve the goals of a particular project, with its study being the focus of the methodology. The methodology goes beyond process description, encompassing the methods and techniques to be employed. According to Minayo (2007), methodology is the epistemological discussion on the "path of thought" required by the research object, the justified presentation of methods, techniques, and instruments, and the researcher's personal mark derived from creativity.

Singleton and Straits (1999) classify research methods according to associated research strategies:

1. **Experimental research method:** involving the manipulation of an environment and subsequent observation to detect systematic changes.
2. **Questionnaire-based method:** aiming to identify characteristics in groups or target populations.
3. **Field method:** where the researcher embeds themselves in the set of events occurring and from which they seek knowledge, collecting information without influencing the environment.
4. **Action method:** wherein the researcher applies a positive intervention to the environment and observes changes in themselves and the observed environment.

Two essential research perspectives exist: the quantitative and the qualitative perspective. Qualitative research focuses on aspects of reality that cannot be quantified. Its empirical nature, together with the specific subjectivity and the propensity for the researcher's reflection profile, are subjects of targeted criticism towards qualitative research (Martins, 2004). On the other hand, quantitative research is based on results that can be quantified and is generally associated with defining representative samples, assuming that the results represent the target population. Quantitative research centers on objectivity, believing that reality can only be understood through the analysis of data collected from a representative sample, using instruments with appropriate precision.

While the quantitative perspective relies on numerical expression of an objective reality, promoting experimental studies where measurements and relationships are established, qualitative research is more descriptive, based on a phenomenological view, focusing on processes and meanings, and more open (Bogdan & Biklen, 1999).

Table 1 - Comparison between Quantitative and Qualitative Assessment Perspectives.

Qualitative	**Quantitative**
Observation	Measurement and control
Holistic view	Specific view
Greater emphasis on context	Lesser emphasis on context
Researcher acknowledges mutual influence of personal experience and science	Researcher strives to be emotionally neutral
Process-focused	Results-focused
Subjective nature of phenomena is taken into account	Considers only aspects that can be measured, observed, and quantified
Descriptive, inductive, and exploratory	Deductive, inferential, and confirmatory
"Rich" and "profound" data	"Solid" and "repeatable" data
Dynamic reality	Static reality

In qualitative research, various methods are employed, with a focus on case study and action research. Action research is a highly dynamic method aimed at supporting the study of a system, enabling the researcher to take an active role as a participant in the research itself (Baskerville & Myers, 2004). The term "change" pertains to both alterations in the subject under study and the transformation of the researcher themselves. Therefore, based on the results obtained throughout the research, it's possible that the researcher may be asked to adapt their approach during the course of their work. These changes are recorded and documented as qualitative observations, which will be utilized in subsequent iterations.

Several authors have proposed different models for the action research method, concerning the steps that comprise it. In this research study, we have adopted the model proposed by Susman and Evered (1978), which includes five essential steps in each investigation cycle:

1. Diagnosis, wherein the problem to be solved is identified and defined;
2. Action planning, wherein alternative solutions to the problem and the associated actions are identified;
3. Action execution, wherein one of the alternative solutions identified in the previous step is selected;
4. Evaluation, wherein the results of the executed action are observed;
5. Learning, wherein the results of the observation conducted in the preceding step are used to create or update the theoretical or conceptual model of the solution under investigation.

Figure 2 illustrates the cycle comprised of these five essential steps.

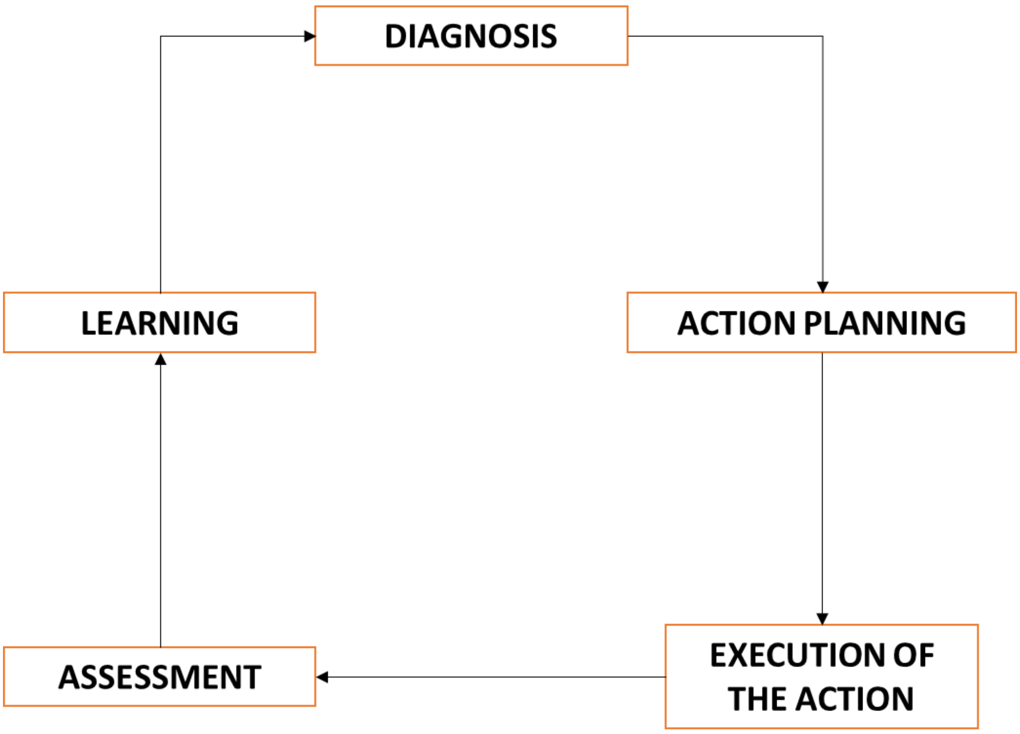

Figure 2 - Phases of the Action Research Method (Susman & Evered, 1978).

This investigative process follows a recurring pattern, repeating itself through several iterations, which can be visually represented by means of a spiral, as illustrated in Figure 3. In each iteration, the understanding of the studied problem deepens, the problem's definition is established or updated, a set of actions is planned with the aim of achieving the solution, these actions are put into practice, and the results are assessed. This evaluation can lead to the start of a new cycle, in which the problem is reformulated based on the results obtained in the previous cycle. This cycle repeats itself until the solution to the analysed problem is achieved.

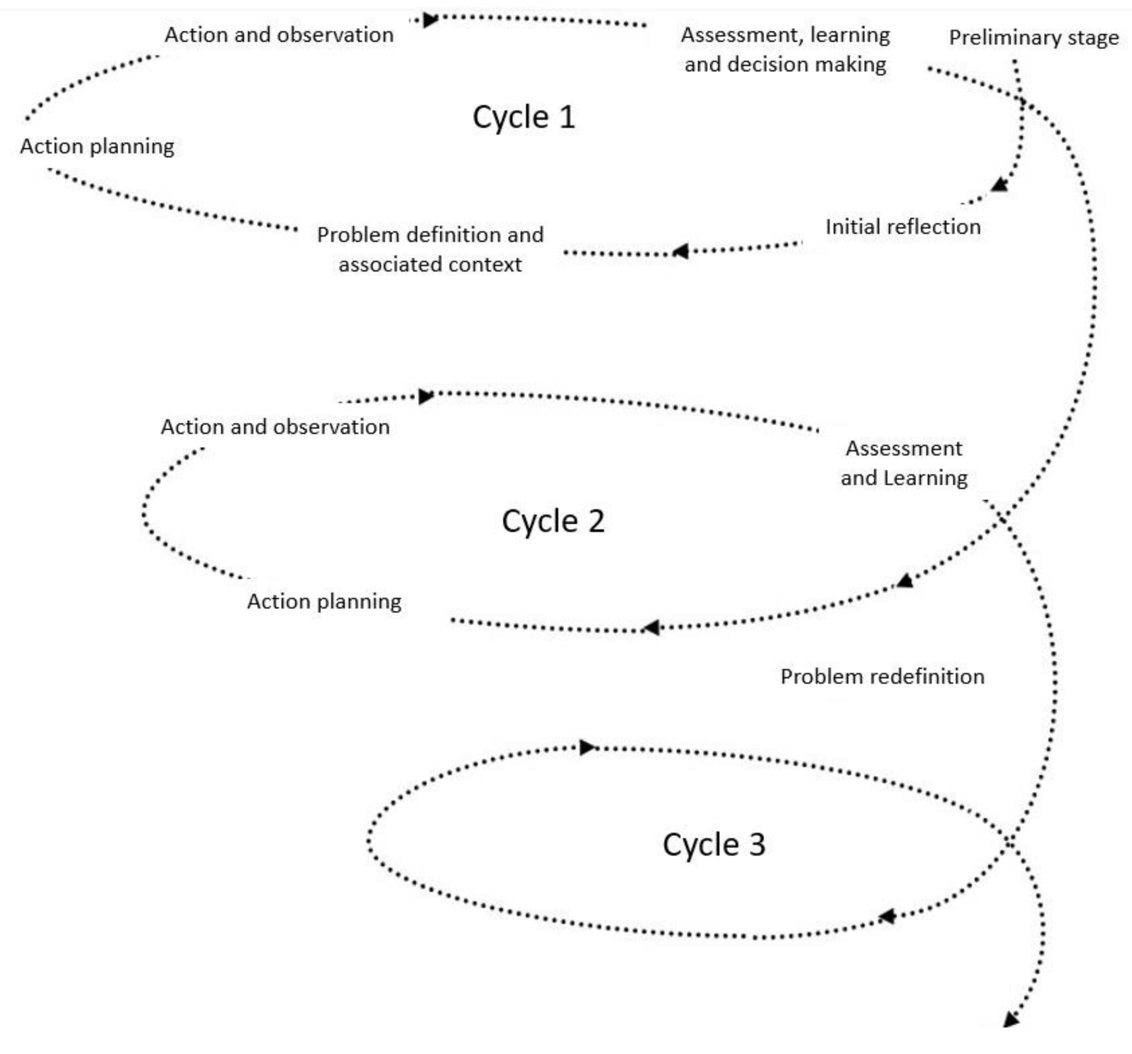

Figure 3 - Lewinian self-reflective spiral (adapted from Lavoie, et al., 2006).

The action research approach has its roots in the fields of social sciences and education, with Lewin (1946) being attributed a pioneering role in this field (Argyris, et al., 1985; Checkland, 1981). Over the years, its usage has significantly grown, especially in the mentioned domains, although it has not escaped criticisms (Susman & Evered, 1978; Oquist, 1978). These criticisms are mainly related to a certain confusion between action research and consultancy (a topic addressed by

Westbrook, 1995, and Coughlan & Coghlan, 2002, highlighting the differences between the two concepts). Additionally, the evaluation of this method has also been debated (Checkland & Holwell, 1998; Winter, 2002; McInnes, et al., 2007).

Mumford brought action research into the field of information systems by developing a system development technique called ETHICS, based on this approach (Mumford & Weir, 1979). According to Kock (2003), Checkland also contributed to the application of the action research methodology in the domain of information systems. Wood-Harper (1985) incorporated the concepts associated with action research into a system development methodology called Multiview.

The active participation of the researcher as an intervening element in the action research process was the reason that led to choosing this doctoral project. In practice, the action research cycle can be seen as an adaptation of the plan-do-check-act cycle proposed by Deming (1997). By carrying out multiple cycles of planning, execution, recognition or identification of facts, evaluation, and planning of the next step (as described by Lewin, 1946), cycles of research will be conducted that gradually approach the final solution.

1.6. Research Plan

The work plan encompasses the execution of three sets of practical research, which can be synthesized by Figure 4.

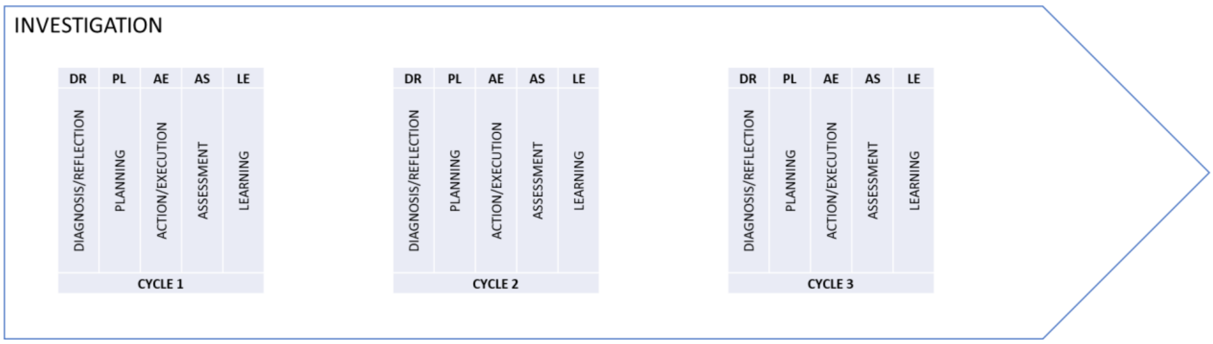

Figure 4 - Planned cycles of action research.

Regarding the research cycles, the fifteen associated activities are enumerated below:

Cycle 1:

- *In the initial stage of the research process, the project objectives are first identified, encompassing the following aspects:*
  - i) Clear formulation of the research question and pertinent hypothesis formulation.
  - ii) Definition of the research methodology to be adopted.
  - iii) Establishment of the overarching objectives associated with the project in question.
  - iv) Precise delimitation of the specific goals to be achieved.
- *This is followed by an analysis of the state of the art concerning Industry 4.0 and Sustainability:*
  - i) A detailed analysis is conducted on the concept of Industry 4.0, addressing its challenges, opportunities, and considerations on sustainability.
- *Next, a comprehensive analysis is conducted on the state of the art related to Robotic Process Automation (RPA) technology:*
  - i) A thorough analysis of the concept of RPA is carried out.
  - ii) The inherent benefits of applying RPA technology are identified.
  - iii) An exhaustive review of the existing literature addressing RPA-related models is undertaken.
- *Finally, a detailed analysis of the state of the art within the realm of planning, scheduling, and multi-objective problems is conducted:*
  - i) Fundamental concepts and their applicability in decision-making are addressed.
  - ii) Techniques and methods commonly employed in resolving these types of problems are identified.
- *This stage culminates in the formulation of the doctoral project.*

Cycle 2:

- *In the second research cycle, the description of the problem under study is initiated, along with the presentation of the case study and the collection of pertinent data:*
  - i) A thorough analysis of the specific case study is carried out.
  - ii) User requirements are defined, taking into consideration the diverse stakeholders influencing the feasibility of RPA systems.
- *This is followed by the formulation of a mathematical model for multi-objective optimization:*
  - i) The mathematical problem to be addressed is rigorously defined.

ii) Selection of the most suitable platform for implementing the developed model is carried out.

- *Concurrently, a concrete approach for model implementation is delineated:*

i) A comprehensive review of the state of the art concerning identified implementation approaches is conducted.

- *During this phase, an update of the literature review is also undertaken, along with the publication of relevant scientific articles.*

Cycle 3:

- *The third research cycle is centred around the effective implementation of the developed model, considering two distinct scenarios:*

i) Scenario 1: Utilization of the weighted sum method.

ii) Scenario 2: Application of the Tchebyshev method.

- *Following implementation, the analysis and interpretation of results obtained in each of the scenarios are conducted:*

i) In Scenario 1, where the weighted sum method was adopted.

ii) In Scenario 2, where the Tchebyshev method was applied.

- *Validation of results is achieved through appropriate statistical analysis, encompassing the following phases:*

i) Definition of the statistical analysis to be conducted.

ii) Evaluation of the performance of the proposed approach based on the results obtained.

iii) Issuance of conclusions derived from this validation.

- *In this final stage, further scientific articles are published, and the writing of the thesis, which encapsulates the entire undertaken work, is carried out.*

Table 3 clarifies the various stages that comprise the practical research process, adapted to the current situation.

Table 3 - Stages of the research process implemented in the thesis chapters.

Cycle	Chapter 2	Chapter 3	Chapter 4	Chapter 5	Chapter 6	Chapter 7	Chapter 8
1	x	x	x				
2			x	x	x		
3					x	x	x

1.7. Implementation of the Research Project

After a clear definition of the research problem, an in-depth initial literature review was conducted. Subsequently, the research methodology that guided the project's execution was selected. The three research cycles were completed, as evidenced in Figure 5.

During the first cycle, an exploration of the state of the art in the realm of Industry 4.0 and Sustainability was undertaken. Furthermore, a comprehensive study of Robotic Process Automation (RPA) technology was carried out. Additionally, a meticulous examination of the current landscape pertaining to production planning, scheduling challenges, and multi-objective issues was conducted. Within the same initial cycle, a proposal for the doctoral project was formulated, subsequently presented and defended within the Department of Production and Systems at the University of Minho.

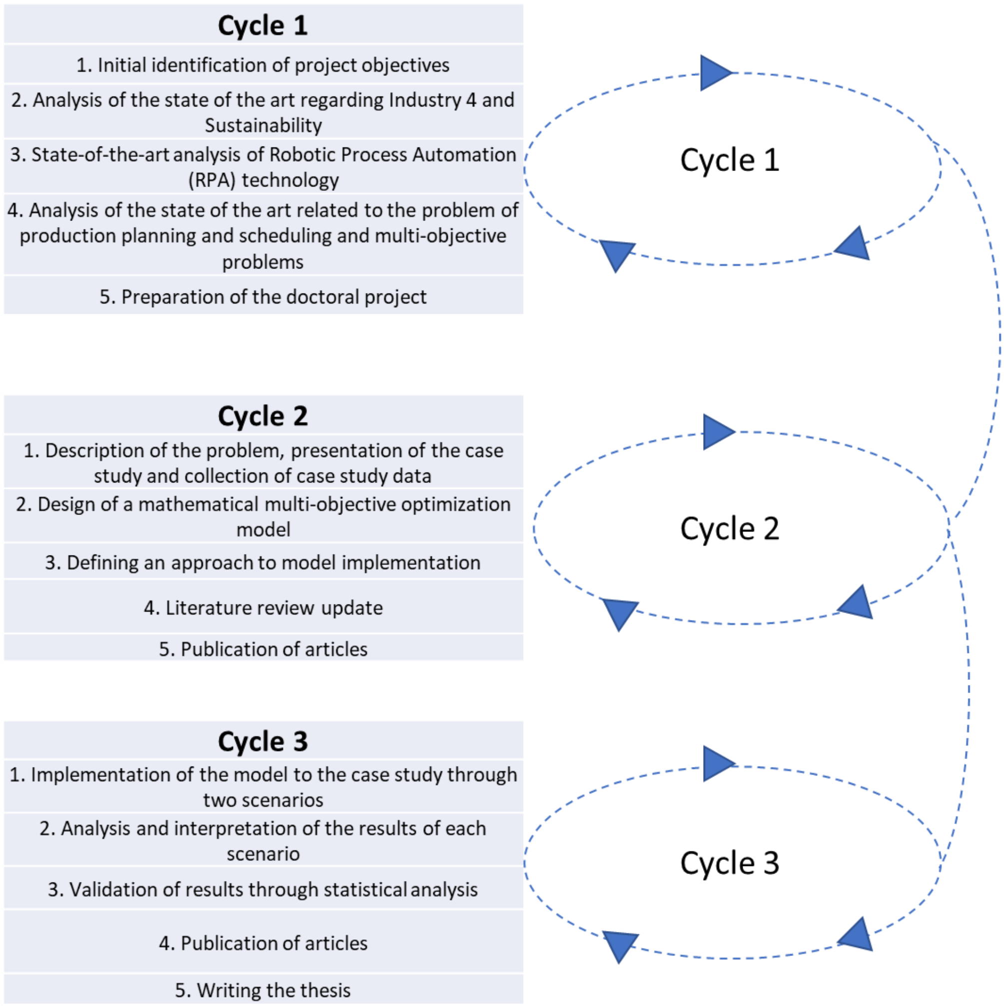

Figure 5 - Cycles of the action research method conducted in the doctoral project.

We proceeded to the second research cycle, during which the problem description was outlined, the case study was presented, and data from the said case study was collected. Simultaneously, the formulation of user requirements was undertaken in the context of stakeholders who influence the decision-making regarding the feasibility of RPA systems. After this step, the design of the multi-objective optimization model was carried out. Throughout this second cycle, several articles related to the ongoing research were published (refer to Leonel's article list).

The third and final cycle of the research project commenced with the implementation of the model in the case study, encompassing two distinct scenarios. Subsequently, an analysis and interpretation of the results obtained in each of these scenarios were conducted. Finally, a statistical analysis was performed along with the corresponding conclusions. The completion of the third cycle culminated in the composition of the present thesis and the publication of relevant articles (consult Leonel's article list). The final results of the undertaken research are summarized in Figure

6.

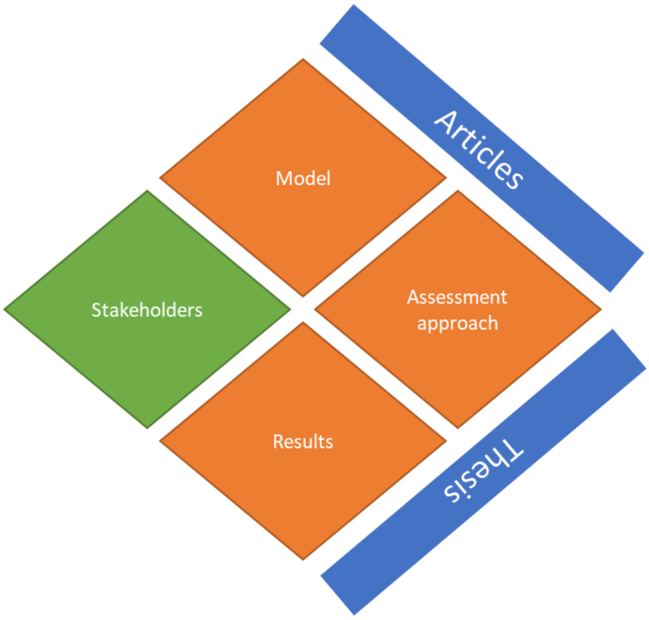

Figure 6 - Deliverables associated with the doctoral project.

The multi-objective optimization model proposed here, along with the results, have been regarded as the primary outcomes of the work carried out. The approach to evaluating the results chosen for this study allows for the future implementation of the model and its assessment, following the same criteria used to ascertain the conclusions related to the defined objectives.

1.8. Thesis Organization

This thesis is divided into eight chapters, which are structured according to the framework outlined in this section.

In the **first chapter**, the doctoral project is introduced, addressing its initial context. The objectives and central research question are defined, along with the corresponding research hypotheses. The adopted research methodology is described, and the project execution plan is presented.

The **second chapter** delves into the concepts associated with Industry 4.0, discussing the inherent challenges and opportunities, while also integrating the concept of sustainability.

The **third chapter** conducts an analysis of the state of the art concerning Robotic Process Automation (RPA) technology.

The **fourth chapter** focuses on analysing the state of the art related to the planning and scheduling problem, as well as multi-objective challenges.

In the **fifth chapter**, the problem is described, the case study is presented, and the corresponding data is collected. Subsequently, the user requirements are defined in the context of stakeholders who influence the decision-making about the sustainable viability of RPA systems. Following this, the mathematical model for multi-objective optimization is presented, along with the formulation of the mathematical problem.

The **sixth chapter** centres on implementing the model within the case study, considering two distinct scenarios.

In the **seventh chapter**, the obtained results are analysed, and a statistical study is conducted to arrive at well-founded conclusions.

The **eighth chapter** is devoted to presenting the conclusions of the work undertaken. This is followed by the inclusion of the author's bibliography and used references, concluding the document with the relevant appendices.

2. INDUSTRY 4.0 AND SUSTAINABILITY

With the advancement of technology and the emergence of Industry 4.0, it becomes absolutely crucial to address the significance of sustainability within this context. The purpose of this chapter is to delve into the intersection between Industry 4.0 and sustainability, highlighting the benefits of implementing sustainable principles in the industry, as well as the challenges and obstacles encountered in this implementation. Furthermore, concrete applications of Industry 4.0 will be presented with a focus on sustainability. Likewise, the challenges and opportunities that Industry 4.0 offers for sustainability will be discussed, including an assessment of adverse impacts and the identification of opportunities to foster sustainable practices in this context. Lastly, the key technologies, methodologies, frameworks, tools, and techniques of intelligent and sustainable systems applicable to Industry 4.0 will be showcased. By recapping the essential points discussed and summarising the contributions from existing literature, this chapter will also provide suggestions for future research in this ever-evolving field.

2.1. Theoretical Foundatios

> *Industry 4.0 is the fourth industrial revolution, a new way of organizing and managing production that relies on the convergence of digital technologies, including the Internet of Things (IoT), artificial intelligence (AI), and robotics* (Deloitte, 2017).

Industry 4.0 is a technological revolution that is reshaping the industrial landscape worldwide. Rooted in the digitization and automation of production processes, it leverages cutting-edge technologies such as the Internet of Things (IoT), artificial intelligence, big data, and cloud computing (Kagermann, Wahlster, & Helbig, 2013). This transformation holds the potential to enhance the efficiency, productivity, and competitiveness of enterprises, while fostering innovation and spawning novel business models (Ávila, et. al., 2021).

However, to fully grasp the impact of Industry 4.0, it is crucial to contextualize it within a broader panorama. The first industrial revolution emerged in the 18th century with the mechanization of production processes, notably in the textile industry. The second industrial revolution, in the late 19th century, introduced electrification and mass production. The 20th century witnessed the third industrial revolution marked by process automation and computerization with the advent of computers (Rifkin, 2011).

Industry 4.0 signifies the next phase in this industrial evolution, characterized by the interconnectedness of physical and digital systems, real-time data collection and analysis, and autonomous decision-making by machines. It fosters the integration of the entire value chain, spanning from product conception to commercialization, encompassing development, production, and logistics (Lasi, et al., 2014).

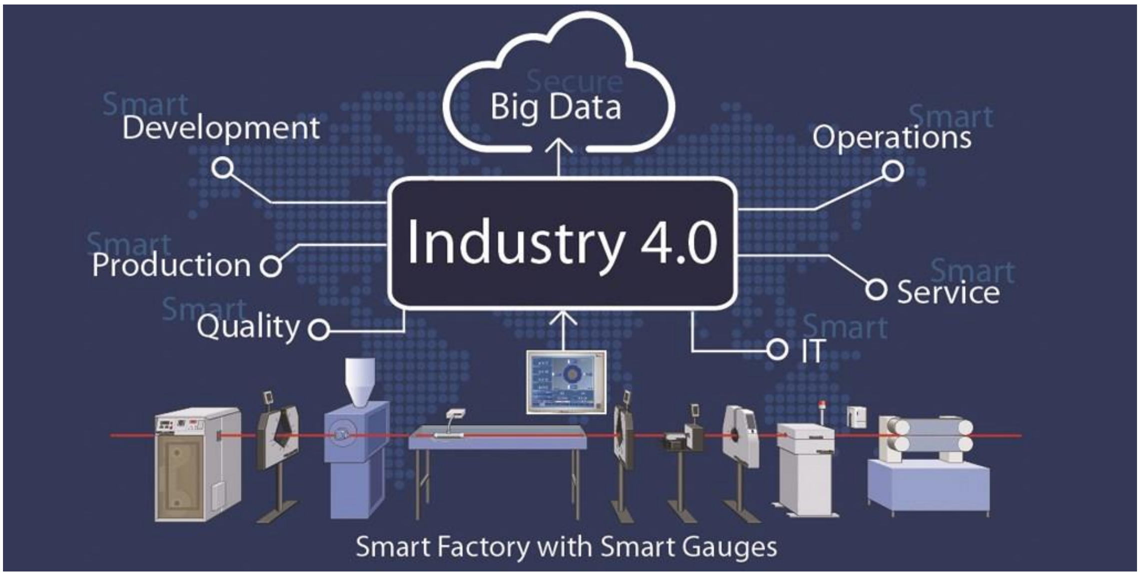

Figure 7 - smart factory with Industry 4.0 technologies (Luis, J., 2020).

The fourth industrial revolution brings forth manifold opportunities, as well as significant challenges. One such challenge revolves around sustainability. As technology advances and businesses embrace the tenets of Industry 4.0, it is imperative for this transformation to be underpinned by a sustainable approach.

The significance of sustainability in the era of Industry 4.0 cannot be underestimated. Sustainability entails the pursuit of practices and technologies that promote balanced economic, social, and environmental development (World Commission on Environment and Development, 1987). This implies that enterprises must consider not only economic aspects such as efficiency and profitability but also social and environmental facets.

From a social perspective, Industry 4.0 engenders concerns related to employability. The automation and digitization of production processes hold the potential to supplant human workers with machines. This may lead to unemployment and heightened social inequality. Hence, it is pivotal for companies to adopt social responsibility policies and explore alternatives to mitigate negative societal impacts, such as retraining affected workers (Schwab, 2017).

Industry 4.0 presents opportunities for optimizing production processes, resulting in significant reductions in energy consumption and the use of natural resources (Papaioannou, et al., 2020). Through real-time monitoring and data analysis, companies can identify areas of waste and implement corrective measures. This encompasses the deployment of intelligent sensors for lighting and climate control, efficient energy management systems, and the development of more sustainable materials and products (Hermann, Pentek, & Otto, 2016).

According to Schwab, it can be seen that,

> *The fourth industrial revolution is fundamentally changing the way we live, work, and produce. It is imperative that we harness this transformation to create a sustainable future. This means ensuring that Industry 4.0 technologies are used to promote economic growth, social equity, and environmental protection* (Schwab, K., 2017).

Furthermore, Industry 4.0 enables the creation of circular economy business models. Via digitization and information sharing, collaborative networks among companies can be established, promoting the reuse, recycling, and remanufacturing of products (Gyulai, 2021). This diminishes reliance on virgin natural resources and minimizes waste generation, contributing to environmental preservation.

It is crucial to underscore that sustainability should not be viewed merely as a regulatory requirement or a marketing strategy, but rather as an ethical commitment and a competitive advantage. Consumers are increasingly discerning and conscious, valuing companies that embrace sustainable practices (Porter & Kramer, 2011). Furthermore, the pursuit of innovative and sustainable solutions can yield long-term economies, reducing operational costs and bolstering the resilience of enterprises.

In summary, Industry 4.0 heralds a technological revolution that is reshaping our modes of production and consumption. Nonetheless, for this transformation to be genuinely beneficial, it must be accompanied by a sustainable approach. Sustainability in the era of Industry 4.0 entails considering not only economic aspects but also social and environmental dimensions, striving for equilibrium between industrial development and planetary preservation. By adopting sustainable practices, companies can contribute to a fairer, more prosperous, and environmentally responsible future.

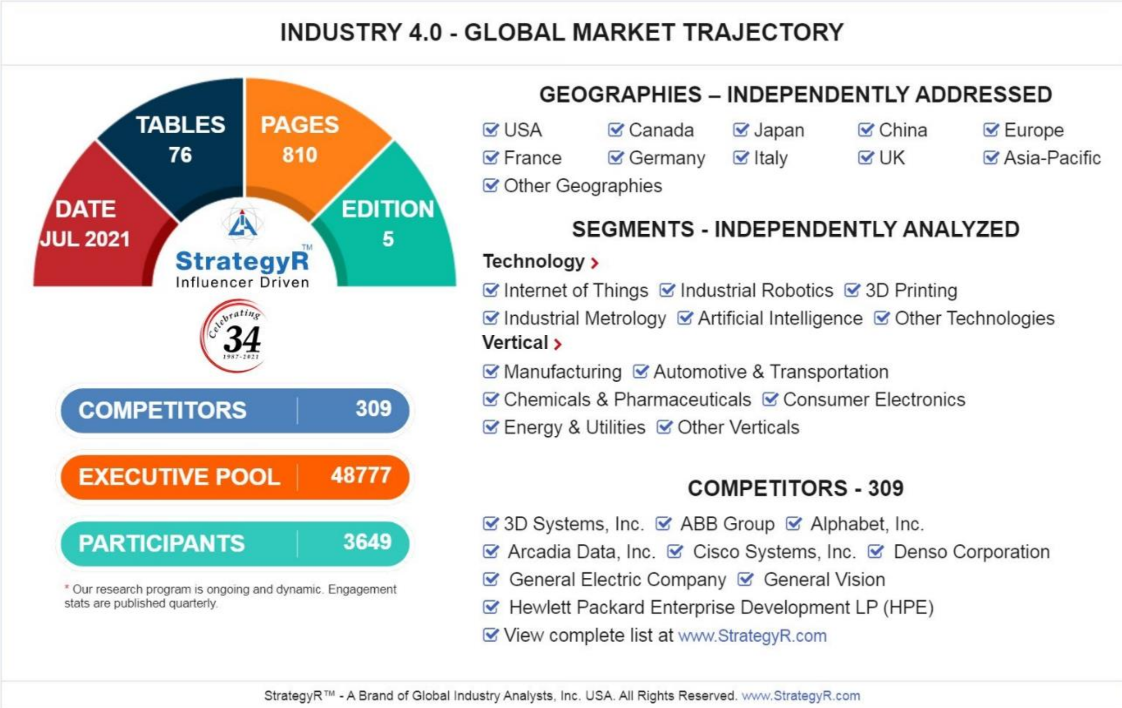

Figure 8 - Industry 4.0 - Global Market Trajectory (Global Industry Analysts, Inc., 2021).

The objective of this chapter is to explore the intersection of Industry 4.0 and sustainability, highlighting the benefits of applying sustainable principles to industry, as well as the challenges and obstacles faced in their implementation. Additionally, practical applications of Industry 4.0 with an emphasis on sustainability will be presented. The challenges and opportunities that Industry 4.0 offers for sustainability will also be discussed, including an assessment of negative impacts and the identification of opportunities to promote sustainable practices within this context. Finally, key technologies, methodologies, frameworks, tools, and techniques for intelligent and sustainable systems applicable to Industry 4.0 will be presented, along with sustainability criteria for decision-making among partners in collaborative networks. Summarizing the key points addressed and synthesizing contributions from existing literature, this chapter will also provide suggestions for future research in this ever-evolving domain.

Industry 4.0 is a term that has emerged to describe the fourth industrial revolution, characterized by the convergence of digital technologies, advanced automation, and system integration in the industrial domain (Schwab, 2016). This revolution brings forth a set of key concepts that are essential to grasp and implement Industry 4.0 (Carillo, Dwivedi, & Kumar, 2020).

One of the pivotal concepts within Industry 4.0 is the Internet of Things (IoT), which pertains to the interconnection of physical devices through sensors, networks, and software. Through IoT, machines, products, and systems can communicate and exchange information in real-time, enabling heightened efficiency and more precise decision-making (Porter & Heppelmann, 2014).

Another pivotal concept is cloud computing, enabling the remote storage and processing of substantial data volumes. This allows rapid and flexible access to pertinent information and facilitates collaboration among various entities involved in an industrial process (Lasi, et al., 2014).

Additive manufacturing, better known as 3D printing, stands as another key concept of Industry 4.0. This technology permits the creation of three-dimensional objects from digital models, eliminating the necessity for specific molds or tools. Additive manufacturing offers greater production flexibility, thus reducing costs and manufacturing time (Lasi, et al., 2014).

Beyond these concepts, Industry 4.0 is founded upon several fundamental principles. One of these is interoperability, referring to the capacity of systems and devices to efficiently connect and communicate. This enables information exchange and integrated control of various aspects of the production process (Asif, Fuchs, & Pigni, 2018).

Another principle is virtualization, involving the creation of digital replicas of products, processes, and systems. These virtual replicas permit simulations and testing prior to physical implementation, thereby reducing risks and enhancing efficiency.

Decentralization constitutes another crucial principle within Industry 4.0. With decentralization, autonomous systems make decisions, possessing their own processing and decision-making capabilities. This allows for greater agility and flexibility in production, as well as facilitating adaptation to rapid changes within the industrial environment (Porter & Heppelmann, 2014).

Modularity is another key principle in Industry 4.0, where systems and processes are divided into independent modules that can be reconfigured according to specific needs. This allows for greater product and process customization, catering to individual customer demands (Porter & Heppelmann, 2014).

Lastly, sustainability is a pivotal dimension of Industry 4.0. With increasing environmental concerns and natural resource constraints, the industry is progressively focused on adopting sustainable practices. Industry 4.0 presents opportunities to reduce energy consumption, optimize production processes, and use natural resources more efficiently. Through the application of intelligent technologies such as real-time monitoring sensors and data analysis, it is possible to identify and rectify waste and inefficiencies within industrial processes.

Furthermore, Industry 4.0 promotes the implementation of renewable energy solutions, such as solar panels and energy harnessing systems, thereby decreasing reliance on non-renewable sources and contributing to carbon footprint reduction (Carillo, Dwivedi, & Kumar, 2020).

Another significant aspect of sustainability within Industry 4.0 is the promotion of circular economy principles. Through digitization and connectivity, more efficient waste management systems can be created, enabling recycling and reuse of materials, prolonging their lifespan and reducing environmental impact.

Additionally, Industry 4.0 is intertwined with social responsibility and concern for working conditions. Automation and collaborative robotics can minimize accident risks and create safer and healthier working environments. Furthermore, technology can contribute to empowering and developing workers, preparing them for the novel demands of the modern industry (Frey & Osborne, 2017).

To sum up, Industry 4.0 is defined by a range of key concepts such as the Internet of Things, cloud computing, and additive manufacturing. These concepts are propelled by principles such as interoperability, virtualization, decentralization, and modularity, promoting efficiency and flexibility within industrial processes (Asif, Fuchs, & Pigni, 2018).

Moreover, Industry 4.0 embraces the dimension of sustainability, aiming to reduce energy consumption, optimize production processes, adopt circular economy practices, and promote social responsibility. Thus, Industry 4.0 not only drives technological advancement but also seeks to ensure a more sustainable and balanced future for both industry and society at large (Frey & Osborne, 2017).

The implementation of Industry 4.0 brings about an array of benefits and challenges. Among the benefits are improved operational efficiency, increased productivity, cost reduction, mass customization, and the creation of new business models. By embracing advanced technologies and system integration, companies can optimize processes, minimize errors, enhance product quality, and respond more swiftly to market demands (Lasi, et al., 2014).

Furthermore, Industry 4.0 offers the potential to create highly personalized products and services, catering to individual customer needs. Through the collection and analysis of vast amounts of data, it becomes possible to comprehend consumer profiles, preferences, and behaviours, thereby enabling the creation of tailored offerings and personalized experiences.

However, the implementation of Industry 4.0 also presents significant challenges. One of these is the need for technology and infrastructure investments. Transitioning to Industry 4.0 necessitates the upgrading and integration of systems, acquisition of advanced equipment, and employee training. This demands substantial financial resources and strategic planning on the part of companies.

Furthermore, cybersecurity is a paramount concern within Industry 4.0. With increasing connectivity and data exchange between devices and systems, the risks of cyberattacks and security breaches escalate. Companies must adopt robust protective measures such as data encryption, authentication systems, and continuous monitoring to ensure information integrity and confidentiality.

Another challenge is the adaptation of workers to the new reality of Industry 4.0. Automation and the introduction of advanced technologies require proper training and skill development for employees to handle new demands and perform tasks complementary to machines. Qualification and requalification of professionals are essential to ensure a smooth transition and foster a collaborative work environment between humans and machines.

Furthermore, considering the social impacts of Industry 4.0 is crucial. Automation and digitization can lead to the displacement of certain functions and even job reductions in specific sectors. Careful planning and appropriate policies are required to mitigate negative impacts and ensure a fair and inclusive transition for all stakeholders.

In conclusion, Industry 4.0 constitutes an industrial revolution encompassing key concepts, principles, and challenges. Through the adoption of advanced technologies, system integration, and a focus on sustainability, it holds the potential to profoundly transform how we produce, work, and interact with the world around us. Maximizing its benefits and overcoming its challenges necessitates a strategic, collaborative, and adaptable approach from both companies and society as a whole (Frey & Osborne, 2017).

2.2. Relationship between Industry 4.0 and Sustainability

The significance of incorporating sustainability into Industry 4.0 has been increasingly evident, as the demand for responsible and sustainable practices has become a global necessity. Industry 4.0, characterized by the digital interconnection of production processes and the use of advanced technologies, presents significant opportunities for applying sustainable principles, resulting in benefits across environmental, social, and economic domains (Patrício, et. al., 2022c).

The implementation of sustainable principles in Industry 4.0 brings forth various advantages that positively impact organizations and society at large. Regarding the environment, a notable advantage is the reduction in energy, water, and raw material consumption. The utilization of intelligent and efficient technologies enables the optimization of production processes, minimizing waste and environmental impact. Additionally, the integration of renewable energy sources like solar and wind contributes to greenhouse gas emission reduction.

From a social perspective, the adoption of sustainable practices in Industry 4.0 can generate new employment opportunities and promote the development of skills and knowledge related to digital technologies and sustainability. Furthermore, a focus on sustainability can enhance the reputation of companies, bolstering their image and increasing the trust of consumers and investors (Baines, et al., 2017).

In the economic realm, the integration of sustainability into Industry 4.0 can lead to greater operational efficiency and cost reduction. The optimization of production processes, coupled with smarter resource utilization, results in heightened productivity and competitiveness. Additionally, embracing sustainable practices can open doors to new markets and attract customers who value socio-environmental responsibility (Hermann, et al., 2016).

However, the application of sustainable practices in Industry 4.0 also faces challenges and obstacles. One of the primary challenges is the need for substantial investments in technology and infrastructure. The transition to a more sustainable industry necessitates adopting advanced equipment and systems, as well as training employees to handle these technologies. Furthermore, the collection and analysis of large-scale data, crucial for implementing sustainable practices, demand robust and secure Information Technology systems (Baines, et al., 2017).

Another obstacle is the resistance to change from both companies and employees (Behrendt, et al., 2020). The shift toward a more sustainable industry often entails changes in production processes, organizational culture, and work methodologies. It is imperative that companies foster a change in mindset and encourage active employee participation in this process (Schumacher, et al., 2018).

Moreover, the absence of specific norms and regulations for the application of sustainable practices in Industry 4.0 can also hinder progress. The lack of clear and standardized guidelines complicates the consistent and comprehensive adoption of sustainable practices (Behrendt, et al., 2020). It is crucial for governments and regulatory entities to develop policies and norms that encourage and guide companies in integrating sustainability into their production processes (Hermann, et al., 2016).

Additionally, cybersecurity remains a constant concern in Industry 4.0, and the integration of sustainability can heighten system complexity, thereby increasing vulnerability to cyberattacks. Ensuring data protection and operational security is essential, involving appropriate security measures to mitigate potential threats (Baines, et al., 2017).

Collaboration and cooperation among companies are also crucial to overcome the challenges of implementing sustainable practices in Industry 4.0. Sharing knowledge, best practices, and experiences can accelerate the adoption of sustainable solutions and foster innovation (Tchouvelev & Kiritsis 2018). Partnerships among businesses, governments, academia, and civil society are fundamental in driving the transition to a more sustainable industry and ensuring tangible outcomes.

To surmount obstacles and capitalize on the benefits of integrating sustainability into Industry 4.0, a strategic commitment from organizations is essential (Pigosso, et al., 2017). Companies must establish clear and measurable sustainability-related objectives, integrating them into their vision, mission, and values. Additionally, involving all hierarchical levels within the organization, from top management to frontline employees, is vital to ensure engagement and participation (Hermann, et al., 2016).

In summary, the integration of sustainability into Industry 4.0 is of utmost relevance today. The environmental, social, and economic benefits stemming from sustainable practices are evident (Pigosso, et al., 2017). However, the implementation of these practices faces challenges such as technology investments, resistance to change, lack of clear regulation, and cybersecurity concerns. Through business collaboration and strategic actions, it is possible to overcome these obstacles and achieve a more sustainable industry capable of meeting current and future societal demands (Baines, et al., 2017).

Transitioning to a more sustainable industry requires a holistic approach, considering not only environmental aspects but also social and economic ones (Tchouvelev & Kiritsis, D., 2018). It is essential for companies to incorporate sustainability at all stages of their production processes, from product design and development to production, distribution, and disposal (Tao, et al., 2018). In terms of product design, Industry 4.0 offers opportunities to create more sustainable products (Porter & Heppelmann, 2014). The use of eco-friendly materials, reduction in toxic substance use, and the application of circular economy strategies like recycling and reusability are essential elements for product sustainability. Furthermore, digitization and the Internet of Things enable the monitoring of product lifecycles, facilitating the identification of improvement opportunities and resource optimization (Tao, et al., 2018).

Regarding production processes, Industry 4.0 enables the adoption of more efficient and sustainable practices (Porter & Heppelmann, 2014). Automation and collaborative robotics reduce the need for manual labor and minimize human errors, leading to increased productivity and reduced energy consumption. Additionally, real-time data analysis allows for the monitoring of equipment performance, identifying improvement opportunities, and preventing failures and waste (Schumacher, et al., 2018).

Logistics and the supply chain can also benefit from the incorporation of sustainability into Industry 4.0 (Porter & Heppelmann, 2014). The use of intelligent algorithms and tracking technologies enables the optimization of transport routes, reducing fossil fuel consumption and emissions of pollutants. Additionally, implementing reverse logistics practices and partnering with suppliers committed to sustainability contribute to reducing environmental impact throughout the production chain (Schumacher, et al., 2018).

Despite the benefits and opportunities offered by incorporating sustainability into Industry 4.0, it's crucial to recognize that transitioning to a more sustainable industry requires a collective and continuous effort. Raising awareness and education about the importance of sustainability should be disseminated at all levels of society, encouraging a change in mindset and engaging all stakeholders (Schumacher, et al., 2018).

Additionally, it is imperative for governments to play an active role in promoting sustainability in Industry 4.0. Creating public policies and implementing fiscal and financial incentives can encourage companies to adopt sustainable practices. Moreover, clear and uniform regulations must be established to ensure that companies adhere to sustainability principles and guidelines (Tao, et al., 2018).

In conclusion, the integration of sustainability into Industry 4.0 is pivotal for the development of a more responsible industrial landscape. Accomplishing this integration necessitates collaborative efforts from businesses, governments, and other stakeholders, alongside strategic initiatives and an unwavering dedication to change. Only through such combined endeavours can an industry be fostered that can adequately address the exigencies of the present without compromising the prospects of generations to come.

2.3. Applications of Industry 4.0 for Sustainability

> *Sustainability 4.0 is being enabled through the effective adoption of modern technologies such as the Internet of Things (IoT), Artificial Intelligence (AI), Machine Learning (ML), Machine Vision (MV), Data Analytics (DA), Additive Manufacturing (AM) and other modern technologies. These technologies enable services at significantly lower prices due to the effective use of energy and resources with lesser wastage. Manufacturers are constantly looking for methods to lower the operating expenses associated with production processes* (Javaid, et al., 2022).

Industry 4.0, a concept encompassing the digitization and interconnection of production systems, is playing a pivotal role in the pursuit of sustainable practices and the reduction of environmental impact (Hermann, Pentek, & Otto, 2016). Through the application of advanced technologies, Industry 4.0 has brought about significant improvements in energy efficiency and waste reduction, establishing itself as a key ally in the quest for a more sustainable future (Porter, & Heppelmann, 2014).

One of the prime examples of sustainable practices in Industry 4.0 revolves around real-time monitoring and control systems (Patrício, et. al., 2022b). Utilizing intelligent sensors and the Internet of Things (IoT), detailed data concerning energy consumption, waste production, and overall industrial process performance can be collected. These data can be analyzed to identify optimization opportunities, enabling informed decision-making and the implementation of corrective measures to reduce environmental impact (Porter & Heppelmann 2014).

Furthermore, Industry 4.0 enables the creation of more efficient and flexible production systems through the adoption of technologies like artificial intelligence, advanced robotics, and additive manufacturing. These technologies facilitate process automation, waste reduction, and maximization of resource utilization, directly contributing to improved energy efficiency. For instance, the use of collaborative robots on the production line can decrease energy consumption while enhancing productivity and reducing error risks (Thoben, Wiesner, & Wuest, 2017).

Industry 4.0 also propels the adoption of more sustainable production models, such as the circular economy. Leveraging digitization and connectivity, it becomes possible to trace and monitor products throughout their life cycles, from manufacturing to final disposal (Bordegoni, Ferrise, & Grassi, 2018). This facilitates material recovery and their reintegration into the production process, diminishing the need for natural resources and minimizing waste generation. Moreover, blockchain technology can ensure transparency and traceability in supply chains, confirming the sustainable origin of materials used in production.

Another exemplar of best practices is the deployment of energy and resource management systems, enabling efficient monitoring and control of energy and water consumption in industrial facilities. Integration of sensors and automation systems permits energy consumption adjustments according to demand and identification of waste reduction opportunities (Bordegoni, Ferrise & Grassi, 2018). These practices contribute to decreasing industrial footprints, simultaneously leading to significant operational cost savings (Hermann, Pentek, & Otto, 2016).

It's worth emphasizing that the implementation of sustainable practices in Industry 4.0 extends beyond technical improvements and necessitates a cultural shift and holistic approach to sustainability. Companies must commit to a long-term mindset, prioritizing environmental preservation and seeking innovative solutions to reduce their environmental impact (Hermann, Pentek & Otto, 2016).

A fundamental aspect for reducing environmental impact in Industry 4.0 is collaboration between companies. Through strategic partnerships and network creation, companies can share knowledge, experiences, and resources, accelerating the development and implementation of sustainable solutions (Bordegoni, Ferrise, & Grassi, 2018). This collaboration can also involve suppliers and customers, establishing a value chain committed to sustainability in all phases (Thoben, Wiesner & Wuest, 2017).

Furthermore, Industry 4.0 can play a pivotal role in educating and raising awareness among employees (De Sousa Jabbour, et al., 2018). Investing in training and capacity-building is crucial to ensure that employees are familiar with new technologies and understand the importance of sustainability. By promoting a culture of sustainability, companies can engage their employees in seeking innovative solutions and adopting more responsible practices.

Within the context of energy efficiency, Industry 4.0 offers numerous opportunities (Min & Zhou, 2019). Implementing data-driven energy management systems allows continuous real-time monitoring of energy consumption. This facilitates the identification of consumption patterns, process optimization, and actions to reduce waste (De Sousa Jabbour, et al., 2018). Furthermore, applying artificial intelligence algorithms and machine learning can further enhance energy efficiency, automatically adjusting energy use based on production demands and conditions (Porter & Heppelmann, 2014).

Manufacturers might optimise their value chain's production and associated processes by adopting sustainability 4.0 technologies. Such technologies will help manufacturers select their optimal facilities and employees, lower operational costs, enhance productivity and resource utilisation and provide a picture of process gaps that can be addressed. Sustainability is based on the effective use and reuse of resources across the product life cycle, from materials and processes to equipment and skills. Sustainable manufacturing produces manufactured goods using economically viable procedures that reduce negative environmental consequences while preserving energy and natural resources (Javaid, et al., 2022).

Waste reduction is also a critical aspect for sustainability in Industry 4.0. Through the implementation of additive manufacturing technologies like 3D printing, significant material waste can be reduced. On-demand manufacturing and mass customization allow for more efficient production of parts and products, avoiding excessive inventory and unnecessary waste generation. Additionally, recycling and reusing materials are facilitated by the traceability provided by digitization and the IoT (Thoben, Wiesner & Wuest, 2017).

In conclusion, Industry 4.0 has proven to be a significant ally in pursuing sustainable practices in the industry (De Sousa Jabbour, et al., 2018). Through the application of advanced technologies like IoT, artificial intelligence, and additive manufacturing, it is possible to enhance energy efficiency, reduce waste, and promote more sustainable production. However, comprehensive commitment from companies, involving collaboration, education, and employee awareness, is necessary to ensure successful implementation of sustainable practices in Industry 4.0 and to effectively contribute to reducing environmental impact (Thoben, Wiesner & Wuest, 2017).

Transitioning to a sustainability-focused Industry 4.0 demands careful strategic planning. Companies must conduct a comprehensive analysis of their operations, identifying areas for improvement in terms of energy efficiency and waste reduction (Min, & Zhou, 2019). This may involve equipment modernization, automation system implementation, and adoption of circular economy practices (Hermann, Pentek & Otto, 2016).

A practical example is the use of intelligent lighting in industrial facilities. Through sensors and control systems, lighting intensity can be automatically adjusted based on occupancy and specific area lighting needs. This not only reduces energy consumption but also extends the lifespan of light bulbs, avoiding unnecessary waste generation (Porter& Heppelmann, 2014).

Another sustainable practice involves the implementation of smart waste management systems.

Utilizing IoT and monitoring sensors, real-time tracking of the quantity and type of waste generated in industrial operations is possible. This enables more efficient waste management, allowing proper separation of waste for recycling and correct routing for treatment or disposal. Moreover, digitalizing documentation and traceability processes simplifies and expedites compliance with environmental regulations (Hermann, Pentek& Otto, 2016).

Predictive maintenance is another significant contribution of Industry 4.0 to sustainability. Through real-time data analysis and advanced algorithms, equipment performance can be monitored, and failures or maintenance needs predicted. This enables scheduling interventions only when necessary, avoiding unscheduled downtimes, and reducing energy consumption and waste associated with emergency repairs.

It's crucial to highlight that implementing best practices in Industry 4.0 with a sustainability focus goes beyond technical and technological aspects. Companies must consider the human element, investing in employee training and raising awareness about the importance of sustainability. Encouraging active employee participation, promoting a culture of sustainability, and recognizing and rewarding good practices are measures that contribute to engagement and the success of transitioning to a sustainable Industry 4.0 (Thoben, Wiesner& Wuest, 2017).

In summary, Industry 4.0 offers numerous opportunities for adopting sustainable best practices in the industry. Through digitization, automation, and collaboration, it is possible to enhance energy efficiency, reduce waste, and promote more sustainable production. However, a comprehensive commitment from companies, involving collaboration, education, and employee awareness, is necessary to ensure that these practices are effectively and durably implemented. Only by combining technology, strategy, and organizational culture will we be able to reap the benefits of Industry 4.0 with a sustainability focus.

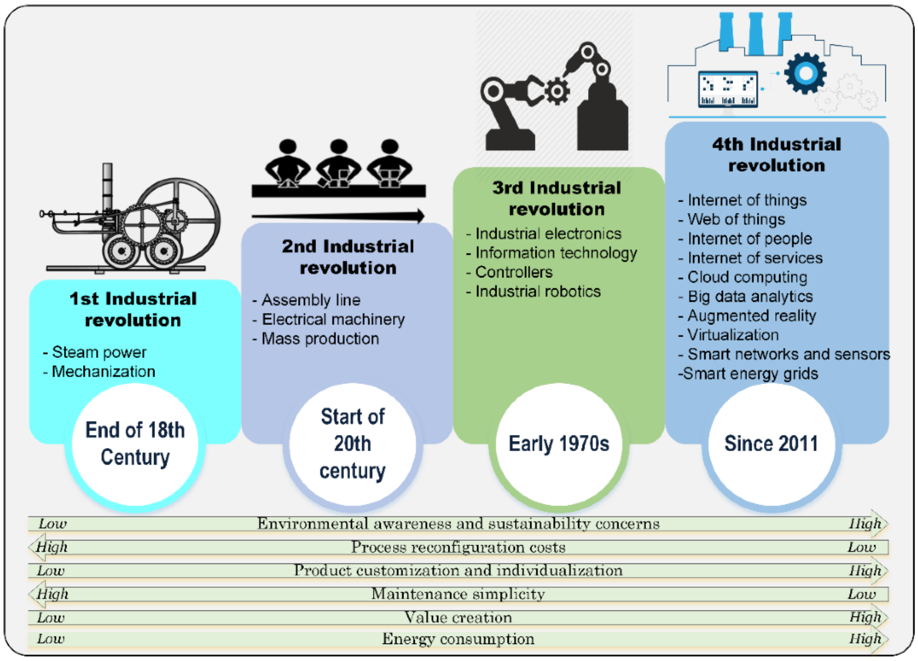

Figure 9 – Four Industrial revolutions and applications (Ng, et al., 2022)

Incorporating these practices will not only lead to reduced environmental impact but can also lead to long-term economic benefits and enhanced brand reputation for companies. By embracing the principles of sustainability within the framework of Industry 4.0, businesses can contribute to a greener future while ensuring their own competitiveness and growth (De Sousa Jabbour, et al., 2018).

Ultimately, the successful integration of sustainability principles into Industry 4.0 is a journey that requires vision, collaboration, innovation, and dedication. As technology continues to evolve and societal awareness of environmental issues grows, the importance of these practices will only become more significant. Through strategic planning and holistic approaches, Industry 4.0 can truly become a catalyst for a more sustainable and prosperous future.

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2.4. Challenges and Opportunities of Industry 4.0 for Sustainability

> *Industry 4.0 has the potential to revolutionize the way we produce and consume goods and services, with far-reaching implications for sustainability. On the one hand, Industry 4.0 technologies can help to reduce resource consumption, emissions, and waste. On the other hand, there are also risks associated with Industry 4.0, such as the potential for increased cyber security threats and the concentration of power in the hands of a few large companies. It is important to carefully consider both the opportunities and challenges of Industry 4.0 in order to ensure that it is used in a sustainable way* (Müller et. al., 2020).

The Industry 4.0 represents a technological revolution grounded in the digitization, automation, and interconnectedness of industrial processes. This transformation has yielded numerous advantages and opportunities for the global economy, such as heightened productivity, cost reduction, and improved product quality. However, it is equally imperative to consider the challenges and negative impacts that Industry 4.0 may entail for sustainability (Thoben, Wiesner, & Wuest, 2017).

One of the foremost challenges is linked to the intensive utilization of natural resources. The digitization and automation of industrial processes may lead to escalated energy and raw material consumption, resulting in heightened environmental pressure. Moreover, the mass production of electronic devices and other technological equipment can lead to a significant surge in electronic waste volume, posing an additional challenge for proper management of these materials (Porter & Heppelmann, 2014).

Another adverse impact of Industry 4.0 is the potential replacement of human labor with machines and automated systems. While this might bring efficiency and productivity benefits, it can also result in job losses, particularly for less-skilled workers (Ashton, 2009). This situation necessitates the implementation of policies and vocational retraining programs to mitigate negative social impacts.

Despite the mentioned challenges, Industry 4.0 also offers opportunities to foster sustainability (Ashton, 2009). The digitization of production processes enables more effective resource monitoring and control, facilitating the identification of areas for improvement and increased energy efficiency. The use of sensors and intelligent devices can assist in optimizing energy, water, and raw material consumption, thereby reducing waste and environmental impacts (Kannegiesser & Gloy, 2017).

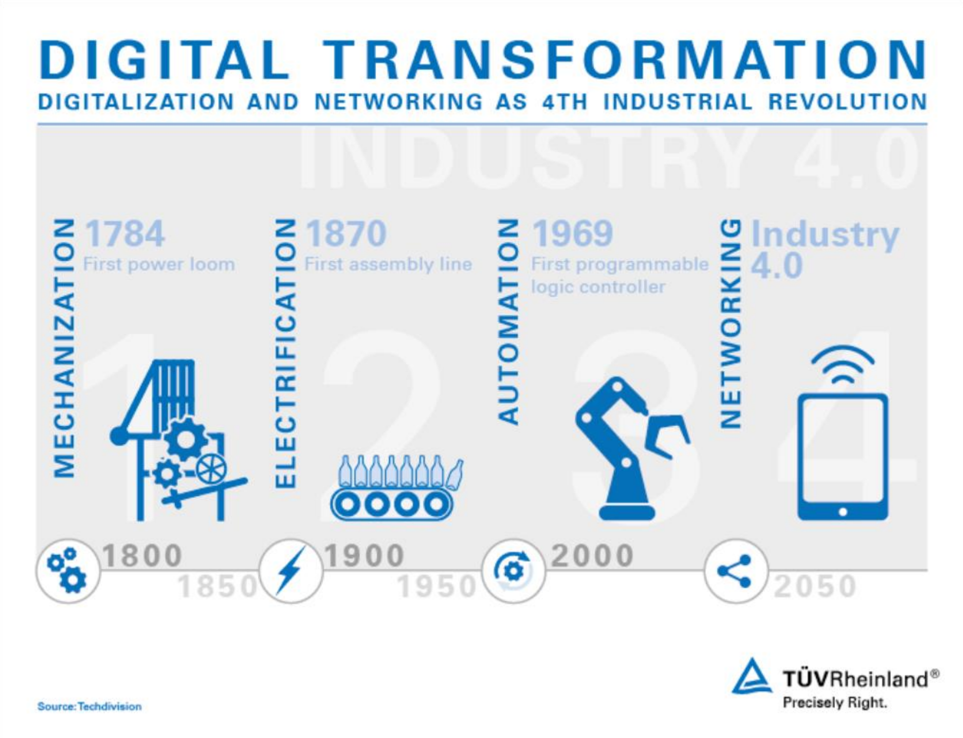

Figure 10 – Development of the digitalization of Industry 4.0 (Rheinland, 2017).

Furthermore, Industry 4.0 enables the implementation of more customized and flexible production models, which can contribute to waste reduction and decreased excessive resource consumption.

Through mass customization, it becomes possible to produce only what is necessary, avoiding large-scale production of products that might go unused, consequently decreasing the industry's environmental footprint (Porter & Heppelmann, 2014).

To promote sustainability in Industry 4.0, a crucial role is played by public policies and regulations. Governments should create an environment conducive to the development and adoption of sustainable technologies, encouraging innovation and the implementation of practices that mitigate the negative impacts of industrial digitization (Kannegiesser, & Gloy, 2017).

One of the measures that can be adopted is the implementation of fiscal and financial incentives for companies embracing sustainable technologies and practices. This could include tax benefits for investments in energy-efficient equipment, subsidies for electronic waste management systems implementation, or financing programs for the adoption of renewable energy solutions in industrial operations (Porter & Heppelmann, 2014).

Furthermore, public policies can stimulate collaboration between companies, research institutions, and civil society organizations to promote the development and sharing of sustainable best practices. This can be achieved through the creation of cooperation incentives, such as public-private partnerships, aimed at developing innovative technologies and solutions that contribute to sustainability in Industry 4.0 (Schumacher, Erol & Sihn, 2016).

Regulations also play an important role in promoting sustainability in Industry 4.0. It is essential to establish standards and guidelines defining minimum requirements for energy efficiency, waste management, and other sustainable practices. These regulations should be regularly updated to keep pace with the rapid pace of digital transformation and ensure that companies adopt responsible practices in their operations.

Moreover, it's important to raise awareness and provide education about sustainability in Industry 4.0. Governments can invest in awareness campaigns, training programs, and capacity building for workers, entrepreneurs, and managers, to foster an understanding of the challenges and opportunities related to sustainability in the age of industrial digitization.

In conclusion, evaluating the challenges and negative impacts of Industry 4.0 on sustainability is crucial to ensure responsible and sustainable digital transformation of industry. Identifying opportunities to promote sustainability in Industry 4.0 through resource optimization, mass customization, and sustainable practices is essential to minimize negative impacts and maximize the benefits of this technological revolution. The role of public policies and regulations is critical to create an environment conducive to innovation and the implementation of sustainable solutions, while also promoting awareness and education about the importance of sustainability in Industry 4.0.

However, it's important to emphasize that promoting sustainability in Industry 4.0 is not the sole responsibility of governments and regulations. Companies also have a fundamental role to play in adopting sustainable practices in their operations. They should embed sustainability into their corporate culture, set environmental performance goals and indicators, implement environmental management systems, and continually seek ways to reduce their environmental impact.

Additionally, collaboration between the public and private sectors is essential to drive sustainability in Industry 4.0. Through strategic partnerships, knowledge sharing, resource pooling, we can accelerate the adoption of sustainable practices and the development of innovative technologies.

> *Industry 4.0 is transforming the manufacturing industry and the economics of value creation. A great deal of positive hype has built up around the sustainable development implications of Industry 4.0 technologies during the past few years. Expectations regarding the opportunities that Industry 4.0 offers for sustainable manufacturing are significantly high, but the lack of accurate understanding of the process through which Industry 4.0 technologies enable sustainable manufacturing is a fundamental barrier for businesses pursuing digitalization and sustainable thinking* (Ching, at al., 2022).

Sustainable manufacturing is elusive and hard to define, as the literature has conceptualized and analysed it from various perspectives depending on its purpose, dimensions, and application.

Sustainability in Industry 4.0 is not limited solely to environmental aspects; it also encompasses social and economic facets. It is crucial for companies to adopt a holistic approach, considering not only environmental impacts but also social aspects, such as promoting fair and safe working conditions, and economic aspects, such as creating quality jobs and developing products and services that meet society's needs.

In conclusion, Industry 4.0 presents challenges and negative impacts on sustainability, such as increased natural resource consumption and potential job displacement. However, it also offers opportunities to promote sustainability through resource optimization, mass customization, and sustainable practices. The roles of public policies, regulations, active business engagement, and collaboration between the public and private sectors are essential to drive sustainability in Industry 4.0. Through this integrated approach, we can achieve a sustainable and beneficial digital transformation for society and the environment.

To drive sustainability in Industry 4.0, investing in research and the development of cleaner and more efficient technologies is essential. This includes developing renewable energy systems such as solar and wind power to fuel industrial operations. Additionally, investing in energy storage technologies, such as long-lasting batteries, is crucial to ensure a continuous supply of clean energy.

The application of circular economy principles also plays a pivotal role in promoting sustainability in Industry 4.0. The circular economy aims to reduce waste and promote the reuse and recycling of materials. This can be achieved through efficient waste management practices, the use of recycled materials in production, and the adoption of service-based business models where products are rented or shared instead of being purchased.

Moreover, fostering sustainable innovation and entrepreneurship ecosystems in Industry 4.0 is important. This involves supporting startups and emerging companies that develop innovative and sustainable technological solutions. Governments can provide funding programs, business incubators, and facilitate partnerships between established companies and startups to promote collaboration and knowledge transfer.

Another crucial aspect is education and raising awareness about the importance of sustainability in Industry 4.0. Promoting training and education for workers to acquire the skills needed to work with new technologies and understand sustainability principles is vital. Additionally, raising general awareness in society about the negative impacts of Industry 4.0 on sustainability and potential solutions is essential to encourage the adoption of sustainable practices and drive for change.

In conclusion, evaluating the challenges and negative impacts of Industry 4.0 on sustainability is crucial for ensuring a responsible digital transformation. Identifying opportunities for promoting sustainability, the roles of public policies and regulations, corporate engagement, and collaboration between the public and private sectors are vital to drive sustainability in Industry 4.0. With the implementation of innovative practices, appropriate regulations, investments in research and development, education, and societal awareness, we can achieve a balance between technological advancements and environmental preservation, along with promoting social and economic benefits (Thoben, Wiesner, & Wuest, 2017).

In the face of Industry 4.0 challenges and negative impacts on sustainability, it is imperative to adopt a proactive and collaborative approach to foster sustainable solutions. This involves forging partnerships among businesses, governments, academic institutions, and civil society to share knowledge, resources, and best practices (Thoben, Wiesner & Wuest, 2017).

One approach to promote sustainability in Industry 4.0 is through the implementation of environmental standards and certifications. These standards establish guidelines and criteria for more sustainable production, considering aspects such as energy efficiency, reduction of greenhouse gas emissions, waste management, and social responsibility (Chiarini, 2019). Adoption of these standards can be incentivized through fiscal benefits, public procurement preferences, and recognition of companies excelling in sustainable practices (Thoben, Wiesner & Wuest, 2017).

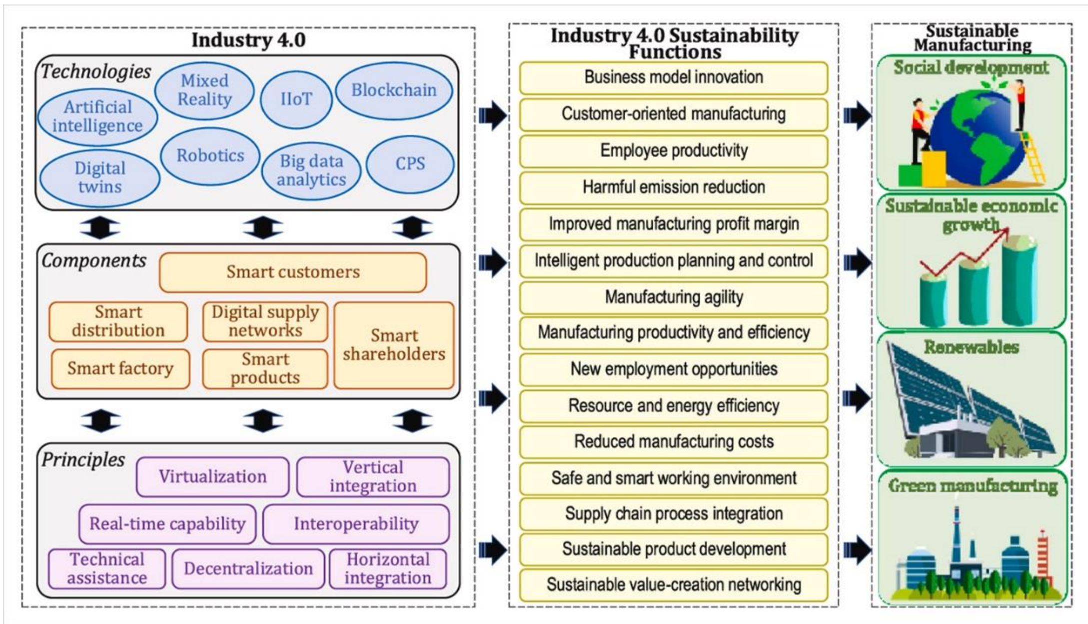

Figure 11 - Industry 4.0 applications for sustainable (Ching at al., 2022)

Furthermore, fostering technological innovation aimed at sustainability in Industry 4.0 is crucial. This can be achieved by supporting research and development of new clean technologies, such as Internet of Things (IoT) applications for efficient resource management, artificial intelligence (AI) for process optimization, and collaborative robotics to reduce workplace accidents and improve working conditions. Encouraging innovation can occur through funding programs, partnerships between companies and universities, and events promoting sustainable entrepreneurship (Thoben, Wiesner & Wuest, 2017).

Public policies play a fundamental role in promoting sustainability in Industry 4.0 (Hermann, Pentek & Otto, 2016). Governments must establish clear guidelines and ambitious targets for reducing the industry's environmental impact, such as implementing legislation that encourages the transition to renewable energy sources, adopting energy efficiency measures, and proper waste management (Chiarini, A. (2019). Additionally, promoting environmental education and awareness, both among industry workers and the general public, is necessary (Porter & Heppelmann, 2014).

Another significant aspect is promoting collaborative economics and resource sharing in Industry 4.0 (Chiarini, 2019). Through business models based on sharing, such as equipment rental and shared economy platforms, resource utilization can be optimized, reducing the demand for new production and minimizing waste (Kannegiesser & Gloy, 2017).

In summary, sustainability in Industry 4.0 requires a comprehensive and collaborative approach involving companies, governments, and civil society. It takes a combined effort to address challenges and maximize opportunities presented by this technological revolution, ensuring a sustainable future for generations to come. Through innovative practices, appropriate regulations, research and development investments, education, and awareness, we can strike a balance between technological progress and environmental preservation, as well as promote social and economic benefits.

2.5. Key Enabling Technologies, Methodologies, Frameworks, Tools and Techniques of Smart and Sustainable Systems

Industry 4.0 is a German project that combines manufacturing with high-level information technology and digitization (Adolph, et al., 2016). It is a revolution in manufacturing and brings innovative perspectives on how manufacturing can participate in new technologies, methodologies, frameworks, tools and techniques, in short, approaches, to achieve maximum production effectiveness and efficiency, alongside with automation and integration levels, with minimum or optimized use of resources. The effect of this new paradigm derives from the evolution of intelligent or smart factories, by refining this concept and further improving and exploring it at higher levels of digitalization and high standard technologies. One central concern and objective of the application of the I4.0 paradigm consists on reaching extremely effective and efficient use of resources, means, products, materials, and tools to enable a very fast dynamism, flexibility, and (re)configurability capabilities, to enable customized production, and a full integration of all stakeholders and "things" in an organization, from suppliers to customers and all associated business partners, in a large network of partners, which may be organized in different ways, for instance, in virtual organizations or enterprises, distributed or extended manufacturing systems or collaborative networks, to enable a more effective and prompt adaptation to the current highly demanding requisites associated to a dynamically and fast changing globally distributed market, alongside with manufacturing and management goals (Kagermann, et al., 2013; Deloitte, 2014;

Smit, et al., 2016; Wittenberg, 2016; Putnik, & Ferreira, 2019).

In recent years, intelligent or smart manufacturing has received a great interest in academia and industry, because it gives competitive advantage to manufacturing organizations, making this type of industry more effective, and efficient through the use of advanced ICT (Kagermann, et al., 2013; Deloitte, 2014; Smit, et al., 2016; Wittenberg, 2016; Putnik, & Ferreira, 2019). Moreover, in the current Industry 4.0 (I4.0), companies and underlying manufacturing and management approaches, technologies and systems have further to be sustainable (Varela, et al., 2019).

In I4.0 the duality of flexibility and productivity is a recurring challenge for organizations, which seek to reduce costs, and a greater offer of customized products. The flexibility of manufacturing systems can be understood as the ability to produce a wide variety of products, being considered one of the most important requirements for new applications, for instance in robotics (Esmaeilian, et al. 2016). Moreover, for reaching this flexibility it is further fundamental to put available manufacturing systems with high level of reconfigurability and reliability (Samala, et al., 2021a,b; Putnik, et al., 2021).

Manufacturers faced the impulses of product specification, with the need to increase resource efficiency and reduce product projection times. These stimuli are related to digitization, use of information technologies and the connection of products, resources and production processes, which are leveraged by the internet of things (IoT) (Scheuermann, et al., 2015; Rennung, et al., 2016).

Moreover, the previous requisites should further be fulfilled along with economic, social and environmental sustainability ones (Varela, et al., 2019), as expressed in Fig. 12, by (Morrar, & Husam, 2017).

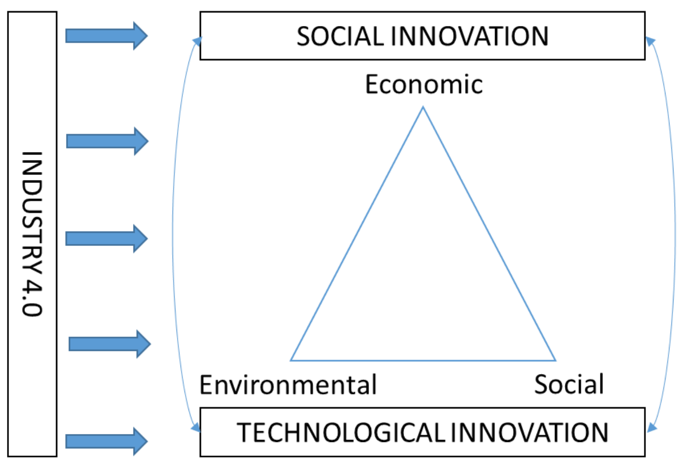

Figure 12 - Sustainable structure applicable to Industry 4 (Morrar, and Husam, 2017).

The issue of sustainability is becoming very important at the manufacturing level, particularly for industries with intensive practices of resources and energy. Sustainable development is instituting changes in the way manufacturing systems are designed and implemented. Sustainability emerges as one of the topics in the international governance market and they are interconnected (Putnik, & Ávila, 2016). Almeida, et al. (2015) says that it is common to ignore the interdependence of the sustainability pillars for short periods of time, but history has shown that before long, mankind is reminded of it through some types of alarms or crisis.

Researchers have identified the relationships and contributions of Industry 4.0 to sustainability as an emergent and dynamic research subject (Fonseca, Amaral & Oliveira, 2021; Ghobakhloo, 2020). The successful adoption of Industry 4.0 can positively impact sustainability by improving knowledge sharing, collaborative work, production efficiency and productivity (Jena, Mishra & Moharana, 2020; Machado, Winroth & Ribeiro da Silva, 2020). Moreover, I4.0 can support novel business models and contribute to cost reduction and customer experience enhancement (Machado, Winroth & Ribeiro da Silva, 2020; Fonseca, Amaral & Oliveira, 2021) and improve communication and information flows (Linder, 2019). Research results also posit that combining Industry 4.0 technologies with development practises (e.g., Lean, contributes to improved employee morale, reduced lead time, enhanced product quality, customized products, and waste reduction (Bogle, 2017; Kamble, Gunasekaran & Dhone, 2020). Nevertheless, Industry 4.0 can also have some potential negative influence on sustainability due to cybersecurity risks, labour-saving technologies causing job losses and labour market disruption, and increased production and consumption rates leading to over resource consumption (Beir, et al., 2020; Nara, et al., 2021).

This work identifies the main enabling technologies, approaches, methodologies, methods, techniques, models, tools and platforms for intelligent or smart and sustainable manufacturing systems in Industry 4.0, founded on organised works review, including, conceptual articles about I4.0, approaches, technologies, and platforms for a sustainable I4.0. The review will be conducted with the following central research question in mind:

- **Is there an increased attention being given to sustainability issues nowadays in the Industry 4.0 oriented smart manufacturing and management context?**

To achieve the objective of this work, the rest of this document is organized as follows.

2.5.1. Methodology

Carrying out a careful literature review is very important to come up with some important insights regarding the state of the art about some specific, and more or less widened, research topic or domain, and its evolution in time. In this work a works review was done in instruction to evaluate and analyse existing contributions about sustainable and intelligent manufacturing in companies.
Saunders, et al. (2016) established an organized review process, based on an iterative cycle for defining appropriate keywords to a specific theme, by searching important literature and carrying out a corresponding analysis. In this work a similar methodology was used.
In order to deepen the knowledge about the main technologies, methods, techniques, approaches, methodologies, models, tools and platforms for intelligent and sustainable manufacturing systems in Industry 4.0, and based on distributed manufacturing environments or collaborative networks, a study was carried out, based on the information reached through scientific publications searched and analysed.
Therefore, in this research work several steps were taken, according to the methodology previously described and the main groups of keywords shown in Fig. 1. According to that methodology, the search, selection and analysis of the various articles, directly related to the theme of this literature review, is summarized in three main stages, as about: "identifying, evaluating, and synthesizing the existing body of completed and recorded work produced by researchers, scholars, and practitioners" (Fink, 1998). There was a need to carry out these steps in order to clarify how this work was carried out, regarding the research theme, and further evolve and classify the articles, besides its geographic distribution identification, their main characteristics and methods, methodologies, technology, approaches, models, techniques, tools and/or platforms used. For the development of this research work, it was thus necessary to start to establish the search string and selecting the academic database for carrying out the search process.
The B-ON data base was chosen for carrying out this research work. This library enables admission to an extensive range of academic publications in international scientific journals and conferences, indexed in most well-known indexation systems, e.g., Web of Science and Scopus. The B-ON is an extensive database including thousands of peer-reviewed journals and publications in a widened set of fields and arising from different scientific areas. These publications include peer-reviewed articles from several well-known publishers and editors, such as Elsevier, Springer, MDPI and IEEE,

among others, that were considered in this study and further analysed, published until the first trimester of 2021.

For this research a search string was defined by including a set of considered key terms, referring to the theme of this work. It is important to notice that for each term used there are several synonyms that can be mentioned and were also used in the search process underlying this work. Table 2 shows the search terms and respective synonyms used in the search process.

Table 2 - Groups of key words considered for searching the literature.

Group KW1	Group KW2	Group KW3
(Approach or technology or method or model or methodology or tool or framework or platform or system or architecture)	(Smart manufacturing or Industry 4.0, or Industrie 4.0 or I4.0 or Intelligent manufacturing)	(Sustainability or sustainable or eco-efficient)

The search string used in the work for getting articles from the B-ON online library database was based on the key terms and the respective synonyms indicated in Table 2:

String = (Group KW1) AND (Group KW2) AND (Group KW3)

String = (Approach or technology or method or model or methodology or tool or framework or platform or system or architecture) AND (Smart manufacturing or Industry 4.0, or Industrie 4.0 or I4.0 or Intelligent manufacturing or distributed manufacturing or collaborative networks or collaboration) AND (Sustainability or sustainable or eco-efficient)

The string is composed by the main keywords intended to be considered, and that are further used to organize the information in 3 groups: (Title, Abstract; Subject Terms).

In order to get the articles more closely related to the theme of this work, the articles were filtered according to their relevance to the theme under study. Duplicate and not considered key articles, and articles with incomplete bibliographic data, were removed. In addition, parameters that were used for the filters applied were related to the following issues: peer reviewed and full text available. Initially, the research results reached a total of 717 publications. After applying the search filters, the total set of articles did decrease to 249 articles, and among these the ones that were considered to be more closely or directly related to the research underlying this work were verified. Therefore, the number of articles analysed dropped to a total of just 20 articles. In Table 3 it is possible to see the filters applied in the search results, as well as the number of articles obtained throughout the search process.

Table 3 - Filters applied to the search process.

	Articles
Initial result:	717
1 - Restrict to: Peer Reviewed	383
2 -Type of fonts: Academic Journals; Conference Materials; Books	382
3 - From: 2010 to 2021	380
4 - Language: English	372
5 - Editor (addleton academic publishers; elsevier b.v.; mdpi ag; elsevier ltd; mdpi; ieee; mdpi publishing; elsevier sci ltd; taylor & francis ltd; elsevier; elsevier science)	334
5 - Restrict to: Full Text	249
Final result:	**249**

Figure 13 represents a flow diagram of the literature search carried out, and respective screening of the topic used in this research work. To analyse the main data of the articles found, it was necessary to carry out two types of characterization. In the first categorization phase, the year of publication and the type of article (research, review, conference, book chapter, journal paper, and editorial) were classified. In the second type of analysis, the publications found were characterized as being theoretical or conceptual contributions, literature reviews or case studies.

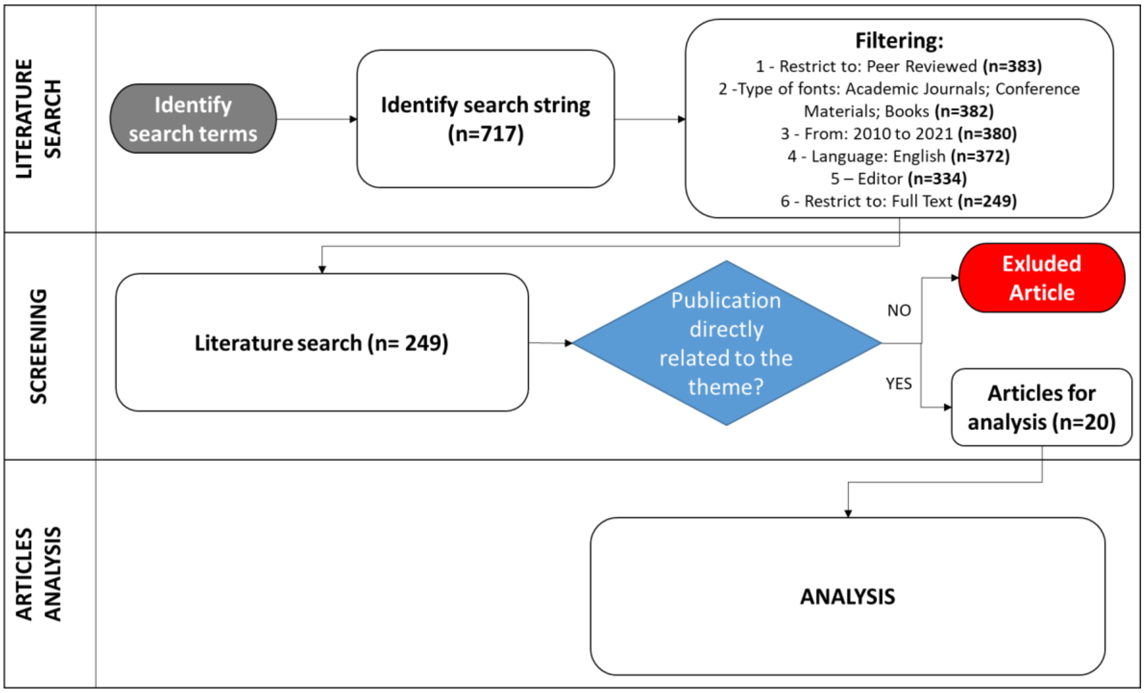

Figure 13 - Flow diagram of literature search and respective screening (Neves, et al., 2020).

2.5.2. Article Synthesis and Analysis

In order to deepen the knowledge on enabling technologies, approaches, methodologies, structures, tools and techniques of intelligent and sustainable manufacturing systems for I4 .0, a study based on scientific articles was necessary to investigate the comprehensive information on this topic. Throughout this chapter, we will review different contributions from the most relevant papers that address this topic, which falls in the context of I4.0, and the underlying smart manufacturing concept, along with sustainability issues.

Regarding the I4.0, the main pillars that were considered, and for which contributions were found, are related to: Big Data and Data Analytics, Simulation, Horizontal and Vertical Integration, [Industrial]Internet of Things, Autonomous Robots, the cloud, Cyber Physical [Production] Systems, and Security, Augmented Reality, and Additive Manufacturing (Kagermann, et al., 2013; Deloitte, 2014; Smit, et al., 2016; Putnik, & Ferreira, 2019).

The collection of articles found and analysed, as previously mentioned, was made using the database of the online library B-ON. According to the selection parameters described previously, 19 articles were selected for further analysis, as it is shown in Table 4.

Table 4 - Synthesis of information retrieved from most relevant articles analysed.

Authors	Title	KW	Journal
Man, & Strandhagen (2017)	*An Industry 4.0 research agenda for sustainable business models*	*Sustainability; Business Model; Industry 4.0; Research Agenda*	*Procedia CIRP*
Giret, et al. (2017)	*A holonic multi-agent methodology to design sustainable intelligent manufacturing control systems*	*Sustainability; Multi-Agent Systems; Holonic Control; Manufacturing; Design Method;*	*Journal Of Cleaner Production*
Yazdi, et al. (2018)	*An Empirical Investigation of the Relationship between Overall Equipment Efficiency (OEE) and Manufacturing Sustainability in Industry 4.0 with Time Study Approach*	*Small And Medium Enterprises; OEE; OECD; Manufacturing Sustainability; Time Study; Industry 4.0; Material Handling Systems; Agent-Based Control Architecture*	*Sustainability*
Thomas, et al. (2018)	*Smart Systems Implementation in UK Food Manufacturing Companies: A Sustainability Perspective*	*Food Manufacturing; Digital Hub; Sustainability Profile; Smart Systems; Survey*	*Sustainability*
Varela, et al. (2019)	*Evaluation of the Relation between Lean Manufacturing, Industry 4.0, and Sustainability*	*Lean Manufacturing; Industry 4.0; sustainability; economic; environmental; and*	*Sustainability*

		social; structure equations modeling	
Scavarda, et al. (2019)	*An Analysis of the Corporate Social Responsibility and the Industry 4.0 with Focus on the Youth Generation: A Sustainable Human Resource Management Framework*	*Sustainable Human Resources; Industry 4.0; Corporate Social Responsibility; Conceptual Framework; Youth Generation*	*Sustainability*
Hidayatno, et al. (2019)	*Industry 4.0 Technology Implementation Impact to Industrial Sustainable Energy in Indonesia: A Model Conceptualization*	*Industry 4.0; Sustainable Energy; Making Indonesia 4.0; Technology Adoption; Model Conceptualization*	*Energy Procedia*
Ren, et al. (2019)	*A comprehensive review of big data analytics throughout product lifecycle to support sustainable smart manufacturing: A framework, challenges and future research directions*	*Big Data Analytics; Smart Manufacturing; Servitization; Sustainable Production; Conceptual Framework; Product Lifecycle*	*Journal Of Cleaner Production*
Ghadimia, et al. (2019)	*Intelligent sustainable supplier selection using multi-agent technology: Theory and application for Industry 4.0 supply chains*	*Sustainable supplier selection; Industry 4.0; Multi-agent systems; Cyber-physical systems; Industry 4.0 supply chain*	*Computers & Industrial Engineering*

Lee, et al. (2019)	*Development of na Intelligent Tool Condition Monitoring System to Identify Manufacturing Tradeoffs and Optimal Machining Conditions*	*Smart and Sustainable Manufacturing; Artificial Intelligence; Evolutionary Strategies; Tool Condition*	*Procedia Manufacturing*
Fatimah, et al. (2020)	*Industry 4.0 based sustainable circular economy approach for smart waste management system to achieve sustainable development goals: A case study of Indonesia*	*Industry 4.0; Internet Of Thing (Iot); Maturity Model; Smart Waste Management; Sustainability; Sustainable Circular Economy; Sustainable Development Goals (SDG's)*	*Journal Of Cleaner Production*
Bai, et al. (2020)	*Industry 4.0 technologies assessment: A sustainability perspective*	*Industry 4.0; Technology; Sustainability; Hesitant Fuzzy Set; Cumulative Prospect Theory; VIKOR*	*International Journal Of Production Economics*
Yadava, et al. (2020)	*A framework to achieve sustainability in manufacturing organisationsof developing economies using industry 4.0 technologies' enablers*	*Developing Nations; Empirical Study; Industry 4.0; Manufacturing Supply Chain; New Technologies; Robust Best Worst Method (RBWM);*	*Computers In Industry*

		Sustainability	
Villara, et al. (2020)	*Fostering economic growth, social inclusion & sustainability in Industry 4.0: a systemic approach*	*Sustainable Development; Social Inclusion Approach; Soft Systems Methodology; Industry 4.0; Smes Strategy; Manufacturing Sector*	*Procedia Manufacturing*
García-Muiña, et al. (2020)	*Sustainability Transition in Industry 4.0 and Smart Manufacturing with the Triple-Layered Business Model Canvas*	*Industry 4.0; Sustainability; Manufacturing; Business Model Canvas*	*Sustainability*
Ahmad, et al. (2020)	*Towards Sustainable Textile and Apparel Industry: Exploring the Role of Business Intelligence Systems in the Era of Industry 4.0*	*Business Intelligence Systems Adoption; Industry 4.0; Sustainability; Textile Industry; Apparel Industry*	*Sustainability*
Yadav, et al. (2020)	*A framework to overcome sustainable supply chain challenges through solution measures of industry 4.0 and circular economy: An automotive case*	*Sustainable Supply Chain; Challenges; Industry 4.0; Circular Economy; Solution Measures; Best Worst Method; ELECTRE*	*Journal Of Cleaner Production*

Nara, et al. (2021)	*Expected impact of industry 4.0 technologies on sustainable development: A study in the context of Brazil's plastic industry*	*Cloud Computing Search Subject For Cloud Computing , Industry, Internet Of Things, Models, Plastics, Robots, Sustainable Development, Brazil*	*Sustainable Production And Consumption*
Enyoghasi, & Badurdeen (2021)	*Industry 4.0 for sustainable manufacturing: Opportunities at the product, process, and system levels*	*Industry 4.0; Sustainable Products; Sustainable Processes; Sustainable Systems*	*Resources, Conservation And Recycling Volume*
Costa, Ávila, Bastos, Pinto Ferreira (2021)	*A new simple, flexible and low-cost machine monitoring system*	*Industry 4.0; Machine Monitoring; Beacon, Bluetooth BLE; Remote Monitoring; Low Cost; SME's; b-Remote*	*Dyna Ingenieria e Industria*

Man, J. and Strandhagen, (2017) present an article that discusses possible sustainable business landscapes and proposes a research agenda on how Industry 4.0 can be used to produce sustainable business models, where opportunities for sustainable contributions exist when designing products for longevity. Sustainability means not only being more efficient, but also using less raw material and recycling more products. This changes the value proposition, supply chain, customer association, and financial validation of a business model. This work addressed the following I4.0 pillars: 3, 5 and 8.

Giret, et al. (2017) proposes a work focused on a method that helps researchers to design sustainable intelligent manufacturing systems. The approach centers on identifying the producing elements and hence the style and integration of sustainability-oriented mechanisms within the system specification, providing specific development tools with integrated support for proprietary resources. It is carried out through a set of case studies, investigation in which the projected technique can be gauged. This work addressed the following I4.0 pillars: 3 and 9.

Yazdi, et al. (2018) present a paper with the objective of designing and analysing the implementation of an intelligent and sustainable materials handling system for materials distribution using an agent-based algorithm as a control architecture. The study focused on recognizing and analysing effective factors in the sustainability of improved processes, using a simple model. For this, through expert opinions, the effective factors on the sustainability of process improvement activities are determined. This work addressed the following I4.0 pillars: 3 and 9.

Thomas, et al., (2018) present an investigation aiming to explore the applicability of intelligent systems in food manufacturing companies in the United Kingdom and to identify the main priority areas and improvement levers for the implementation of such systems. A survey is carried out including a questionnaire, follow-up interviews and visits to 32 food manufacturing companies in the UK. The questionnaire and interviews are guided by a unique measurement instrument that the authors developed with a focus on SS (Smart Systems) technologies and systems. This work presents an original contribution, as it is one of the few academic studies to explore the implementation of SS in industry and provide a new perspective on the main motivators and inhibitors of its implementation. The results suggest that the current turmoil in the sector may be bringing food companies closer to adopting such systems; therefore, this is a good time to define and develop the optimal SS implementation strategy. This work addressed the following I4.0 pillars: 3 and 8.

In (Varela, et al., 2017) a review on Lean Manufacturing (LM), Industry 4.0 (I4.0), and the three pillars of Sustainability is put forward, with the main goal of the explanation of the meaning of these three main subjects underlying the work (LM, I4.0, and Sustainability). Moreover, the authors focus on a proposed structural equation model, based on two exogenous constructs (LM and I4.0) and the three endogenous constructs (EcS, EnS, and SoS), each construct composed by three manifest variables, and with six hypotheses, for quantitatively measuring the effects of LM and I4.0, in the Sustainability pillars. Additionally, so as to statistically validate such hypotheses, a collection of 252 valid questionnaires from industrial firms of Iberia (Portugal and Spain) were analysed. The validation of the projected model was obtained through the appliance of the corroborative correlational analysis and also the corresponding values of the adjustment quality given a liableness and validity with a decent fitness. in addition, a correlation between luminous flux unit and I4.0

was conjointly confirmed. As a worldwide conclusion, the results obtained through the study administrated enabled to state that exists a relation between I4.0 and property, and a not confirmed relation between luminous flux unit and property. These conclusions will contribute as a crucial call support for the commercial firms and its stakeholders, even as a result of not all the results square measure in line with different opinions and studies. Moreover, this can mean that companies have now a stronger knowledge base to further decide about the implementation of LM and I4.0, and their implications in Sustainability.

Hidayatno, et al. (2019) present research that aims to discover the systemic impact of the development and implementation of technology from Industry 4.0 for the transition of sustainable energy in developing countries, which eventually needs a valid model conceptualization that acts as a standard for future research. The United Nations Industrial Development Organization has defined the relevance of Industry 4.0 and sustainability in the global sustainable development goals 7 and 9, that digital industrial development will support the growth of the Sustainable energy industry. Therefore, the implication will certainly affect all countries with different meanings, including one of the emerging industry countries, Indonesia. In response to this, Indonesia is currently mapping out the way to enter Industry 4.0 era, making Indonesia 4.0. This work addressed the following I4.0 pillars: 3.

Ren, et al. (2019) present a study combining the main technologies of smart manufacturing and the idea of ubiquitous servitization. A comprehensive overview of big data in intelligent manufacturing was undertaken and a conceptual framework proposed from a product lifecycle perspective. As one of the most important technologies for intelligent manufacturing, big data analytics can reveal insights, such as relationships between lifecycle decisions and process parameters, helping industry leaders make more informed business decisions in management environments. This work addressed the following I4.0 pillars: 1, 3 and 9.

Ghadimia, et al. (2019) presents a study called a Multi-Agent that is a systems approach (MASs) proposed to address the process of evaluating and selecting sustainable suppliers to provide an appropriate communication channel, structured information exchange and visibility between suppliers and manufacturers. In addition, the application of MASs in this process, and its natural applicability as one of the technologies that allow the move to the 4.0 supply chain industry, are investigated in detail. It turns out that what is proposed in this approach can help decision makers within manufacturing companies to make quick decisions with less human interaction. The merit of the developed MAS is demonstrated through a real-world implementation by a medical device manufacturer. Finally, the limitations and advantages of the proposed approach are presented in conjunction with some observations for future work. Advances in information and communication systems offer immense opportunities for supply chain intelligence and autonomy by establishing stepping stones for Industry 4.0 supply chains (SCs). However, this process has not yet been carried out in the SCs of Industry 4.0, where interconnection, in real time transparency of information, technical assistance and decentralization of members of a physical system (members of the supply chain) are considered the main design principles. This work addressed the following I4.0 pillars: 3 and 9.

Lee, Wo, et al. (2019) present a work with a tool condition monitoring of an intelligent system that they present in a research work aimed at identifying manufacturing trade-offs related to sustainability and an ideal set of machining conditions monitoring the status of the machine-tool. In addition, they use a multi-objective optimization based on an evolutionary algorithm that is used to find the ideal operating conditions. Through the result of the increased use of sensors and networked machines in manufacturing operations, artificial intelligence techniques play a fundamental role in deriving significant value from the big data infrastructure. These techniques can inform decision-making and can enable the implementation of more sustainable practices in the manufacturing industry. In machining processes, a considerable amount of waste (scrap) is generated as a result of failure to monitor a tool condition. This work addressed the following I4.0 pillars: 1, 2, 3, 5, 8 and 9.

Scavarda, et al., (2019) developed research that was developed between 1 March 2019 to 2 September 2019, through a bibliographic review involving human resources and deadlines related to the concept of sustainability, industry 4.0, corporate social responsibility and young generation. Its public target is the young generation of the world. Two proposals were created after reviewing the literature and collecting data, which allowed the elaboration of “an analysis of corporate social responsibility and industry 4.0 with a focus on the young generation: a sustainable management of human resources structure." The authors of this research contribute with theoretical and practical educational purposes to insert the young citizen in society. This contribution also involves the work of companies in planning and preparing their team for the development of activities in the communities in their neighbourhood, which will allow the creation of new proposals to be presented, so that nations can incorporate their young people in the transition labour market and have a sustainable vision for future generations. This work addressed the following I4.0 pillars: 3.

García-Muiña, et al., (2020) present a paper with the objective of analysing the introduction of sustainability in the corporate value proposal, through the evolution from a traditional to a sustainable business model. The business model innovation is investigated in the case of a producer of ceramic tiles in the district of Sassuolo, Italy. The company has introduced several sustainability practices over the years and, through investments in Industry 4.0 technologies, is able to carry out impact assessments of its production process. The tool applied to the business model transition will be the Business Model Canvas by Triple-Layered, by Joyce and Paquin. The results illustrate the new company's sustainable value proposal, considering all three pillars of sustainability: environment, economy and society. Despite the limitations resulting from the individual case study, the results can be easily adapted to other ceramic tile companies in the sector. In addition, the authors' research can inspire other manufacturing companies to develop a sustainable business model project. This work explores the still limited literature on the application of sustainable business model methods in operational scenarios. This work addressed the following I4.0 pillars: 3 and 9.

Ahmad, et al., (2020) present a study on one of the determinants of the adoption of Business Intelligence Systems (BIS) with an eye to understand how BIS can solve sustainability issues in a company with industry 4.0 technologies. The methodology they use is a qualitative research approach that is applied with 14 semi-structured detailed interviews with 12 of the world's leading T&A companies. The snowball and purposeful sampling strategy is used to select participants. The qualitative content analysis technique is used to analyse the interview data. The results revealed several topics, such as sustainability problems in T&A companies, improved value creation processes with leading Business Intelligence (BI) solutions and difficulties in adopting BIS. Major improvements are seen in apparel retailing because apparel companies are more likely to adopt Industry 4.0 technologies with advanced technologies for business intelligence (BI) solutions. The results prove the fundamental role of economic sustainability in the adoption of BIS and Industry 4.0 technologies in T&A companies. This work addressed the following I4.0 pillars: 1, 3 and 8.

Fatimah, et al. (2020) presents a work whose objectives are to investigate the fundamental issues and opportunities and develop a sustainable and intelligent waste management system in Indonesia, using technologies from industry 4.0. The system should provide a multidimensional approach, determine the maturity level of the waste management system in a technical method and seek the objective of designing a new strategy to minimize the problems of waste management. In this work they present a comprehensive systematic review of the literature, intensive discussions in focus groups and direct observation in Indonesian cities were the approaches used to develop waste management business processes and their system design. The waste business processes consist of mixed collection, classification, transportation, varied treatment and chain disposal. The proposed waste management system project features circular economy processes that can separate municipal waste, identify waste characteristics and determine sustainable waste treatment technologies through the use of the Internet of Things (IoT) as an integrator. This study contributed to the objectives of sustainable development (SDGs), such as good health and well-being (SDG 3); Drinking water and sanitation (SDG 6); Decent work and economic growth (SDG 8); Responsible Consumption and Production (SDG 12) and Climate Action (SDG 13). The study proposes a new smart and sustainable waste management project, which can achieve satisfactory economic, social and environmental performance in waste management. This work addressed the following I4.0 pillars: 3 and 4.

Bai, et al. (2020) present a structure of measures for sustainability based on the United Nations Sustainable Development Goals; incorporating various economic aspects, environmental and social attributes. They also develop a hybrid decision method of multiple situations integrating a hesitant fuzzy set, cumulative prospecting theory and VIKOR. This method can effectively evaluate Industry 4.0 technologies based on their sustainable performance and application. They apply the method using the secondary case information from a report by the World Economic Forum. The results show that mobile technology has the greatest impact on sustainability across all industries, and nanotechnology, mobile technology, simulation and drones have the greatest impact on sustainability in the automotive, electronics, food and beverage and textiles, apparel and footwear, respectively. The recommendation of this paper is to take advantage of the Industry 4.0 adoption technology to improve the impact of sustainability, being needed that each technology has to be carefully assessed in the context of each sustainability dimension. Investment in such technologies should consider appropriate priority investment and promotion. This work addressed the following I4.0 pillars: 2 and 3.

Yadav, et al. (2020) present a study with the objective of developing a framework to improve the adoption of sustainability in manufacturing organizations in developing nations using technologies from Industry 4.0. Initially, facilitators who strongly influence the adoption of sustainability are identified through a literature review. In addition, they present large-scale research which is conducted to reach Industry 4.0 enabling technologies to be included in the structure. Based on empirical analysis, a framework is developed and tested in an Indian manufacturing case organization. Finally, Robust Best Worst Method (RBWM) is used to identify the intensity of influence of each capacitor included in the structure. The results of the study reveal that managerial, economic and environmental facilitators have a strong contribution to the adoption of sustainability. The results of the present study will be beneficial for researchers, professionals and policy makers. This work addressed the following I4.0 pillars: 1, 4, 5 and 9.

Villara, et al. (2020) present an investigation that proposes a soft systems methodology to deal with the context of sustainable complexity and inclusive industrial development phenomena. Its holistic nature provides useful insights that plan how I4.0 and social inclusion fit into the Mexican context. The theoretical proposal is based on the state of the art of social inclusion in the sector 4.0 and a survey for an I4.0 initiative accessible through a stakeholder system network communication approach. The inclusive strategy is an effort to align root systems for sustainable development with stakeholders for Mexican SMEs in the manufacturing sector. This work addressed the following I4.0 pillars: 3 and 9.

Yadav, et al. (2020) present a study that aims to develop a structure to overcome the challenges of SSCM through solution measures based on industry 4.0 and the circular economy. This study identifies a unique set of 28 SSCM challenges and 22 solution measures. In addition, an automotive case organization is used to test the applicability of the framework developed through the hybrid Best Worst Method (BWM) - Elimination and Choice Expressing Reality (ELECTRE) approach. Entries for the BWM-ELECTRE approach are obtained by building a panel of experts within the case organization. Initial entries are taken for BWM comparisons to calculate the weight of SSCM challenges; whereas, a further comparison of challenges and solution measures is also obtained for the ELECTRE approach to calculate the final classification of the solution measures to overcome the SSCM challenges. The results of the case reveal that managerial and organizational challenges and economic challenges emerge as the most critical for the adoption of SSCM. The results of the present study will be beneficial for researchers working in the SSCM 4.0 industry and in the domain of the circular economy; Whereas, practitioners can use prioritized solution measures to formulate effective strategies to overcome SSCM adoption failures. This work addressed the following I4.0 pillars: 3 and 9.

Enyoghasi and Badurdeen (2021) present an investigation with a comparative analysis examining individual technologies in Industry 4.0 and their potential impact on sustainable manufacturing. A structure based on clusters of sustainability metrics for products, processes and systems is applied to examine these impacts. The results reveal that the literature is still limited in identifying opportunities to improve sustainability at different levels using technologies from Industry 4.0. The impact on many criteria related to product, process or sustainability at the system level due to Industry 4.0 technologies has not yet been examined. Comparative analysis, and other literature, are used to provide additional guidance for future research and opportunities on leveraging Industry 4.0 technologies for more sustainable manufacturing. The implications for the industry through providing a framework for identifying potential solutions to improve sustainable manufacturing performance using industry 4.0 technologies are also discussed. This work addressed the following I4.0 pillars: 3 and 9.

Nara, et al. (2021) developed a study investigating the impacts of Industry 4.0 technologies using the Triple Bottom Line perspective for sustainable development. They present a sustainability-oriented model for assessing the influence of Industry 4.0 technologies on sustainable metrics. The model analyses the impact of Industry 4.0 technologies on several key performance indicators related to sustainable development. The model was tested in the plastics industry, which has a high potential for technological 4.0 Industry aggregation in emerging economies. A diffuse multi-criteria TOPSIS method was used to classify Industry 4.0 technologies, identifying those with the strongest and weakest impacts on sustainable development. As a result, it was suggested that the internet of things, cyber-physical systems, sensors and the implementation of big data are engines for sustainable development. It also shown that these technologies are associated with substantial positive impacts on economic metrics. However, there was much less positive influence on environmental and social metrics, suggesting an imbalance in the perspective of the Triple Bottom Line for the plastics industry. In addition, negative impacts of robots on job creation and low influence of cloud computing technologies and systems integration for sustainable development were found. Based on these findings, this work contributed to the decision-making process by helping managers, process engineers and stakeholders to understand and estimate the expected impacts of Industry 4.0 technologies on economic, environmental and social aspects for sustainable development. This work addressed the following I4.0 pillars: 1, 3, 4, 6 and 7.

Costa, Ávila, Bastos and Pinto Ferreira, (2021) present the proposal of a system for remote monitoring of equipment in real time that meets the requirements of low cost, simplicity, and flexibility. The system monitors the equipment in a simple and agile way, regardless of its sophistication, installation constraints and company resources. A prototype of a system was developed and tested in both laboratory conditions and in a productive environment. The proposed architecture of the system comprises a sensor that transmits the machine's signal wirelessly to a gateway which is responsible for collecting all surrounding signals and send it to the cloud. During the testing and assessment of the tools, the results validated the developed prototype. As a main result, the proposed solution offers to the industrial market a new low-cost monitoring system based in mature and tested technology laid upon flexible and scalable solutions.

The articles previously presented were analysed based on the nine main pillars of I4.0 (see Table 5) and for the three pillars of sustainability (see Table 6). In both tables, for each of the works were identified which pillar(s) are addressed, and subsequently it was quantified the total percentage of the papers that cover each pillar and the percentage of the pillars that are covered by each paper.

Table 5 - Pillars of I4.0 addressed by the articles selected in the research.

Research papers \ **Pillars of I4.0**		1 - Big Data and Data Analytics	2 - Simulation	3 - Horizontal and Vertical Integration	4 - Industrial Internet of Things	5 - Autonomous Robots	6 - The Cloud	7 - Cyber Physical Systems/ Security	8 - Augmented Reality	9 - Additive Manufacturing	**% Pillars p/ article**
2017	Giret, et al.			x						x	22
	Man & Strandhagen			x		x			x		33
2018	Yazdi, et al.			x						x	22
	Thomas, et al.			x					x		22
2019	Varela, et al.	x	x			x					33
	Hidayatno, et al.			x							**11**
	Ren, et al.	x		x						x	33
	Ghadimia, et al.			x						x	22
	Lee, et al.	x	x	x		x			x	x	**67**
	Scavarda, et al.			x							**11**
2020	García-Muiña, et al.			x						x	22
	Ahmad, et al.	x		x					x		33
	Fatimah, et al.			x	x						22
	Bai, et al.		x	x							22

	Yadava, et al.	x			x	x				x	44
	Villara, et al.			x						x	22
	Yadav, et al.			x						x	22
	Enyoghasi, & Badurdeen			x						x	22
2021	Nara, et al.	x		x	x		x	x			56
	Costa, et al.				x						**11**
% Articles p/ pillar		28	11	**94**	22	17	**6**	**6**	22	56	

Table 6 - Pillars of sustainability addressed by the articles selected in the research.

Pillars of Sustainability / Research papers		Environmental	Social	Economic	**% Pillars p/ article**
2017	Giret, et al.			x	33
	Man, J. & Strandhagen, J.	x		x	67
2018	Yazdi, et al.			x	33
	Thomas, et al.			x	33
2019	Varela, et al.	x	x	x	**100**
	Hidayatno, et al.	x		x	67
	Ren, et al.			x	33
	Ghadimia, et al.		x	x	67
	Lee, et al.			x	33
	Scavarda, et al.		x		33
2020	García-Muiña, et al.	x	x	x	**100**
	Ahmad, et al.			x	33
	Fatimah, et al.	x	x	x	**100**
	Bai, et al.	x	x	x	**100**
	Yadava, et al.	x		x	67
	Villara, et al.		x	x	67
	Yadav, et al.			x	33
2021	Enyoghasi, & Badurdeen			x	33
	Nara, et al.	x	x	x	**100**
	Costa, et al.			x	33
% Articles p/ pillar		37	37	**95**	

Analysing the previous tables, it is possible verify the following:

- The I4.0 pillars more addressed are: Horizontal and Vertical System Integration; Additive Manufacturing and 3D Printing;
- The I4.0 pillars less addressed are: The Cloud; and the Cyber Security;
- None of the papers covers all the pillars of I4.0;

- The Sustainability pillar most addressed is the economic, by 95% of the papers, and with a large difference compared to the other pillars;
- There are only five papers (25%) that cover the 3 pillars of sustainability.

2.5.3. Conclusion

This work enabled the identification of the main approaches of intelligent or smart and sustainable manufacturing systems, and supply chains or networks in the scope of I4.0, based on a systematic review of the literature. The main objective of this work was to pay particular attention to sustainability issues, as this is considered a central and of upmost concern nowadays, in a I4.0 context, and underlying the smart factory concept. Through this work it was also possible to verify which are the main I4.0 pillars and sustainability pillars considered more frequently in research, which are: for I4.0 the Integration of Horizontal and Vertical Systems (94%) and Additive manufacturing and 3D printing (56%); for sustainability the economic dimension (95%) with a large difference compared to the other pillars.

Attending the central research question exposed in section one "Is there an increased attention being given to sustainability issues nowadays in the Industry 4.0?" the results suggest that there is not yet so much attention to the pillars of environmental and social sustainability, which are fundamental dimensions of sustainability. Considering that, there is space to increase the research of I4.0 with the aim of achieve a better compromise between industrial development and sustainability.

3. ROBOTIC PROCESS AUTOMATION

In the third chapter of this study, we delve into the inherent complexities of RPA Fundamentals, thereby providing a robust foundation for understanding Robotic Process Automation. Subsequently, we address the challenges and ethical considerations associated with RPA. Following this, we delve into Emerging Technologies in the realm of RPA, such as Artificial Intelligence, Blockchain, Hyperautomation, and Process Mining, which are shaping the evolution of this field. We identify some Best Practices for RPA and Emerging Technologies Implementation. We present a study on Decision Models for Sustainable RPA Implementation, aiming to facilitate informed long-term decision-making. Lastly, we introduce a study on a Framework for the Implementation and Control of Automation Projects, offering a practical guide for successful management.

3.1. Theoretical Foundations

> *Robotic process automation (RPA) is the use of software robots to automate repetitive tasks that are currently performed by humans. RPA robots are computer programs that can be programmed to follow specific instructions and complete tasks without human intervention. They can be used to automate a wide range of tasks, including data entry, processing payments, and customer service* (Gartner, 2022).

Robotic Process Automation (RPA) has emerged as one of the most promising technologies in recent years, showing exponential growth on a global scale. RPA entails a business process automation technology that enables the streamlining of repetitive and standardized tasks through the utilization of software robots (Awad & Elhoseny, 2023). These robots execute activities based on predefined rules and interact with existing systems in a manner akin to human beings. RPA stands as a disruptive technology reshaping the operational landscape of enterprises, fostering heightened operational efficiency, cost reduction, and an improved customer experience (Alves & Oliveira, 2023).

RPA distinguishes itself from other business process automation technologies, such as Business Process Automation (BPM), which require the reconfiguration of business processes for automation. RPA can be implemented atop existing processes without necessitating modification of the processes themselves (Alves & Oliveira, 2023).

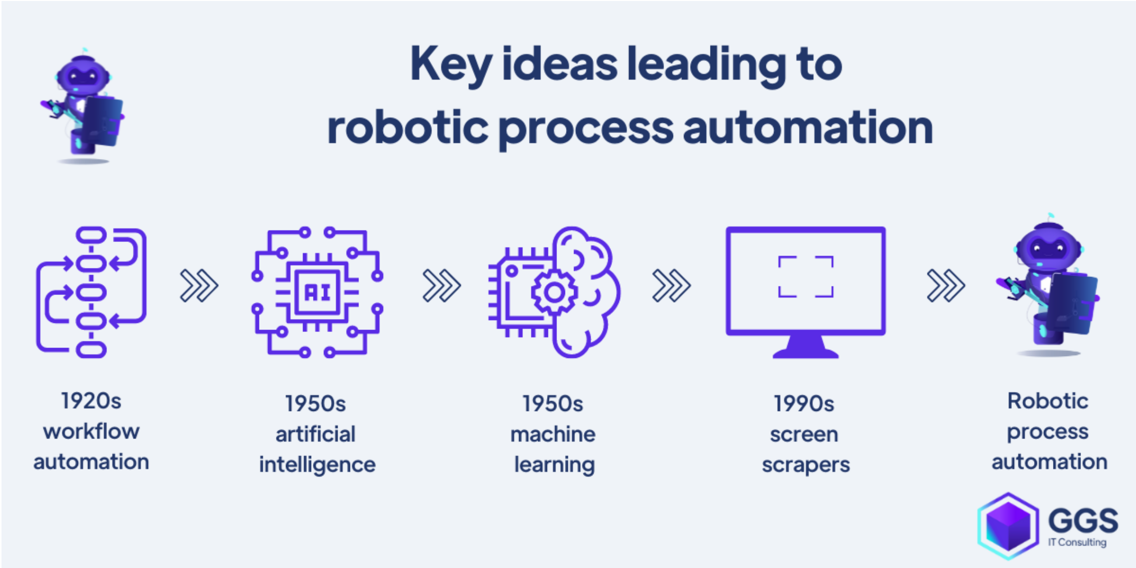

Figure 14 - The origins of robotic process automation (RPA) (Tajak, 2021)

The history of RPA dates back to the 1950s, when industrial automation started gaining widespread acceptance. The first programmable machines were developed in the 1950s and 1960s, enabling the automation of repetitive and standardized tasks in industrial contexts. With the evolution of information technology, new technologies emerged, enabling the automation of repetitive and standardized tasks in office environments. The first technology for business process automation was BPM, which originated in the 1990s (Ghosh & Mukhopadhyay, 2023). BPM facilitated large-scale automation of business processes but required restructuring of the processes to be automated (Chen, Xu, Z. & Chen, 2023).

> *RPA has the potential to significantly improve efficiency and productivity in a variety of industries. It can free up human workers to focus on more strategic and creative tasks, and it can help to reduce errors and costs (Gartner, 2022).*

In the 2000s, the first RPA solutions emerged, allowing the automation of repetitive and standardized tasks in office environments without altering the underlying processes. These solutions were limited and required human intervention in exceptional situations (Chen, Xu, Z., & Chen, 2023).

As technology advanced, RPA solutions became progressively more sophisticated and capable of handling exceptions, enabling automation of more complex business processes (Awad, & Elhoseny, 2023).

Over time, RPA technology further evolved and began incorporating other technologies such as Natural Language Processing (NLP), Optical Character Recognition (OCR), and Artificial Intelligence (AI). These technologies empower RPA to interact more naturally and intelligently with users, as well as process unstructured information such as images and text (Dimitrov & Ivanov, 2023).

> *RPA is not a magic bullet. It is important to carefully consider the right tasks to automate and to develop a plan for implementing RPA successfully. RPA can be a powerful tool for improving business processes, but it is important to use it wisely (Gartner, 2022).*

Presently, RPA solutions are capable of executing intricate tasks and even complete business processes without human intervention. These solutions can learn and adapt to new circumstances, becoming more efficient and effective over time. The popularity of RPA has grown rapidly in recent years, and numerous companies are adopting this technology to enhance the efficiency and productivity of their business processes. According to a study by Grand View Research, the global RPA market is projected to experience a compound annual growth rate of 33.6% between 2020 and 2027, reaching a value of $25.56 billion by 2027. Furthermore, RPA also holds the potential to positively impact the job market by automating repetitive tasks and enabling employees to focus on more strategic and creative activities. However, it is important to note that the adoption of RPA does not necessarily entail the elimination of jobs, but rather a transformation in the nature of roles performed (Goyal & Kaur, 2023).

3.2. Challenges and Ethical Considerations in Robotic Process Automation

Robotic Process Automation (RPA) has been steadily gaining popularity within enterprises as a means to enhance efficiency and curtail costs (Sousa Costa, et. al., 2023). This technology possesses the capability to automate repetitive tasks such as data entry and document processing, thereby freeing up time for employees to focus on more strategic pursuits. However, the implementation of RPA equally entails technical and ethical challenges that companies must contemplate in order to ensure sustainable and ethical automation (Patrício, et. al., 2023c). One of the foremost technical challenges of RPA is its integration with legacy systems. Numerous companies operate on outdated and intricate IT systems that were not designed to accommodate emerging technologies like RPA (Patrício, et. al., 2023e). This can lead to compatibility issues and technical difficulties during RPA implementation (Guo, Li & Zhang, 2023).

Another technical challenge pertains to scalability. While implementing RPA is relatively straightforward for simple and isolated tasks, it becomes more intricate when dealing with intricate and interdependent processes. It is imperative for companies to factor in RPA scalability within their implementation strategies to ensure the technology is poised to handle future growth. Security also poses a significant technical challenge in RPA implementation. Automation has the potential to expose sensitive and confidential data, necessitating that companies ensure their systems and processes are adequately secure to manage such exposure (Ibrahim& Al-Masri, 2023). This entails the adoption of cybersecurity measures like firewalls and encryption, as well as internal policies and procedures that ensure secure data access.

The implementation of RPA can significantly impact employees, particularly those engaged in tasks susceptible to automation. Automation can lead to job reductions and substantial shifts in employee responsibilities. Companies must meticulously consider the potential impact of RPA on employees and formulate strategies to ensure a smooth and equitable transition (Jamil & Khan, 2023).

> *Robotic process automation (RPA) is a rapidly growing field that is transforming the way businesses operate. RPA uses software robots to automate tasks that are currently performed by humans. These tasks can include data entry, customer service, and compliance.*
>
> *RPA offers a number of benefits, including:*
>
> - *Increased efficiency: RPA can automate tasks that are time-consuming and error-prone. This can free up human workers to focus on more strategic tasks.*
> - *Improved accuracy: RPA can help to reduce errors by eliminating human input.*
> - *Reduced costs: RPA can help to reduce costs by automating tasks that would otherwise be performed by humans.*
>
> *However, RPA is not without its challenges. One challenge is that RPA can be expensive to implement. Another challenge is that RPA can be difficult to scale.*
>
> *Overall, RPA is a powerful tool that can offer significant benefits to businesses. However, it is important to carefully consider the challenges of RPA before implementing it (Verhoeven, 2023).*

Companies also hold legal and regulatory responsibilities to ensure that RPA is used ethically and in compliance with applicable laws and regulations. This encompasses data privacy laws, consumer protection legislation, and labour laws. Companies must ensure their RPA strategies are designed in accordance with these laws and regulations, and that their systems and processes are audit-ready and transparent for easy review and monitoring.

RPA relies on data collection and utilization to make decisions and automate processes. However, data collection and usage raise pertinent ethical questions. Companies must ensure that collected data is obtained legally and that the collection process is transparent and fair to all parties involved. Additionally, it is paramount that companies guarantee ethical data utilization and transparent, fair decision-making based on that data.

Figure 15 - Ethical consideration in RPA (Kashif, 2023)

Companies also carry a social and environmental responsibility to ensure that RPA is used sustainably and responsibly. This involves reducing carbon emissions and minimizing the environmental impact of the technology, as well as ensuring that the technology is employed to enhance people's quality of life rather than harm them (Kannan & Kumar, 2023).

Prior to embarking on RPA implementation, companies must thoroughly assess the risks and potential impact of the technology on their employees, customers, and stakeholders. This entails evaluating the technical, ethical, legal, and regulatory risks of RPA and devising strategies to mitigate those risks (Kannan & Kumar, 2023).

Companies need to ensure that their RPA strategies are transparent and responsible. This encompasses transparency in data collection and utilization, transparency in algorithm-based decisions, and accountability for the impact of RPA on employees and stakeholders (Lin & Chen, 2023).

Companies must involve their employees in the RPA implementation process and ensure they are adequately trained and equipped to work with the technology. Furthermore, companies need to consider the impact of RPA on employees and develop strategies to ensure a fair and equitable transition (Mukhopadhyay & Ghosh, 2023).

Companies must ensure that their RPA systems and processes undergo regular audits and monitoring to ensure compliance with applicable laws and regulations, as well as to identify any potential technical or ethical issues (Siddiqui & Shah, 2023).

The implementation of RPA presents both technical and ethical challenges that companies must contemplate in order to ensure sustainable and ethical automation. It is crucial for companies to meticulously assess the risks and potential impact of RPA on their employees, customers, and stakeholders.

3.3. Emerging Technologies in Robotic Process Automation

> *Robotic process automation (RPA) is a relatively new technology approach that potentially can be utilized in a digital transformation initiative by automating the business processes in an enterprise. In RPA, the tasks are completed to simulate human-machine interaction behaviour (Lacity & Willcocks, 2016).*

In recent years, RPA has emerged as one of the technologies that has gained popularity among businesses looking to enhance the efficiency and effectiveness of their business processes. By automating repetitive and manual tasks, RPA has helped companies reduce operational costs, improve process quality, decrease human errors, and free up time for employees to focus on more strategic tasks (Patrício, 2023).

Despite all the benefits of RPA, the technology still has its limitations and challenges. For instance, automating complex and highly variable processes remains a challenge, and RPA solutions might be limited in terms of intelligence and adaptability. To address these challenges, various emerging technologies are being integrated into RPA, such as artificial intelligence, blockchain, hyperautomation, and process mining (Lacity & Willcocks, 2016).

> *This new technology is emerging and gaining more attention, including RPA in the digital*

*transformation research. RPA is mapped to be an important theme if we talk about digital transformation initiatives (*Maalla, 2019).

In this chapter, we will introduce these emerging technologies in RPA, explain how they can be used to enhance business process automation, and discuss the challenges and opportunities they present (Patrício, 2023).

Artificial intelligence (AI) is one of the most promising technologies that can be integrated into RPA. AI can enhance the automation of repetitive and manual tasks, allowing software robots to make decisions based on contextual information and machine learning (Maalla, 2019).

With AI, RPA robots can identify patterns in large datasets, predict outcomes based on statistical models, and even learn from human interaction. This means that RPA robots can adapt to different scenarios and environments, improving the accuracy and efficiency of business process automation (Patrício, 2023).

Some examples of AI use in RPA include fraud detection, demand forecasting, and data quality improvement (O'Leary & McLeod, 2020). AI can also enhance user interface and customer experience through the implementation of chatbots and virtual assistants.

However, incorporating AI into RPA also presents challenges. For example, implementing AI solutions may require advanced technical knowledge and a large volume of data to train machine-learning models. Additionally, data privacy and security must be ensured, along with transparency in the decisions made by RPA robots.

Blockchain is another emerging technology that can be used in conjunction with RPA. Blockchain is a decentralized and secure network of digital records that can be used to ensure data and transaction transparency and security.

By incorporating blockchain into RPA solutions, it is possible to ensure the integrity and authenticity of data and transactions, as well as transparency and traceability of processes. This can be particularly useful for companies dealing with sensitive and critical information, such as financial transactions and customer data.

One potential application of blockchain in RPA is the automation of audit processes. With blockchain, an immutable record of all transactions and business activities can be created, allowing audits to be conducted more efficiently and transparently. Additionally, blockchain can help reduce fraud and corruption by ensuring data and process integrity (Patrício, 2023).

However, implementing blockchain in RPA solutions also presents challenges. As blockchain is a relatively new technology, many companies still lack experience in its implementation. Furthermore, implementing blockchain in RPA solutions can be complex and require advanced technical knowledge.

Hyperautomation is another emerging technology with the potential to revolutionize how companies implement business process automation. Hyperautomation combines various automation technologies, such as RPA, AI, machine learning, and process mining, to create a comprehensive and integrated solution for business process automation (Patrício, 2023).

With hyperautomation, it becomes possible to automate more complex business processes that require human intervention. For instance, hyperautomation can be used to automate processes involving document interpretation and complex decision-making based on data.

> *RPA is a technology that uses software to automate tasks that would otherwise be performed by humans. It is often used in business process automation (BPA), where it can be used to automate repetitive, rule-based tasks. RPA can be used in a variety of industries, including finance, healthcare, and manufacturing* (Turban, et al., 2022).

Process Mining is another emerging technology that can be used in conjunction with RPA to improve the efficiency of business processes. Process Mining is a data analysis technique that allows companies to visualize and analyse their existing processes, identify bottlenecks and inefficiencies, and provide insights for improvements (Patrício, 2023).

By incorporating Process Mining into RPA solutions, it becomes possible to automate business processes more efficiently and effectively. Process mining can be used to identify processes that are best suited for automation, as well as to improve the efficiency of existing automated processes.

Emerging technologies like AI, blockchain, hyperautomation, and Process Mining have the potential to transform the way companies implement business process automation. By incorporating these technologies into RPA solutions, it is possible to automate business processes more efficiently and effectively, reduce costs, improve accuracy, and increase efficiency (Patrício, 2023).

However, the implementation of these technologies also presents challenges. Advanced technical knowledge is required to implement these solutions effectively and ensure data security and privacy. Additionally, implementing these technologies can be complex and require significant investments in technology and resources.

RPA is a rapidly emerging technology that has the potential to revolutionize the way businesses operate. It is a software-based solution that uses bots to automate tasks that would otherwise be performed by humans. RPA can be used to automate a wide range of tasks, including data entry, customer service, and invoice processing (Verma and Sharma, 2022).

In summary, the success of implementing RPA solutions that incorporate these technologies depends on a careful and strategic approach that considers the specific needs and goals of each organization. Companies need to carefully evaluate the available RPA solutions in the market and choose the one that best fits their specific needs and requirements (Verma & Sharma, 2022).

Furthermore, it is essential for companies to understand the ethical and legal implications of business process automation and ensure compliance with applicable laws and regulations. This includes ensuring data privacy and security, as well as transparency and explain ability of decisions made by RPA robots (Patrício, 2023).

By leveraging emerging technologies such as AI, blockchain, hyperautomation, and Process Mining, RPA has the potential to revolutionize the way companies automate their business processes. However, to fully harness these technologies, companies need to adopt a strategic and collaborative approach involving all relevant departments and stakeholders.

3.4. Best Practices for the Implementation of Robotic Process Automation and Emerging Technologies

The integration of RPA and emerging technologies within a company can prove to be an intricate process, demanding meticulous planning and strategic deliberation. In this chapter, we shall outline the best practices for a successful implementation of RPA and emerging technologies within businesses (Patrício, et. al., 2023b). We will delve into optimal strategies for selecting processes to be automated, assessing vendors, and deploying automation solutions. Furthermore, we will address the most prevalent challenges that arise during the implementation of RPA and emerging technologies, as well as the methods to overcome them (Wrona & Pająk, 2022).

The selection of processes to be automated constitutes a pivotal phase in the implementation of RPA and emerging technologies. It is of utmost importance to choose the most suitable processes, capable of delivering tangible benefits to the company. To achieve this, an in-depth analysis of the processes becomes imperative in order to pinpoint those with the highest potential for automation. The chosen processes should exhibit a significant volume of manual tasks, possess repetitive characteristics, and conform to well-defined patterns (McKinsey & Company, 2022).

The evaluation of suppliers represents another critical step in the implementation of RPA and emerging technologies. It becomes imperative to thoroughly assess supplier options and opt for the one that best aligns with the company's needs. The company should take into account the supplier's experience in RPA and the implementation of emerging technologies, the quality of technical support provided, and the availability of resources for the implementation (McKinsey & Company, 2022).

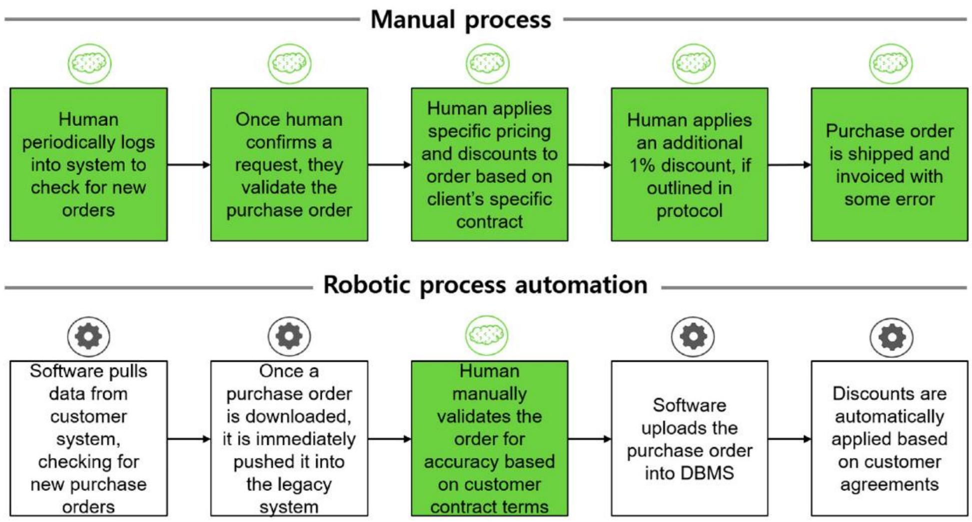

Figure 16 - Differences between manual and robotic processes. Adaptation based on Refs. (Hyen, Lee, 2018; Schatsky, Muraskin, Iyengar, 2016)

The implementation of automation solutions constitutes the final phase of RPA and emerging technologies implementation (Patrício, 2023d). It becomes paramount to execute them judiciously and systematically, adhering to best practices, to ensure the realization of expected benefits. Prior to implementation, rigorous testing is essential to ascertain the proper functionality of all components. Additionally, involving the team responsible for process operations in the implementation process is crucial, ensuring they comprehend the new solution and employ it effectively (Ruecker & Weske, 2019).

The implementation of RPA and emerging technologies may encounter common challenges. One such challenge is team resistance, as they might perceive the automation of processes as a threat to their jobs (Hamid, & Khan, 2021). Clearly communicating the benefits of automation and involving the team in the implementation process becomes essential. Another frequent challenge is the integration with legacy systems that may not be compatible with the new solution. In this context, conducting a meticulous analysis of existing systems and implementing appropriate integration solutions assumes significance (Ruecker & Weske, 2019).

Below is a section on a literature review work developed to identify the existing models in the literature review on the topic under study (Appendix 1).

3.5. Literature review of decision models for the sustainable implementation of Robotic Process Automation

RPA aims to automate business processes or parts of them with software bots (bots for short) by mimicking human interactions with the graphical user interface (Patrício, et al., 2023). Software robots allow the automation of many BackOffice related jobs that were previously performed by human workers (Varela, et al., 2022). Recently, many RPA approaches were implemented and the RPA software market grew by 60% in 2018 (Asatiani & Penttinen, 2016). On one hand, RPA shall relieve employees from tedious works (Leopold, et al., 2018). Employees might, therefore, refuse the use of bots, fearing that they lose their job otherwise (Gartner, 2020).

The concept of sustainability has received increasing global attention from the public, academic and business sectors. The World Commission on Environmental Development (WCED) defined sustainable development as development that meets the needs of the present without compromising the ability of future generations to meet their own needs (Hallikainen, et al., 2018). The importance of social issues and the natural environment for societies and businesses has evolved dramatically over the past 50 years. Corporate managers are becoming aware of the need to expand their goals beyond traditional financial expectations. It can be seen that since the term business sustainability emerged, more and more companies have emerged that address the importance of sustainability for their business, thus improving their economic, environmental and social goals (Fernandez & Aman, 2018). Organizations that seek to be sustainable must pay attention to their performance in three dimensions: economic performance, social equity and ecological preservation (World Commission on Environment and Development (WCED, 1987).

Next, according the main aspect presented, the central research question underlying this work is formulated.

- **What are the decision models for the implementation of Robotic Process Automation that exist in the literature?**

The objective of this work is focused on a literature review for the identification and analysis of Robotic Process Automation implementation models. To achieve the objective of this work, a bibliographic analysis was first carried out, focusing on the identification of works that develop models related to this theme. In a second phase, we will carry out an analysis and synthesis of the models that address the issue of Robotic Process Automation implementation.

3.5.1. Methodology

The methodology underlying this work was based on the analysis of a set of considered relevant data sources. Throughout this work, relevant information for the topic under study will be put forward, based on the set of contributions analysed, from leading authors who addressed this theme or some part of it. The collection of articles found and analysed was obtained by using the database of the online "B-on" library. This platform was selected as it does enable to reach the full content of a wide range of scientific publications in relevant and indexed journals, along with publications in international scientific conferences, also indexed in ISI WOS and/ or Scopus systems. "B-on" is one of the most extensive databases, which include thousands of peer-reviewed journals in a widened range of fields of different scientific areas. Through the online scientific library "B-on", from the Portuguese Foundation for the Science and Technologies, researchers can access to most well-known international scientific databases, thus this library was used to carried out the search process underlying this work, based on the following three groups (Group 1, Group 2, and Group 3) of shown in the Table 7.

Table 7 - Groups of searched through "B-on".

Group 1	Group 2	Group 3
"RPA" Or "Robotic Process Automation" Or "Intelligent Process Automation" Or "Tools Process Automation" Or "Artificial Intelligence In Business Process" Or "Machine Learning In Business Process" Or "Cognitive Process Automation"	"Model" Or "Model Evaluation" Or "Tool" Or "Tool Evaluation" Or "Evaluation" Or "Framework"	"Sustainability" Or "Sustainable" Or "Social Sustainability" Or "Environment" Or "Environmental Sustainability" Or "Economic Sustainability" Or "Sustainable Development"

Four research tests were carried out through the "B-on" by using the three groups and the OR operator as a connector between the Title or the Key words (KW) of the intended sets. In Table 8 are expressed the number of articles found in each research test.

Table 8 - Research tests performed through the “B-on”.

	Title	OR	Key words (KW)	
Set 1	(Group 1 AND Group 2 AND Group 3)	OR	(Group 1 AND Group 2 AND Group 3)	n = 0
Set 2	(Group 1 AND Group 2)	OR	(Group 1 AND Group 2)	n = 320
Set 3	(Group 1 AND Group 3)	OR	(Group 1 AND Group 3)	n = 13

Next, throughout the research process, a set of filters were applied, based on the sets of publications obtained, and the results obtained, in terms of number of publications, are summarized in Table 9.

Table 9 - Publications obtained through the B-on, after the application of some filters.

	Set 1	Set 2	Set 3
Initial result:	0	320	13
1 - Restrict to: Peer Reviewed	0	222	9
2 -Type of fonts: Academic Journals; Conference Materials; Books	0	222	9
3 - From: 2000 to 2021	0	166	9
4 - Language: English	0	160	9
5 - Restrict to: Full Text	0	126	9
Final result:	0	126	9

After the applied filters, a reading of the title, the key terms and the resume of each of the articles was carried out to verify which articles were directly related to the research. From the carried-out research, 333 papers were obtained, applied the filters we verified a total of 135 articles and of which only 14 were framed with the theme. One of the reasons for the small number of framed papers is related with the fact that most of them were related with evaluation of the formation of a collaborative network that is not the scope of this work. So, evaluating the formation of a network is not the same as evaluating the participation or integration of an organization in a network. Figure 15 represents a flow diagram of the literature search carried out, and respective screening of the methodology used in this research work.

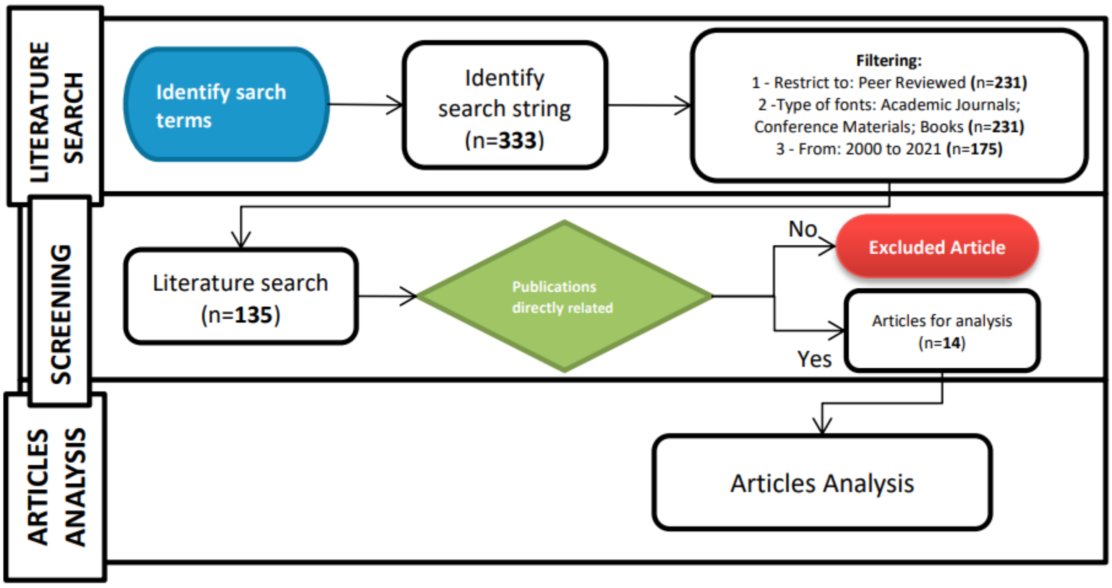

Figure 17 - Flow diagram of literature search and respective screening, adapted of (Neves, Godina, Azevedo, Matias, 2020).

3.5.2. Articles Synthesis and Analysis

In this section, the synthesis and analysis of the articles are presented. Data about the articles will be presented found, and which were considered the most relevant on the topic focused on in this work. Table 10 presents the 14 articles found and the themes of the identified models.

Table 10 - Identified articles and the respective themes of the models found.

Themes of the models / Articles	Decision support model for implementing RPA	Decision support template for selecting RPA tool	RPA Governance Assessment Model	RPA Financing Return Assessment Model	RPA monitoring assessment model
Silva, A. (2017)		X			

Pozdnyakov, O. (2019)	X				
Sobczak, A. (2019)				X	
Wanner, et al. (2019)				X	
Kopper, et al. (2020)	X				
Timbadia, et al. (2020)	X				
Wellmann, et al. (2020)					X
Wewerka, et al. (2020)	X				
Mora & Sánchez (2020)	X				
Pargana (2020)	X				
Amaral (2020)			X		
Farinha (2021)	X				
Grande (2021)	X				
Hernm, et al. (2022)	X				
% Themes p/ articles	**64**	7	7	14	7

It was verified among all the models found that there are 5 different themes of models related to RPA. The topic that is most studied is the decision support model of RPA implementation (64%). For this work, we will consider for a more detailed analysis the models that consider the decision support theme for the implementation of RPA. Table 12 presents the inputs, constraints, tools and outputs of the decision support models for RPA implementation.

Table 11 - Articles and the respective topics of the models.

Analysis topic \ **Articles**		Pozdnyakov, O. (2019)	Kopper, et al. (2020)	Timbadia, et al. (2020)	Wewerka, et al. (2020)	Mora & Sánchez (2020)	Pargana (2020)	Farinha (2021)	Grande, V. (2021)	Hernm, et al. (2022)
Inputs	Number of employees performing the process.	x		x			x	x	x	x
	Degree of data structure of process	x		x			x	x	x	x

	inputs.									
	Number of systems.	X		X			X	X	X	X
	Degree of process standardization.	X		X			X	X	X	X
	Process maturity level (changed in the last 12-18 months).	X		X			X	X	X	X
	Number of process exceptions.	X		X			X	X	X	X
	Degree of value of the process to the business (high or low).	X		X			X	X	X	X
	Number of transactions.	X		X			X	X	X	X
	Process complexity level (high, medium or low).	X		X			X	X	X	X
	Workflow degree (repetitive and monotonous).	X		X			X	X	X	X
	System stability degree.	X		X			X	X	X	X
	Current cost of the process.	X		X			X	X	X	X
	The process is rule-based.	X		X			X	X	X	X
	RPA user acceptance				X					

	Facilitating conditions				X					
	Presentation of the final result				X	X				
	Joy of innovation				X	X				
	Social influence				X					
	Software development		X							
	FTE savings			X						
	Faster process	X				X				
	Availability improvement	X				X				
	Compliance improvement	X		X		X				
	Higher Education Institutions with Business Process Management					X				
	Financial / Administrative / Back-office						X		X	
	Startup, Implementation, and Scaling RPA Project									X
	Theoretical investigation				X					
	Validated with criteria from 5 RPA projects							X		
Constraints	Data from Heliotec, a Paraguayan solar and renewable		X							

	energy company									
	Validated with 1 case study	X		X			X			
	Partial least squares algorithm				X					
	Delphi							X		
	Business Process Reengineering (BPR)		X							
	Questionnaire and statistical analysis					X	X			
	Algorithm for filling in weights to criteria and decision making at pre-defined intervals			X						
	Interviews and statistical analysis	X							X	X
	Linear Sequential Model Algorithm									X
Tools	Fuzzy Inference System Algorithm								X	
	Economic level Evaluation	X	X	X		X	X	X	X	X
Outputs	Social level Evaluation				X	X				

	Environment level Evaluation									

To present the results of this work, we detail below the synthesis of the results of the in-depth analysis of the articles examined.

3.5.3. Synthesis of the results

Analysing the previous tables, it is possible verify the following remarks:

- It was verified the existence of five themes of RPA evaluation models;
- It was found that 64% of the models found refer to the issue of RPA implementation;
- The pillar of Sustainability most addressed in the models is the economic one;
- The Social Sustainability pillar is also addressed in models;
- There are no works that contemplate the pillar of Environmental Sustainability, which leaves the door open to be one of the first works that evaluate technology in terms of this level of sustainability;
- There is no integration of the three pillars of sustainability in any of the works;
- It is important to carry out the evaluation and implementation of an RPA Project, which can integrate the three pillars of sustainability, social, economic and environmental;
- Few works were found as models;
- There is an opportunity to create a new evaluation model for the RPA and, moreover, that brings with it a joint evaluation of the three pillars of sustainability, thus managing to evaluate in a general and complete way, in addition to the economic levels, which are already studied, the social and environmental levels for the organization.

3.5.4. Conclusion

The implementation of Robotic Process Automation (RPA) in a sustainable way is a topic of wide spectrum and of great interest in research, since the magnitude of the resulting value of decision support models for the implementation of RPA does not aim at the integration of three pillars of sustainability. Existing models alone assess decision making from a primarily economic perspective.

This work analysed the models and works available in the literature and identified important analysis topics for the pre-evaluation of future RPA implementations.

Considering the results of the work, the authors are convinced that there is room to improve research in this area and that a more robust evaluation model should be developed. Seems like there are not many jobs on this topic, making a link between the pillars of sustainability and the implementation of RPA, and this work aimed at this integration, considering the three pillars of sustainability. These pillars are extremely important for companies and individuals, for example, in the proper recognition and relevance of sustainability concerns.

3.6. Structure for the Implementation and Control of Robotic Process Automation Projects

The implementation of good management and governance practices has become one of the main focuses within organizations. Therefore, it is necessary for each sector/area to make adaptations to ensure better adaptation to the management policies adopted by the business organization (Brown, C. V., 2003). This work will focus on the adequacy of these management policies within the Robotic Process Automation (RPA) area, one of the IT (Information Technology) areas.

The management of processes in the IT (Information Technology) area seeks to develop policies, standards, norms, and guidelines that ensure everything is done correctly. In this way, it contributes to the guarantee of increasingly reliable and robust processes (Almeida, 2017).

The governance and management of IT end up harmonizing and combining the activities that the IT area develops according to the needs and strategic objectives established by the organization. Always looking to develop reliable and available services to achieve business excellence where management processes are implemented (Herm, 2022).

The implementation of a management structure in the RPA area should contribute to a greater effectiveness of all the processes developed, in addition to directing efforts to then achieve the defined results.

RPA aims to automate business processes or parts of them with software robots, through the reproduction of human interactions with the graphical user interface (Leopold, Van der Aa, Reijers, 2018; Hallikainen, Bekkhus, Pan, 2018). In addition to productivity and improvement of administrative processes, it helps to relieve employees of tedious and repetitive work. Despite being a tool that significantly contributes to improving the quality of life at work, a critical point related to this technology is the rejection by employees for fear of losing their jobs due to the implementation of robots (Lange, Busch, Delgado-Ceballos, 2012).

RPA is about using digital robots and artificial intelligence to eliminate/minimize human errors in repetitive processes and make them faster and more efficient. It is a technology that mimics the way a human interacts with the machine, performing tasks through configured software or another technological aspect, such as one (or more) robots (Zhang, Wen, 2021).

The implementation of RPA reduces the manual burden within companies, in their various administrative or operational sectors. In this way, it guarantees greater autonomy to the teams, to focus on strategic issues that lead the company to fulfil its objectives (William, 2019).

To manage the quality of products, several tools and techniques are used, among them the PDCA cycle, which is also called the Deming cycle. Initially it was created for the process of quality improvement in the production area, however, this is a tool capable of being used in any management process (Moen, 2009).

The PDCA was developed in the 17th century by Francis Bacon when he proposed inductive studies, which went through stages that were later identified in the PDCA cycle.

The application of the PDCA cycle is possible when:

- Starting a new improvement project;
- Developing a new or improved design of a process, product, or service;
- Defining a repetitive work process;
- Planning data collection and analysis in order to verify and prioritize problems or root causes;
- Implementing any change;
- Working toward continuous improvement.

In its currently used version, the PDCA cycle presents steps for the execution of a process, promoting continuous and incremental improvements, as a managerial decision-making tool, promoting the standardization of processes (Feltraco, 2012). As the cycle repeats itself, the process is confirmed or adjusted, generating improvements and learning, involving the stages of: Planning (Plan), in which strategies and objectives are defined. paths to be followed, the re-sources to be used, the attribution of responsibilities, and the definition of objectives in a measurable way;

Execution (Do), in which the implementation of the planning occurs, promoting the implementation of the strategy; Control (Check), to study and examine the results, check if the objectives were met, monitor to identify if there were deviations from what was planned; Act, in which the strategy is confirmed or re-thought, lessons about the results of the process are identified, and the standardization of results is carried out, in the search for continuous improvement (Pietrzak, Paliszkiewicz, 2015).

The use of the PDCA in the Governance process applied to RPA, was carried out from the definition of the actions to be carried out in each of the stages of the PDCA, as shown below:

Planning:

- Identify the objectives of the business area;
- Define your company's RPA goals.

Execution:

- Definition of necessary actions (internal or external to your organization)

Control:

- Definition of Measuring mechanisms of the performance achieved, comparing it with the objectives defined in the planning.

Action:

- Analyse cycle results to complete the process or restart and analyse failures.

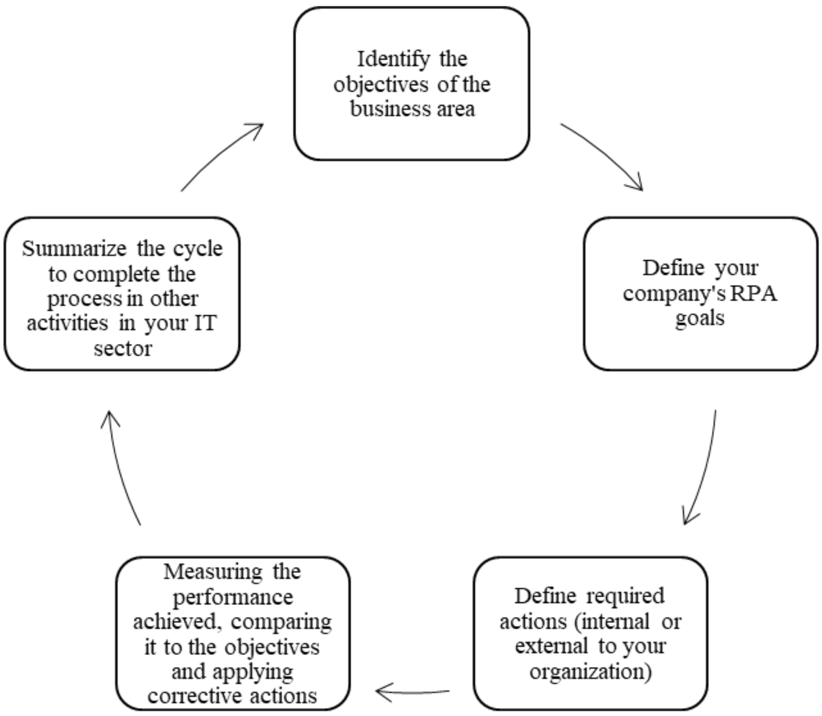

Figure 18 - Steps to Implement a Governance Process in RPA.

The management process of IT processes is constantly evolving, so the development of management/ governance methods must be adapted to the specificities of technology, thus ensuring an improvement in the quality of the projects developed. With this idea as a reference, this work seeks to answer a key question:

- **How is it possible to guarantee the quality of implementation and control of Robotic Process Automation (RPA) projects?**

The importance of using management methodologies is directly related to the results achieved by the organization. Regardless of the management model used, planning and monitoring the strategies adopted is the key to achieving the expected results.

The objective of this work is to develop a structure for the implementation and control of Robotic Process Automation projects.

3.6.1. Methodology

The methodology for the present work is based on the analysis of a set of data sources considered very important. Through the set of contributions analysed throughout this work, with investigations of reference authors who investigate this theme or part of it. The set of articles and investigations that were verified and analysed here were obtained through the database of the online library "B-on". This platform was selected because it allows reaching the full content of a wide range of scientific publications in relevant and indexed journals, together with publications in international scientific conferences, also indexed in the ISI WOS and/or Scopus systems. "B-on" is one of the most extensive databases, which includes thousands of peer-reviewed journals in a wide range of fields from different scientific fields. Through the online scientific library "B-on", of the Portuguese Foundation for Science and Technologies, researchers can access the best-known international scientific databases, so this library was used to carry out the research process underlying this work, based on the following three groups (Group 1, Group 2 and Group 3) shown in Table 12.

Table 12 - Groups of searched through "B-on".

Group 1	Group 2	Group 3
"RPA" Or "Robotic Process	"Governance" Or	"Implementation"

Automation" Or "Intelligent Process Automation" Or "Tools Process Automation" Or "Artificial Intelligence in Business Process" Or "Machine Learning in Business Process" Or "Cognitive Process Automation"	"Management" Or "process control" Or "management tools" Or "project management" Or "team management" Or "cycle PDCA"	Or "Model" Or "analysis" Or "development" Or "framework"

Four research tests were carried out through the "B-on" by using the three groups and the OR operator as a connector between the Title or the Keywords (KW) of the intended sets. In Table 13 are expressed the number of articles found in each research test.

Table 13 - Research tests performed through the "B-on".

	Title	OR	Keywords (KW)	
Set 1	(Group 1 AND Group 2 AND Group 3)	OR	(Group 1 AND Group 2 AND Group 3)	n = 7
Set 2	(Group 1 AND Group 2)	OR	(Group 1 AND Group 2)	n = 47
Set 3	(Group 1 AND Group 3)	OR	(Group 1 AND Group 3)	n = 1675

After the applied filters (Figure 17), a reading of the title, the key terms and the resume of each of the articles was carried out to verify which articles were directly related to the research. From the carried-out research, 1729 papers were obtained, applied the filters we verified a total of 948 articles and of which only 18 were framed with the theme.

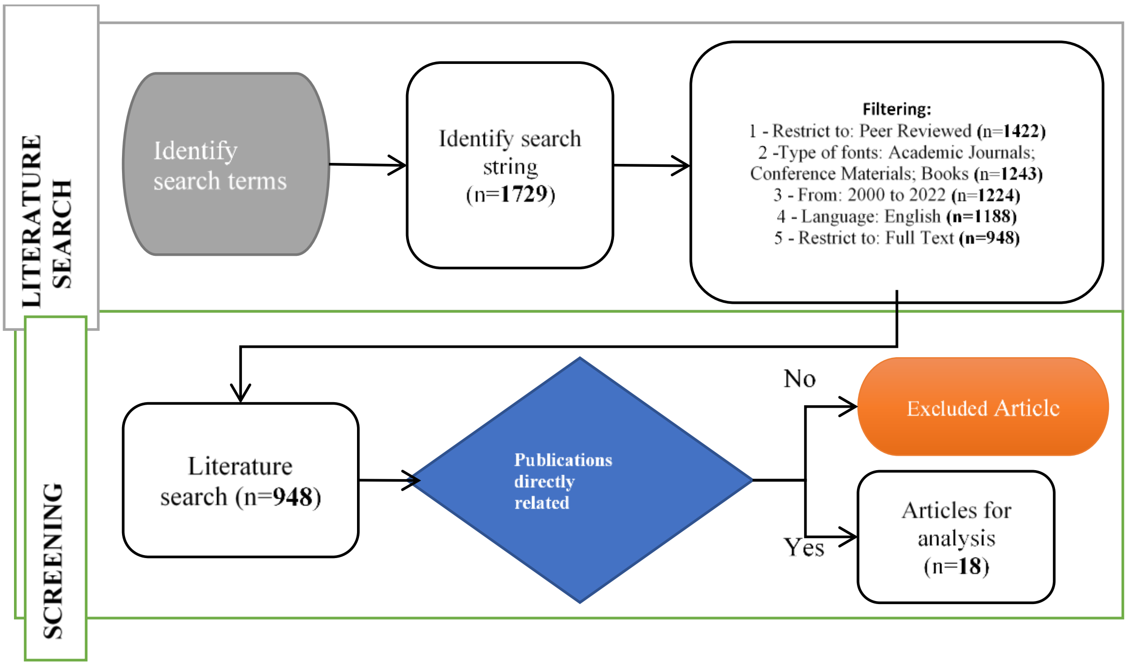

Figure 19 - Flow diagram of literature search and respective screening adapted from (Neves, Godina, Azevedo, Matias, 2020).

Next, throughout the research process, a set of filters were applied, based on the sets of publications obtained, and the results obtained, in terms of number of publications, are summarized in Table 14.

Table 14 - Publications obtained through the B-on, after the application of some filters.

	Set 1	Set 2	Set 3
Initial result:	7	47	1675
1 - Restrict to: Peer Reviewed	5	22	1395
2 -Type of fonts: Academic Journals; Conference Materials; Books	5	21	1217
3 - From: 2000 to 2022	5	19	1200
4 - Language: English	5	18	1165
5 - Restrict to: Full Text	5	18	925
Final result:	5	18	925

The following section 3.6.2. the analysis and synthesis of the articles. Here, data about the articles we consider relevant to the subject of this work are presented.

3.6.2. Articles Analysis

The following table 16 presents an analysis of the 18 articles identified related to the subject under study and the phases of the PDCA governance life cycle. We can see the table below.

Table 15 - Studies carried out in RPA and the implementation phases of the governance model based on PDCA.

PDCA Cycle / **Papers References**	1- Identify the objectives of the business area	2- Define your company's RPA goals	3 - Define the necessary actions (internal or external to your organization)	4 - Measure the performance achieved, comparing it with the objectives and applying corrective actions	5 - Summarize the cycle to complete the process in other activities in your IT sector
Kazim, A., 2020				x	
Borghoff, V., Plattfaut, R., 2022			x		
Kämäräinen, T., 2018			x		
Petersen, J., Schröder, H., 2020		x	x		

Kedziora, D., Penttinen, E., 2020			x	x	
Asatiani, A., Kämäräinen, T., Penttinen, E., 2019			x	x	
Wang, S., Sun, Q., Shen, Y., Li, X., 2022		x		x	
Rogers, S., Zvarikova, K., 2021				x	
Bhuyan, P. K., Dixit, S., Routray, S., 2018		x	x		
Anagnoste, S., 2013	X	x			
Vasarhelyi, M. A., 2013			x	x	
Feio, I. C. L., Santos, V. D., 2022				x	
Rutschi, C., Dibbern, J., 2020				x	
Marciniak, P., Stanisławski, R., 2021		x	x	x	
Asatiani, A., Copeland, O.,	X	x	x		

Penttinen, E., 2022					
Herm, L. V., 2022			x	x	
Nitin Rajadhyaksha, C., Saini, J. R., 2022		x	x		
% Articles / phase	11%	39%	**61%**	**61%**	0%

3.6.3. Synthesis Results

After analysing the previous table, you can verify the following observations:

- The phases that are most addressed by the investigations found are, respectively, with 61%, at 3 - Define the necessary actions (internal or external to your organization); and 4 - Measure the performance achieved, comparing it with the objectives and applying corrective actions.
- None of the identified works addresses phase 5 - Summarize the cycle to complete the process in other activities in your IT sectoring their investigation.
- There is no work that addresses all phases of the PDCA governance life cycle, that is, there is a possibility here for the creation of this work, that is, a model proposal that covers all these phases of the PDCA life cycle governance.
- The works with the reference (Marciniak, Stanisławski, 2021; Asatiani, Copeland, Penttinen, 2022) were the ones that addressed more phases of the PDCA cycle in their investigations.
- The works with the reference (Kazim, 2020; Borghoff, Plattfaut, 2022; Kämäräinen, 2018; Rogers, Zvarikova, 2021; Feio, Santos, 2022; Rutschi, Dibbern, 2020) were the ones that addressed fewer phases of the PDCA cycle in their investigations.

3.6.4. Implementation and control Robotic Process Automation projects: framework proposal

In this section, the proposed framework will be presented.

Through this proposal for a Robotic Process Automation management model, an organization can implement its exact functions and have the human resources indicated, knowing exactly what each of the functions must perform in its day-to-day work. Determine which are the process indicators and monitor the development of each project in an optimized way.

After identifying the conclusions of the analysis table of the identified works, we move on to the presentation of the proposal for the Robotic Process Automation framework.

3.6.5. Identify the objectives of the business area

In the first stage, the objective of the RPA area was identified, as observed in the literature review (Anagnoste, 2013; (Asatiani, Copeland, Penttinen, 2022) and the definition adopted for this work. Perform routine activities, normally performed by humans, in an automatic, simple and flexible way, making organizations more effective in business processes.

3.6.6. Define your company's Robotic ProcessAutomation goals

In the second stage, the main goals that guarantee the achievement of the pro-posed objective were defined, according to the works (Petersen, Schröder, 2020; Wang, Sun, Shen, Li, 2022; Bhuyan, Dixit, Routray, 2018; Anagnoste, 2013; Asatiani, Copeland, Penttinen, 2022; Nitin Rajadhyaksha, Saini, 2022).

- Increase in service productivity;
- Processing improvements;
- Reduce service costs;
- Operational efficiency gains;
- Greater service profitability.

3.6.7. Define the necessary actions (internal or external to your organization)

In the stage, a definition was created for the organization of the tasks carried out from the analysis of the RPA life cycle and from there different levels of implementation and organization of work were defined.

3.6.8. Organizational Structure of the teams

After the articles, the need to create different levels of complexity of the governance process in the area of RPA analysis was defined. Because according to the number of processes, the structure needs a greater organization and specialization of the team in each of the operational and management processes. This was based on the literature and on-site organization of RPA processes in companies using this technology.

Firstly, we identified the various phases of the Robotic Process Automation life cycle.

Table 16 - RPA lifecycle stages.

RPA lifecycle stages
1 – Analysis
2 - Requirements gathering
3 - Design - Project development
4 - Testing phase
5 - Deployment & Hyper care
6 - Go-live and Support

Each of these phases presented has specific characteristics, which are described below:

1. **Analysis –** here the main objective is to identify new project opportunities and carry out an analysis of the same project.
2. **Requirements gathering –** here the main objective is to carry out all the requirements gathering (access/inputs/outputs/details) associated with the project.
3. **Design – Project development –** here the main objective is to carry out the final design of the solution and the development of the project.
4. **Testing phase –** here the main objective is, after the end of development, to start testing the project.
5. **Deployment & Hyper care –** here the main objective is the deployment of the project in production and its follow-up, and final approval of the project.
6. **Go-live and Sustentation –** here the main objective is to get the project into support, that is, its monitoring, and the accomplishment of some necessary evolution to the project.

After identifying the various phases of the RPA lifecycle, it was proposed, for the implementation of

RPA, three levels of Robotic Process Automation state in an organization (Level 1; Level 2; Level 3). Level 1 is the basic level, that is, the moment when an organization is in an initial state of implementation of Robotic Process Automation technology. Level 2 is the intermediate level, that is, the moment when an organization has left Level 1 and is in an intermediate state, with some workload, where there is a need for more functions for the Robotic Process Automaton. Finally, Level 3 is the advanced state, that is, the moment when an organization has left Level 2 and is in an advanced state, with a lot of work, where it has the need to create sub-stations teams within the RPA team to do specific tasks.

To this end, specific jobs were identified for each of the team levels, a demonstrated in Tables 18, 19 and, 20.

Table 17 - Level 1 functions.

Workplace - Level 1
Senior RPA Developer (DS)
RPA Team Manager (TM)

Table 18 - Level 2 functions.

Workplace - Level 2
Business Analyst (BA)
Full RPA Developer (DP)
Senior RPA Developer (DS)
RPA Team Manager (TM)
RPA Project Manager (PM)

Table 19 - Level 3 functions.

Workplace - Level 3
Business Analyst (BA)
Full RPA Developer (DP)
Senior RPA Developer (DS)

RPA Solution Architect (SA)
RPA Team Manager (TM)
RPA Project Manager (PM)
RPA Support Leader (SL)
RPA Support(s)

After identifying the jobs for each of the different levels, we present a set of specific tasks associated with each of the phases of the Robotic Process Automation life cycle, and we classify them for each of the different levels (Level 1; Level 2; Level 3) who are responsible for each of the functions identified for each phase of the life cycle.

Table 20 - Accountability for RPA lifecycle tasks.

1 - Analysis	Level 1	Level 2	Level 3
- Identify opportunities;	DS	BA	BA
- Analyze As-Is process;	DS	BA	BA
- Initial estimation of development effort;	DS	DS	DS, SA
- Initial estimate of return on investment (ROI) & project benefits;	TM	BA, TM	BA, TM, PM
- Assessment document with all the analysis done;	DS	BA	BA
- Customer approval to start the project;	Customer	Customer	Customer
2 - Requirements gathering	Level 1	Level 2	Level 3
- Deep analysis of the As-Is process;	DS	BA	BA
- Risk assessment and contingency plans;	TM	BA	BA, PM
- Construction of the PDD (Process Definition Document);	DS	BA	BA
- Approval of PDD - client;	Customer	Customer	Customer
3 - Design - Project development	Level 1	Level 2	Level 3

- Analysis and construction of the To-be process;	DS	BA	SA
- Construction of the SDD (solution design document);	DS	DS	SA
- Project development;	DS	DS	DS, PM
- Unit tests / Integration tests;	DS	DS	SA, DS; PM
4 - Testing phase	Level 1	Level 2	Level 3
- UAT construction report (user acceptance test);	DS	DS	SA, DS
- End-to-end testing of the project;	DS	DS	SA, DS, PM
- Test approval - UAT report;	Customer	Customer	SA, PM, Customer
5 - Implantation and Hyper care	Level 1	Level 2	Level 3
- Implementation of the project in Production;	DS	DS	SA, DS, PM
- Monitoring the project in Production;	DS	DS	DS, PM
- Construction of the Manual;	DS	DS	SA, DS
- Approval Manual;	Cliente	Cliente	Cliente
- Final approval of the project;	Customer	Customer	Customer
6 - Go-live and Support	Level 1	Level 2	Level 3
- Construction of Business Case;	TM	BA, TM	BA, TM, PM
- Handover for Support time;	DS	DS	DS, SL
- Project monitoring;	DS	DP	s, SL
- Management of evolutions (changes);	TM	BA, DS	BA, DS, SL

The table 21 summarizes the organizational structure considering the RPA lifecycle and the roles identified in each of the phases of the cycle. In addition, 3 levels of RPA implementation are presented where the roles for the various identified positions were distributed. Regarding the structures worked on, the RPA team was considered as an internal structure and the client's integration/responsibility as an external structure.

3.6.9. Governance Frameworks

RPA acts at the tactical and operational level within an organization, for the implementation of efficient indicators it is necessary to develop medium and short-term goals. In order to make clear to the whole team the objectives to be achieved. Thus, one must question the objectives to be achieved and the results that should have been generated as governance in the RPA area is being implemented.

By setting clear goals, it becomes simpler to identify the best KPIs (Key Performance Indicator) for your RPA governance. Due to its form, we present here a set of methodologies that will help each one of the organizations to identify the most suitable KPIs for them. Knowing the frameworks (work models) responsible for providing the metrics and guiding the path to be followed is essential to ensure the effectiveness of the implemented practice.

The main enabling frameworks you have implementing RPA governance are:

- COBIT (Control Objectives for Information and related Technology) = Work model most used when implementing IT governance.

This framework presents resources that include objective controls, audit maps, executive summary, goal and performance indicators and a guide with management techniques. The management practices of this framework are used to test and guarantee the quality of the IT services provided and it uses its own metrics system.

- ITIL (Information Technology Infrastructure Library) - defines the set of practices for managing IT services through "libraries" that are part of each management module.

This is a customer-oriented framework and unlike Cobit it is a more focused model for the IT services themselves.

- PmBOK (Project Management Body of Knowledge) - Focuses on the management of projects in the area, in order to improve the development and performance of information technology professionals.

Therefore, all definitions, sets of actions and processes of PmBOK are described in its manual, which exposes the skills, tools and techniques needed to manage a project.

3.6.10. Conclusion

The framework proposal for the implementation and control of RPA projects, which is presented here, is a very important topic because the value resulting from the management of RPA technology projects can compromise the flow of operation of a business area.

This work analysed the works available in the literature and identified some gaps that served to propose complementary guidelines to the structural framework proposed in this work. The indicated guidelines covered the phases of the PDCA governance cycle, which served as the basis for the design of the model.

Considering the results of the work, the presented structure was developed from the definition of the RPA life cycle. Then, the various functions associated with each of the stages of the RPA life cycle were identified, and the external and internal structure of the organization chart was presented, by RPA implementation levels, given the complexity of this technology. Finally, a proposal of methodologies that help in the creation of RPA KPI's was also presented.

As a suggestion for future work, the implementation and validation of this structure is verified, as well as the elaboration of a research work associated with the identification of KPI's linked to RPA.

4. PLANNING AND SCHEDULING PROBLEM AND MULTI-OBJECTIVE OPTIMIZATION

In this chapter, we will delve into the complexity of planning and scheduling problems, as well as explore the challenges associated with multi-objective optimization. We shall commence by defining and formulating planning and scheduling problems, highlighting their mathematical modelling, decision variables, constraints, and typical objectives. Following that, we will discuss resolution methods, comparing precise and heuristic approaches, such as Linear Programming, Integer Programming, Dynamic Programming, Genetic Algorithms, Ant Colony Algorithms, Tabu Search, and Simulated Annealing. Lastly, we will delve deeply into multi-objective optimization, grasping the fundamentals, the definition of Pareto dominance and Pareto-optimal set, in addition to exploring methods for addressing multiple objectives.

4.1. Definition of the Planning and Scheduling Problem

Planning and scheduling are fundamental processes across various spheres of modern life, ranging from managing industrial projects to orchestrating daily activities. These processes aim at efficiently allocating resources, be they temporal, financial, or human, in order to achieve specific goals (Baker, 2011). A clear definition of the planning and scheduling problem is pivotal to the success of these processes, as it establishes the parameters and constraints that will guide the formulation of solutions (Pinedo, 2012).

The planning and scheduling problem can be defined as the task of determining the order and timing of activities to be carried out, in order to optimize specific criteria under pre-established constraints (Brucker, et al., 1999). In other words, it involves finding the optimal sequence of actions within a set of limitations. These limitations may encompass finite resources, deadlines, task precedence, and dependency constraints.

A pivotal element in defining the planning and scheduling problem is identifying the goals to be achieved (Baker & Trietsch, 2009). These goals can vary widely depending on the context in which the problem is applied. For instance, in an industrial production line, the goal might be to maximize production while minimizing labour and energy costs. On the other hand, in a public transport scheduling system, the goal could be to minimize passenger wait times and travel delays. Clearly formulating these objectives is essential, as it will guide the formulation of specific algorithms and resolution techniques.

In addition to goals, constraints constitute another vital component of problem definition (Baker & Trietsch, 2009). These constraints are the practical limitations that solutions to the problem must adhere to. In the context of planning and scheduling, constraints can be of diverse nature. They might include precedence constraints, where a task can only begin after the completion of another; resource constraints, involving limited availability of equipment or personnel; and temporal constraints, where tasks must be completed by certain deadlines.

The complexity of the planning and scheduling problem can range from simple to highly intricate, contingent on the number of activities, resources, and constraints involved. As more constraints are added, the space of potential solutions tends to shrink, rendering the task of finding a viable solution more challenging. This necessitates the development of specialized algorithms and methods to solve planning and scheduling problems across different domains (Dowsland & Thompson, 2000).

A common approach to addressing problem complexity involves breaking it down into simpler subproblems. For instance, a production scheduling problem can be decomposed into subproblems of resource allocation and task sequencing. Solving these subproblems independently and combining the solutions can yield more efficient and feasible solutions for the overarching problem (Brucker, et al., 1999).

Furthermore, optimization techniques are often employed in resolving planning and scheduling problems (Goldberg, 1989). Search algorithms such as genetic algorithms and particle swarm optimization algorithms are frequently applied to find approximate solutions that align with defined objectives while considering specific constraints (Kennedy & Eberhart, 1995). Nevertheless, it is important to note that the inherent complexity of these problems can often lead to approximate solutions rather than optimal ones.

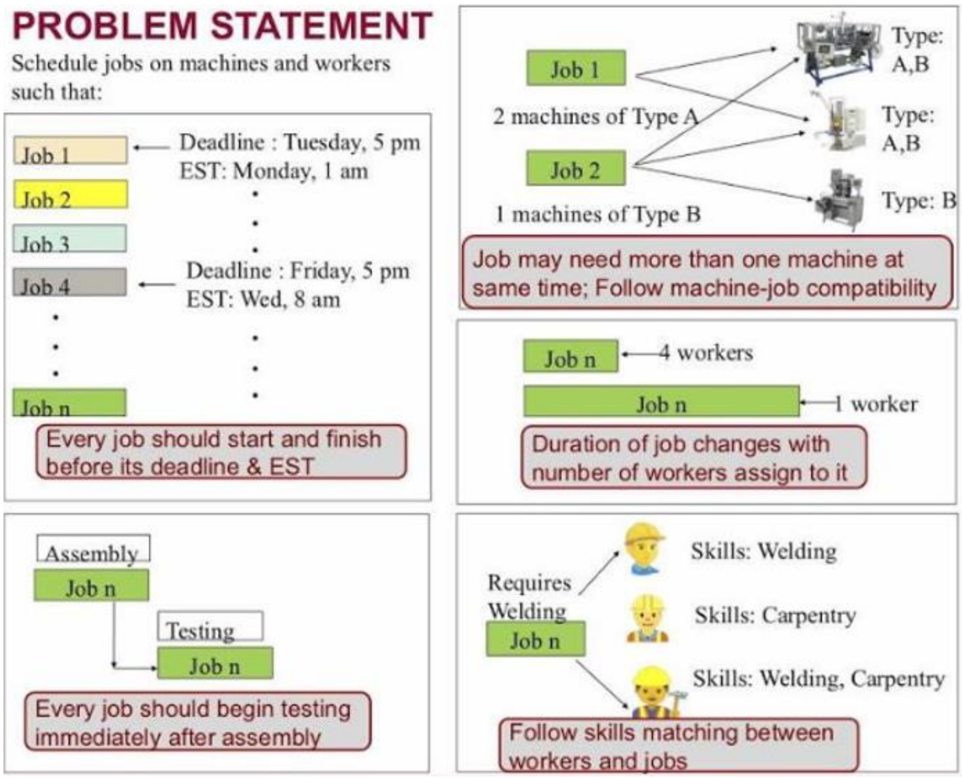

Figure 20 - Example structure of a production planning and scheduling problema (Jakhotia, 2019)

In conclusion, defining the planning and scheduling problem is the essential first step in achieving effective and efficient solutions across various domains. Clearly establishing the goals and constraints that shape the problem is crucial in guiding the development of resolution strategies. Given the complexity of these problems, the application of optimization techniques and specialized algorithms is often necessary to find approximate solutions (Baker, 2011). Thus, problem definition serves as the foundation upon which the entire planning and scheduling process is built, enabling informed and effective decision-making.

4.1.1. Importance and Applications across Various Industrial and Service Sectors

> *Scheduling is the art of allocating resources to activities over time to achieve specified objectives. Sequencing is the determination of the order in which activities should be performed (Baker, 2013).*

Planning and scheduling play a pivotal role across various industrial and service sectors, representing fundamental components in the optimization of processes and resources to achieve specific objectives (Baker, 2013). The significance of these processes extends beyond mere activity organization, directly influencing operational efficiency, resource utilization, and consequently, organizational competitiveness (Pinedo, 2016). In this regard, we shall delve into the relevance and applications of the planning and scheduling problem in diverse industrial and service contexts.

In many industrial sectors, effective time and resource management are paramount for efficient production and profit maximization (Blazewicz, et al., 2011). For instance, in the manufacturing industry, proper planning and scheduling are essential to optimize the utilization of machinery, equipment, and workforce (Brucker, 2004). By determining the sequence of tasks and appropriately allocating resources, it is possible to reduce production times, minimize material storage costs, and ensure timely delivery deadlines.

Within the realm of logistics and transportation, the planning and scheduling problem is fundamental to ensuring efficient product and goods delivery (Ballou, 2019). Through route optimization, considering factors such as distances, travel time, and traffic constraints, companies can reduce transportation costs and enhance delivery punctuality. This holds particular relevance in distribution companies, courier services, and public transportation entities, where scheduling efficiency directly impacts customer satisfaction.

In the healthcare sector, planning and scheduling play a vital role in hospital resource optimization and healthcare professionals' scheduling (Chopra & Meindl, 2016). Efficient scheduling of surgeries, medical appointments, and diagnostic tests can reduce patient waiting times, enhance hospital facility utilization, and ensure medical resources are available when needed. Moreover, proper scheduling of healthcare professionals ensures effective medical services delivery, contributing to better healthcare provision.

In service sectors such as hospitality and the tourism industry, planning and scheduling are crucial for reservation and accommodation management (Heizer & Render, 2020). Through room, space, and activity reservation optimization, companies can maximize occupancy rates, prevent scheduling conflicts, and deliver a positive customer experience. This not only enhances customer satisfaction but also boosts profitability and operational efficiency.

Beyond the mentioned examples, planning and scheduling play a pivotal role in many other sectors, including supply chain management (Krajewski, et al., 2019), energy production (Chase, et al., 2017), construction project management, and even event organization (Stevenson, 2018). In each of these sectors, resource utilization optimization, downtime minimization, and deadline adherence are critical factors achievable through efficient application of planning and scheduling techniques.

The applications of the planning and scheduling problem may vary in complexity. While simple problems can be manually addressed in some cases, the complexity of constraints and the multitude of variables often require the application of advanced computational methods (Baker, 2013). Optimization algorithms, artificial intelligence, and linear programming techniques are frequently employed to find effective and efficient solutions (Pinedo, 2016).

In conclusion, the planning and scheduling problem holds tremendous significance and wide applicability in industrial and service sectors (Blazewicz, et al., 2011). By carefully defining goals and constraints, it is possible to optimize resource allocation and activity scheduling, resulting in heightened operational efficiency, cost reduction, and improved quality of offered products and services (Brucker, 2004). The continuous evolution of computational technologies has enabled increasingly sophisticated approaches to address these challenges, contributing to the maximization of performance and competitiveness across diverse sectors of the economy (Ballou, 2019).

4.1.2. Challenges and Complexities Associated with the Planning and Scheduling Problem

The planning and scheduling problem is a perennial challenge in the realm of project management and operations (Blackburn, 2022). It involves optimizing resource allocation and task sequencing to achieve desired outcomes efficiently. However, the interplay of various factors, such as uncertainty, variability, resource constraints, task dependencies, scale, and human involvement, transforms this seemingly straightforward task into a labyrinth of complexities (Blum & Festa, 2011).

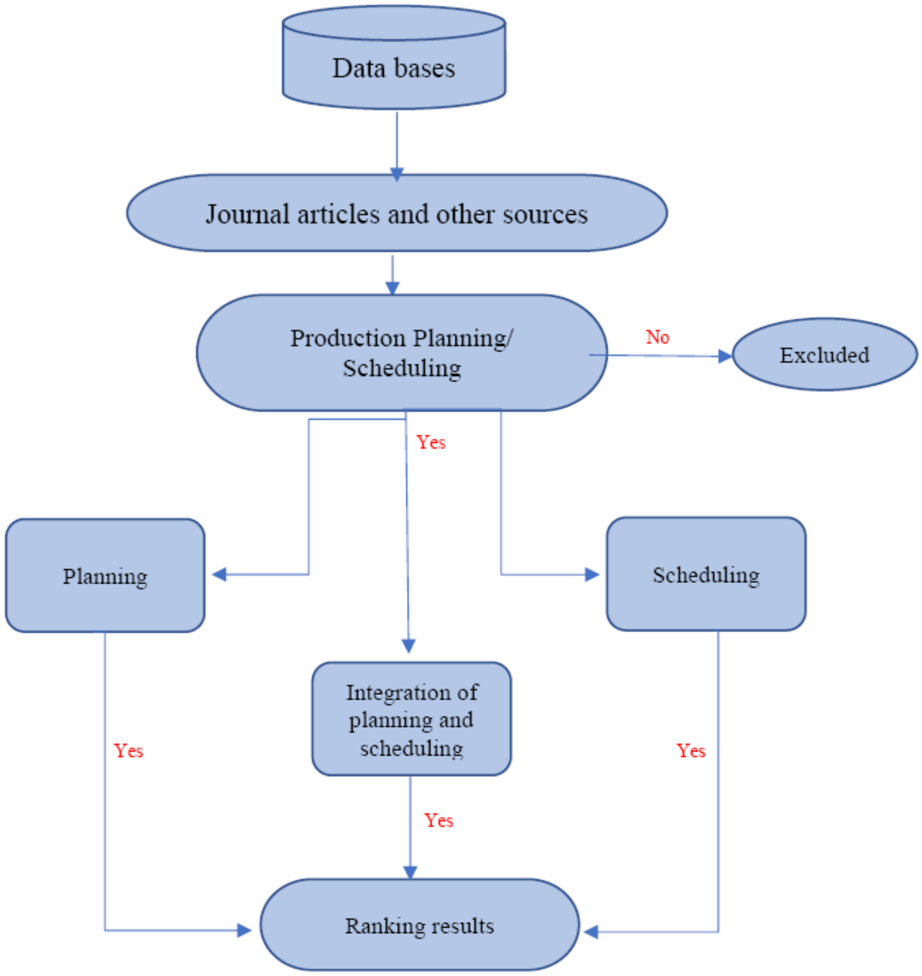

Figure 21 - Process of researching a planning and scheduling problema (Hassani, et al., 2019)

One of the most prominent challenges is the inherent uncertainty and variability in real-world scenarios (Blackburn, 2022). Fluctuations in demand, unforeseen disruptions, and unexpected resource shortages can derail even the most meticulously crafted plans (Baker & Van Hentenryck, 1991). Adapting to these dynamic conditions without compromising efficiency demands a delicate balancing act.

The allocation of resources, be it personnel, machinery, or funds, is another critical aspect of planning and scheduling (Thompson & Moder, 1993). Conflicting demands for limited resources can lead to bottlenecks and conflicts. Navigating these challenges requires sophisticated algorithms that optimize resource utilization, ensuring that critical tasks receive the necessary support (Veert, 2013).

In complex projects, tasks often depend on the completion of others (Levine, 1985). Managing task dependencies and establishing a logical sequence while considering resource availability is a multifaceted puzzle. Efficient scheduling involves minimizing delays caused by interdependencies

and ensuring that critical path activities receive priority attention (Cooke-Davies, 2002).
As projects grow in scale, the number of possible task sequences and resource allocations explodes exponentially, resulting in a combinatorial explosion (Garey & Johnson, 1979). This intricacy demands advanced computational tools, such as heuristics and metaheuristics, to navigate the vast solution space and identify optimal schedules.
Balancing conflicting objectives, such as minimizing costs while maximizing quality, adds another layer of complexity (Lewis, 2015). Decision-makers must consider trade-offs and prioritize objectives based on the project's strategic goals. Achieving equilibrium requires a profound understanding of the project's context and stakeholders' priorities.
The modern business landscape is characterized by rapid changes, making static planning inadequate (Dinsmore, 2019). Adapting schedules in response to evolving conditions requires real-time data, predictive analytics, and flexible frameworks. Dynamic scheduling techniques enable proactive adjustments, mitigating the impact of disruptions (Ramdayal, 2022).
Human involvement introduces both unpredictability and adaptability (Moder, Phillips, & Davis, 2022). Human factors like worker availability, skills, and motivation impact schedules. Moreover, managing stakeholder expectations and communication is paramount. These challenges necessitate the integration of human-centric considerations into planning models (PMI, 2022).
Different industries grapple with unique challenges in planning and scheduling (Heizer & Render, 2023). Manufacturing deals with production line optimization and just-in-time inventory management. Healthcare faces the intricacies of patient scheduling and resource allocation. Similarly, transportation, construction, and IT sectors each confront their own set of challenges.
Advancements in technology have ushered in a new era of planning and scheduling (Portny, 2022). Artificial intelligence and machine learning algorithms offer the potential to tackle complex problems with unprecedented accuracy. Optimization software can handle large-scale scenarios efficiently, while simulation tools facilitate "what-if" analyses.
The challenges and complexities intertwined with the planning and scheduling problem are emblematic of the intricacies that pervade project management and operational efficiency. While these challenges might seem daunting, they present opportunities for innovation and growth. As technology continues to evolve, so too will the solutions that empower us to overcome these complexities and achieve better outcomes in the world of planning and scheduling.
The different challenges associated with planning and scheduling are inextricably linked. For example, uncertainty and variability can impact resource allocation, task dependencies, scale, and

human involvement. Resource constraints can lead to trade-offs between objectives and the need for dynamic scheduling. Task dependencies can complicate scale and combinatorial explosion challenges. The human element can introduce unpredictability into all aspects of planning and scheduling.

The following are some specific examples of how the different challenges interact:

- **Uncertainty and variability:** A manufacturing plant may face unforeseen disruptions due to a supply chain shortage or equipment failure. This can necessitate a reallocation of resources and a revision of the production schedule (Blackburn, 2022).
- **Resource allocation:** A healthcare organization may have limited resources, such as beds, operating rooms, and staff. This can lead to trade-offs between scheduling patient appointments and surgeries (Thompson & Moder, 1993).
- **Task dependencies:** A construction project may have multiple tasks that depend on each other. This can complicate scheduling decisions, as delays in one task can impact the completion of other tasks (Levine, 1985).
- **Scale:** As projects grow in size, the number of possible task sequences and resource allocations increases exponentially. This can make it difficult to find an optimal schedule without using advanced computational tools (Garey & Johnson, 1979).
- **Human element:** Workers may have different skills, experience, and motivations. This can impact their productivity and the duration of tasks. Additionally, managing stakeholder expectations and communication is essential to ensure a successful schedule (Moder, Phillips, & Davis, 2022).

The challenges and complexities intertwined with the planning and scheduling problem are emblematic of the intricacies that pervade project management and operational efficiency. This essay has explored the multifaceted nature of the issue, from uncertainty and resource allocation to task dependencies and human factors. While these challenges might seem daunting, they present opportunities for innovation and growth. As technology continues to evolve, so too will the solutions that empower us to overcome these complexities and achieve better outcomes in the world of planning and scheduling.

4.2. Formulation of Planning and Scheduling Problems

The formulation of planning and scheduling problems is a crucial part of the optimization domain, which aims to find efficient solutions to allocate limited resources to different tasks over time. This process involves the precise mathematical modelling of the problem, the definition of decision variables, constraints and objectives that capture the nuances of the scenario in question.

4.2.1. Mathematical Modelling of the Problem

The mathematical modelling of planning and scheduling problems is the process of representing the problem in a mathematical form that can be solved using optimization techniques. This involves identifying the decision variables, constraints, and objectives of the problem (Pinedo, 2016).

Decision variables are the variables that can be controlled by the decision-maker to find a solution to the problem. For example, in a production planning problem, the decision variables might be the quantities of each product to produce in each period (Hillier and Lieberman, 2010).

Constraints are the restrictions that must be satisfied by any solution to the problem. For example, in a production planning problem, the constraints might include the limited capacity of the machines and the availability of raw materials (Pinedo, 2016).

The objective of the problem is the function that the decision-maker wants to optimize. For example, in a production planning problem, the objective might be to minimize the total production cost (Hillier and Lieberman, 2010).

Once the decision variables, constraints, and objective have been identified, a mathematical model can be formulated using the following steps:

- Define the decision variables.
- Define the constraints.
- Define the objective function.

The following is a general mathematical formulation of planning and scheduling problems:

- **minimize/maximize f(x)**
- **subject to g(x) ≤/≥ h**

where:

- **f(x) is the objective function**

- **x is the vector of decision variables**
- **g(x) is the vector of inequality constraints**
- **h is the vector of constraint bounds**

The objective function can be a linear, nonlinear, or mixed-integer function. The constraints can be linear, nonlinear, or mixed-integer constraints (Hillier and Lieberman, 2010).

The following are some examples of mathematical models for planning and scheduling problems:

- **Job shop scheduling:** The job shop scheduling problem is a classic NP-hard problem that involves scheduling a set of jobs on a set of machines. Each job has a sequence of operations that must be processed on different machines. The objective is to find a schedule that minimizes the total completion time of all jobs (Taillard, 1993).
- **Production planning:** Production planning is the process of determining the quantities of products to produce in each period. The objective is to meet customer demand while minimizing production costs (Taillard, 1993).
- **Vehicle routing:** The vehicle routing problem is the problem of determining the optimal routes for a fleet of vehicles to deliver goods to a set of customers. The objective is to minimize the total travel distance or time (Taillard, 1993).

Once a mathematical model has been formulated, it can be solved using a variety of optimization techniques. Some common optimization techniques include:

- **Linear programming:** Linear programming is a technique for solving linear optimization problems.
- **Nonlinear programming:** Nonlinear programming is a technique for solving nonlinear optimization problems.
- **Mixed-integer programming:** Mixed-integer programming is a technique for solving optimization problems with mixed-integer decision variables.

The mathematical modelling of planning and scheduling problems is a crucial step in the development of optimization solutions. By carefully modelling the problem, decision-makers can identify the best way to allocate limited resources to different tasks over time.

4.2.2. Decision Variables, Constraints, and Typical Objectives

In addition to the general mathematical formulation of planning and scheduling problems, it is important to consider the specific decision variables, constraints, and objectives that are relevant to the problem at hand (Taillard, 1993).

The decision variables in a planning and scheduling problem are the variables that the decision-maker can control to find a solution to the problem. The decision variables can be classified into two main categories (Hillier and Lieberman, 2010):

- **Quantitative variables:** These variables represent quantities, such as the number of products to produce, the number of machines to use, or the amount of time to spend on a task.
- **Qualitative variables:** These variables represent qualities, such as the type of product to produce, the machine to use, or the order in which tasks should be performed.

The choice of decision variables is important because it determines the set of solutions that are possible. For example, if the number of machines is a decision variable, then the problem is a capacitated problem. If the order in which tasks are performed is a decision variable, then the problem is a sequencing problem (Hillier and Lieberman, 2010).

The constraints in a planning and scheduling problem are the restrictions that must be satisfied by any solution to the problem. The constraints can be classified into the following categories (Taillard, 1993):

- **Capacity constraints:** These constraints limit the amount of resources that can be used. For example, a capacity constraint might limit the number of products that can be produced on a machine or the amount of time that a task can take.
- **Demand constraints:** These constraints ensure that the needs of customers or other stakeholders are met. For example, a demand constraint might require that a certain amount of product be produced or that a certain amount of work be done.
- **Technical constraints:** These constraints reflect the physical or logical relationships between tasks. For example, a technical constraint might require that a task be completed before another task can be started.

The constraints define the feasible region of the problem, which is the set of all solutions that satisfy all of the constraints. The objective function is then used to find the optimal solution within the feasible region (Pinedo, 2016).

The objective of a planning and scheduling problem is to optimize some measure of performance.

The most common objectives include (Taillard, 1993):

- **Cost minimization:** This objective is to minimize the total cost of production, transportation, or other resources.
- **Time minimization:** This objective is to minimize the total time to complete a project or task.
- **Profit maximization:** This objective is to maximize the total profit from a production or service process.

The choice of objective is important because it determines the best solution to the problem. For example, if the objective is to minimize cost, then the solution might involve using less-efficient machines or workers. If the objective is to minimize time, then the solution might involve scheduling tasks in a suboptimal order (Pinedo, 2016).

The careful selection of decision variables, constraints, and objectives is essential for the successful formulation of planning and scheduling problems. By carefully considering the specific needs of the problem, decision-makers can develop models that accurately reflect the real-world situation and lead to effective solutions (Hillier and Lieberman, 2010).

In addition to the factors discussed above, there are a number of other considerations that can be important in the formulation of planning and scheduling problems (Pinedo, 2016). These include:

- **Multiple objectives:** Many planning and scheduling problems have multiple objectives, such as cost minimization, time minimization, and quality maximization. In these cases, it is necessary to use a multi-objective optimization technique to find a solution that satisfies all of the objectives.
- **Uncertainty:** In many cases, there is uncertainty about the values of parameters or variables in the problem. In these cases, it is necessary to use a stochastic optimization technique to find a solution that is robust to uncertainty.
- **Real-time constraints:** In some cases, it is necessary to find a solution to the problem in real time, such as in the case of a production line that must be scheduled to meet customer demand. In these cases, it is necessary to use a real-time optimization technique to find a solution quickly.

By carefully considering all of these factors, decision-makers can develop planning and scheduling models that are accurate, effective, and robust.

4.2.3. Examples of Planning and Scheduling Problems in Different Contexts

Planning and scheduling problems are not restricted to a single context, being present in several areas (Goyal & Lee, 2002). An example is the scheduling of production in industries (Goyal & Lee, 2002). Imagine a factory with multiple machines and multiple production orders. The challenge is to allocate orders to machines in a way that minimizes total production time, considering machine capacities and order delivery dates (Goyal & Lee, 2002). Planning and scheduling problems are ubiquitous in the real world and can be found in a wide range of contexts, from manufacturing and logistics to healthcare and transportation (Fox & Gini, 1997). In general, planning and scheduling problems involve determining the best way to allocate resources and activities over time, subject to a set of constraints (Fox & Gini, 1997).

Another example of a planning and scheduling problem is the scheduling of tasks on processors in computer systems (Voevodin, 2012). In this context, the goal is to assign tasks to processors in a way that minimizes total execution time or maximizes the utilization of the processors (Voevodin, 2012). This problem can also be formulated as a mathematical optimization problem, where the variables represent the task assignments and the constraints include task precedence relationships and processor capacities (Voevodin, 2012).

Even in healthcare, planning and scheduling problems can be found (Baptiste, et al., 2013). For example, the scheduling of surgeries in hospitals is a complex problem that needs to consider the availability of operating rooms, surgeons, and other resources, as well as the urgency of the surgeries and the patients' needs (Baptiste, et al., 2013). This problem can also be formulated as a mathematical optimization problem, where the variables represent the surgery assignments and the constraints include resource availability, patient urgency, and surgery duration (Baptiste, et al., 2013).

Planning and scheduling problems are ubiquitous in the real world and can be found in a wide range of contexts (Newell, 1980). These problems can be complex, but they can be solved using mathematical optimization techniques (Vanderbei, 2001). Mathematical modelling provides the basis for analysing and solving these problems, contributing to improved efficiency and informed decision-making (Burke, et al., 2003).

Here is a more detailed and descriptive version of the text, focusing on the examples of production scheduling, task scheduling in computer systems, and surgery scheduling:

Production scheduling is the process of determining when and where to produce goods or services in order to meet customer demand and minimize costs. This problem is often complex, as it needs to consider a variety of factors, such as machine capacities, order deadlines, and material availability (Voevodin, 2012).

One common approach to production scheduling is to use a mathematical optimization model. This model represents the scheduling problem as a set of variables, constraints, and objectives. The variables represent the production decisions, such as which machines to use, when to produce each order, and how much to produce. The constraints represent the limitations of the production system, such as machine capacities and order deadlines. The objective is to optimize a certain metric, such as minimizing total production time or maximizing profits.

Once the optimization model has been formulated, it can be solved using a variety of techniques. One common technique is to use a linear programming solver. Linear programming is a type of mathematical optimization that can be used to solve problems with linear objective functions and linear constraints (Burke, et al., 2003).

Task scheduling in computer systems is the process of assigning tasks to processors in a way that optimizes a certain metric, such as minimizing total execution time or maximizing processor utilization. This problem is often complex, as it needs to consider a variety of factors, such as task precedence relationships, processor capacities, and energy consumption (Burke, et al., 2003).

One common approach to task scheduling in computer systems is to use a greedy algorithm. A greedy algorithm is a type of heuristic algorithm that makes decisions based on the best option at the current time, without considering the future consequences of those decisions. Greedy algorithms are often fast and efficient, but they may not always produce the optimal solution (Burke, et al., 2003).

Another common approach to task scheduling in computer systems is to use a dynamic programming algorithm. Dynamic programming is a type of algorithm that solves a complex problem by breaking it down into smaller, simpler subproblems. Dynamic programming algorithms can be used to find the optimal solution to task scheduling problems, but they can be computationally expensive for large problems.

Surgery scheduling is the process of assigning surgeries to operating rooms, surgeons, and other resources in a way that minimizes delays and ensures that resources are available. This problem is often complex, as it needs to consider a variety of factors, such as patient urgency, surgery duration, and surgeon availability.

One common approach to surgery scheduling is to use a constraint programming solver. Constraint programming is a type of mathematical optimization that can be used to solve problems with complex constraints. Constraint programming solvers can be used to find feasible solutions to surgery scheduling problems, even when the problems are very complex.

Planning and scheduling problems are ubiquitous in the real world and can be found in a wide range of contexts. These problems can be complex, but they can be solved using mathematical optimization techniques.

4.3. Solution Methods for Planning and Scheduling Problems

Planning and scheduling are crucial elements in many areas, including logistics, production, transportation and many others. The efficient allocation of resources and tasks over time is essential to optimize processes, minimize costs and maximize the use of available resources. To address these challenges, researchers and practitioners have explored a variety of solution methods, with exact methods and heuristic methods being two widely discussed and applied approaches.

4.3.1. Exact Methods vs. Heuristic Methods

Exact methods, as elucidated by Brucker (2013), are approaches aimed at discovering the optimal solution to a planning or scheduling problem. These methods rigorously ensure that the solution obtained adheres to the predefined criteria, exemplified by the branch and limit algorithm, which systematically explores all potential solutions, thereby guaranteeing the discovery of the optimal solution (Brucker, 2013).

Nonetheless, exact methods confront significant scalability issues. As the problem's size escalates, the number of conceivable solutions increases exponentially, resulting in a substantial upswing in computational time requirements. Consequently, exact methods prove less pragmatic for solving large-scale real-time problems (Brucker, 2013).

In contrast, heuristic methods, as expounded by Baker (2006), are approaches focused on approximating solutions to planning and scheduling problems more swiftly. These methods rely on rules, strategies, and intuition to navigate the solution-finding process, typified by the particle swarm optimization algorithm, which simulates the behaviour of a particle swarm to uncover promising solutions (Baker, 2006).

Heuristic methods are often preferred when time is of the essence and an approximate solution suffices. While they do not ensure the optimal solution, heuristic methods frequently deliver satisfactory results for large-scale problems within acceptable timeframes (Baker, 2006).

The choice between exact and heuristic methods hinges on the problem's nature, available resources, and time constraints. Exact methods are suitable for tackling small, well-defined problems, leveraging their guarantee of optimal solutions. However, as problems grow in complexity and scale, exact methods may become infeasible due to their time-intensive nature (Baker, 2006).

In such scenarios, heuristic methods emerge as a valuable alternative. While they do not guarantee optimality, their speed of execution and capacity to handle intricate problems make them pragmatic choices. Moreover, heuristic methods can often be adapted to suit diverse contexts, rendering them flexible and versatile (Baker, 2006).

A promising approach, as proposed by Hertz, Pisinger, and Zufferey (2007), involves the fusion of exact and heuristic methods. This entails employing a heuristic method to generate an approximate solution, subsequently refining it using an exact method to enhance its quality. Such a combination harnesses the strengths of both approaches, striking a balance between execution time and solution quality (Hertz, et al., 2007).

Ultimately, the selection between exact and heuristic methods hinges on the specific requirements of the problem at hand. Each approach possesses distinct advantages and drawbacks, with the choice contingent on problem complexity, resource availability, and time constraints. While exact methods guarantee optimality, heuristic methods offer efficiency for large-scale problems. The continual evolution of these methods and the development of hybrid approaches promise to advance the effective resolution of planning and scheduling problems (Hertz, et al., 2007).

4.3.2. Exact Methods

Linear Programming, as described by Dantzig (1963) and further elaborated on by Bazaraa, Jarvis, and Sherali (2004), is a widely employed method for tackling optimization problems characterized by linear relationships between variables. The core principle revolves around formulating a linear objective function subjected to a set of linear constraints. This approach proves highly effective for resolving issues involving resource allocation constraints, such as product distribution, production planning, and supply chain management (Dantzig, 1963). Utilizing algorithms like the Simplex method, it becomes feasible to pinpoint the optimal solution within a multidimensional space. Nevertheless, Linear Programming encounters limitations when confronted with problems featuring integer variables or discrete decisions (Dantzig, 1963).

Integer Programming, an extension of Linear Programming explored in-depth by Nemhauser and

Wolsey (1988), entails constraining variables to exclusively accept integer values. This additional constraint introduces complexity, leading to many problems becoming NP-hard, meaning finding optimal solutions may necessitate exponential time. Nonetheless, Integer Programming finds applications across diverse domains such as production scheduling, resource allocation, and network design (Nemhauser & Wolsey, 1988). Advances in algorithms like Branch and Bound and heuristic methods have rendered Integer Programming feasible for solving large-scale problems within acceptable time frames (Nemhauser & Wolsey, 1988).

Dynamic Programming, a technique illuminated by Bellman (1957) and elaborated upon by Bertsekas (2019), deals with sequential optimization problems. It involves constructing a solution based on smaller, independent subproblems. This approach proves especially advantageous when addressing problems exhibiting overlapping subproblem properties, allowing intermediate solutions to be reused to mitigate computational complexity (Bellman, 1957). Dynamic Programming finds applications in various domains, including project planning, routing, and process control (Bellman, 1957). However, its success hinges on identifying subproblems accurately and understanding the recurrence structure (Bellman, 1957).

Exact methods encompass Linear Programming, Integer Programming, and Dynamic Programming. These methods offer robust strategies for solving a broad spectrum of planning and scheduling problems. Each method possesses distinct advantages and limitations. The choice of the most suitable method hinges on the specific problem characteristics, available computational resources, and required solution precision (Boyd & Vandenberghe, 2004). In many instances, combining exact methods with heuristics or metaheuristic algorithms can yield superior solutions to intricate problems (Boyd & Vandenberghe, 2004).

In conclusion, exact methods play an indispensable role in addressing planning and scheduling problems, contributing to process optimization, efficient resource allocation, and enhanced operational efficiency across various domains. As optimization research advances, these methods will continue to evolve, offering more effective and efficient approaches to tackle the complex challenges posed by real-world planning and scheduling problems (Boyd & Vandenberghe, 2004).

4.3.3. Heuristic Methods

In the field of planning and scheduling, solving complex problems is a challenging task that demands innovative approaches. Heuristic methods have been widely employed to address these complexities, providing approximate solutions within a reasonable timeframe (Rabadi & Mahdi, 2019). In this context, some of the notable heuristic methods include Genetic Algorithms, Ant Colony Algorithms, Tabu Search, and Simulated Annealing (Blum & Roli, 2003).

Genetic Algorithms (GAs) draw inspiration from evolutionary theory and operate based on genetic principles such as natural selection, crossover, and mutation (Goldberg, 1989). They function by generating an initial population of candidate solutions and, over iterations, apply genetic operators to produce new solutions. The most promising solutions are selected to form the next generation. Over time, this approach tends to converge toward high-quality solutions. GAs is frequently applied to combinatorial optimization problems, such as factory scheduling or class timetabling.

Inspired by the foraging behavior of ants in search of food, Ant Colony Algorithms (ACOs) are used to solve optimization problems, including scheduling (Dorigo & Stützle, 2004). These algorithms exploit the capacity for indirect communication among ants through pheromone deposition. Ants prefer to follow trails with higher pheromone levels, leading to a targeted search for promising solutions. The ACO approach has been successfully applied to scheduling problems, such as resource allocation in construction projects.

Tabu Search is a heuristic technique aimed at escaping local minima in optimization problems (Glover & Laguna, 1997). It maintains a record of recent moves and prohibits revisiting these moves, allowing the search to explore new regions of the solution space. This helps prevent the algorithm from getting stuck in suboptimal local optima. Tabu Search can be applied to scheduling problems where exploring various options is crucial for finding high-quality solutions.

Inspired by the annealing process in metallurgy, Simulated Annealing is a heuristic method that simulates the gradual cooling of a physical system (Kirkpatrick, et al., 1983). It explores the solution space through random perturbations and accepts changes that worsen the current solution with a certain probability, decreasing over time. This approach allows for escaping local minima and exploring the solution space more comprehensively. Simulated Annealing finds applications in scheduling problems where optimal or near-optimal solutions are required.

Heuristic methods, including Genetic Algorithms, Ant Colony Algorithms, Tabu Search, and Simulated Annealing, are valuable tools for solving complex planning and scheduling problems. Each method offers unique approaches to explore the solution space and find approximate or even optimal results within a reasonable timeframe. The choice of the method to be used will depend on the nature of the problem, the constraints involved, and the optimization goals (Pan, Wang, & Gao, 2013). Combining these methods with domain insights can lead to effective solutions that meet the practical needs of real-world applications (Talbi, 2009).

4.3.4. Hybrid Methods

Exact methods such as integer programming and dynamic programming are able to find optimal solutions to planning and scheduling problems, but often face limitations in terms of scalability (Bard & Morton, 2014). This is because the computational complexity of these methods increases significantly as the problem size grows. On the other hand, heuristic methods are approximate techniques that seek reasonable solutions in a reasonable time (Graves & Liebling, 2005). Although these solutions are not guaranteed to be optimal, heuristic methods have the advantage of being faster and able to deal with larger scale problems.

Hybrid methods seek to take advantage of both types of approaches, combining the accuracy of exact methods with the efficiency of heuristic methods (Liebling, 2004). This is done by integrating the resolution techniques into a single framework, where the strengths of each method complement each other. Hybrid methods can be implemented in a variety of ways, either by incorporating heuristic methods into exact algorithms or using information from exact solutions to guide heuristic methods.

A common approach to creating hybrid methods is to generate initial solutions using a heuristic method and then improve those solutions using an exact method (Zhang, et al., 2006). This can narrow the search space for the exact method, allowing it to reach an optimal or close solution more efficiently. For example, consider a production scheduling problem in a factory. A heuristic method could be used to create an initial schedule based on priority rules. Then an exact method such as the entire schedule could be applied to further optimize this schedule, taking into account detailed constraints and specific objectives.

Another approach is to combine exact and heuristic algorithms in each iteration of the search process (Zhang, et al., 2006). This allows the hybrid algorithm to take advantage of the speed of heuristic methods to explore the solution space broadly, while using the power of exact methods to refine and verify the solutions found. This continuous interaction between exact and heuristic methods can lead to faster convergence towards high-quality solutions.

Furthermore, hybrid methods may involve extracting knowledge from exact solutions to improve the efficiency of heuristic methods (Zhang, et al., 2023). For example, the information obtained from the linear relaxation of an integer programming problem can be used to guide the search for a heuristic method, directing it to more promising regions of the solution space.

Hybrid methods offer several significant advantages. Firstly, they allow approaching large-scale problems that would be inaccessible to pure exact methods due to the exponential increase in complexity. This is especially relevant in real-world scenarios, where optimizing industrial, logistical and scheduling processes involves many variables and constraints.

Second, hybrid methods provide a unique combination of accuracy and efficiency. While exact methods guarantee optimal or near-optimal solutions, heuristic methods allow for faster exploration of the solution space and the ability to find acceptable solutions in a reasonable amount of time.

However, hybrid methods also face challenges. Integrating different techniques can be complex and requires a deep understanding of the individual methods and how they can be combined effectively. Furthermore, the proper selection of methods to be combined and the definition of strategies for exchanging information between them are critical steps in the creation of successful hybrid methods.

In short, planning and scheduling problems are crucial issues in many areas, and the search for efficient and high-quality solutions has led to the development of hybrid methods. These methods capitalize on the advantages of exact methods in terms of precision and of heuristic methods in terms of computational efficiency. Combining these approaches offers a promising approach to tackling complex problems, allowing larger-scale challenges to be addressed and providing solid solutions in a reasonable amount of time. However, creating successful hybrid methods requires expertise in both techniques and a deep understanding of the problem at hand. With the continued advancement of research in this area, it is likely that hybrid methods will play an increasingly important role in efficiently solving planning and scheduling problems.

4.4. Definition of Multi-objective Optimization Problem

Multi-objective optimization is a sophisticated and essential approach to dealing with complex problems involving the simultaneous optimization of multiple conflicting objectives. While single-objective optimization problems seek to find the best solution for a specific metric, multi-objective problems aim to find a set of solutions that represent a balance between multiple conflicting objectives. In this context, this section of our study explores the definition of multi-objective optimization problems and the fundamentals underlying this approach.

4.4.1. Fundamentals of Multi-objective Optimization

Multi-objective optimization is a natural extension of single-objective optimization, but it introduces additional complexities. In many real-life situations, systems are evaluated by multiple criteria, and improvement in one criterion often implies deterioration in another. For example, consider the design of a car: maximizing engine power can decrease fuel efficiency (Deb, 2001). These trade-offs are inherent in many real problems, and multi-objective optimization focuses on finding solutions that offer a balance between these different criteria.

A key aspect of multi-objective optimization is the Pareto frontier (Steuer & Choo, 2012). The Pareto Frontier is the set of solutions where no solution can be improved in one criterion without worsening in at least one other criterion. Each solution on the Pareto frontier is called "non-dominated," as there is no other solution that is better in all criteria. Finding this frontier is at the heart of multi-objective optimization, as it represents all potentially viable solutions to the problem.

A common approach to exploring the Pareto Frontier is to use multi-objective optimization algorithms, such as multi-objective genetic algorithms, swarm-based algorithms, or ant colony optimization algorithms (Deb & Tiwari, 2001). These methods seek to efficiently explore the solution space to identify non-dominated solutions that make up the Pareto Frontier.

Furthermore, quality metrics such as convergence and diversity are often used to assess the quality of approximate solutions found by these algorithms. Convergence measures how close the solutions found are to the true Pareto Front, while diversity verifies how well distributed these solutions are along this front (Coello Coello, Van Veldhuizen, & Lamont, 2007).

It is noteworthy that multi-objective optimization is not limited to problems with two objectives. It can handle problems involving three, four, or more objectives, although the challenge increases exponentially as the number of objectives increases. In many cases, it is necessary to make informed decisions about which Pareto Frontier solutions are best suited for a particular application.

In summary, multi-objective optimization is a crucial approach to solving complex problems involving the simultaneous optimization of multiple conflicting objectives. The Pareto Frontier and multi-objective optimization algorithms play a key role in the search for solutions that effectively balance different criteria. The application of these concepts can be seen in many areas such as engineering, finance, logistics, and more (Steuer & Choo, 2012). As real-world challenges become more intricate, multi-objective optimization continues to be a valuable tool to assist in making informed decisions and finding efficient, balanced solutions.

4.4.2. Definition of Pareto Dominance and Pareto-optimal Solution Set

Multi-objective optimization is a fundamental field within engineering, computer science, and other disciplines, which deals with finding the best solutions to problems involving multiple conflicting objectives (Deb, 2001). While single-objective optimization problems aim to find a single solution that optimizes a single objective function, multi-objective optimization problems involve searching for a set of solutions that cannot be directly compared due to their diverse nature.

A multi-objective optimization problem is characterized by the presence of several objective functions, each one representing a different aspect that one wants to optimize (Fonseca & Fleming, 1995). For example, in an engineering design problem, we can have as objective functions the minimization of the cost and the maximization of the material resistance. However, these two goals often conflict - higher quality material is usually more expensive. Therefore, multi-objective optimization focuses on finding solutions that offer a balance between these objectives, rather than looking for a single optimal solution.

The concept of Pareto-dominance is central to multi-objective optimization (Zitzler, Deb, & Thiele, 2000). A solution A is said to dominate another solution B if A is equal to or better than B in all objectives and strictly better in at least one objective. In other words, solution A is at least as good as B in all respects and is superior in at least one respect. A solution that is not dominated by any other solution is called Pareto-optimal.

The set of solutions that are not dominated by any other solution is called the Pareto-optimal set of solutions (Coello, Van Veldhuizen & Lamont, 2007). This set represents the best possible solutions to the multi-objective optimization problem, where no solution can be improved in one objective without worsening in another. The aim is to explore and identify as many Pareto-optimal solutions as possible to provide a comprehensive view of the different trade-offs between the objectives.

The visualization of the set of Pareto-optimal solutions is often represented by the Pareto chart, where each point on the chart corresponds to a solution in the objective space. The X-axis represents one objective, the Y-axis represents another objective, and so on for problems with more than two objectives. The Pareto-optimal solutions form the frontier of the graph, where no solution on that frontier can be improved without worsening in at least one objective.

Finding the Pareto-optimal set of solutions is not a trivial task, especially in complex problems with several variables and objectives. Several approaches and algorithms have been developed over the years to deal with these challenges (Zhang & Li, 2010). Some of the popular methods include:

- **Methods Based on Genetic Algorithms:** Multi-objective genetic algorithms use principles of evolution to explore the solution space and identify Pareto-optimal solutions.

They create an initial population of solutions, apply selection, crossover, and mutation operators to generate new solutions, and gradually evolve to the Pareto-optimal set.

- **Methods Based on Mathematical Programming:** Multi-objective mathematical programming algorithms try to solve the problem through the mathematical formulation of objective functions and constraints. However, these methods can become complex and inefficient for high-dimensional problems.
- **Decomposition Methods:** These methods divide the multi-objective problem into smaller subproblems, treating a subset of objectives at a time. These subproblems are solved iteratively until the Pareto-optimal solution is found.
- **Direct Search Methods:** These methods directly explore the solution space in search of non-dominated solutions. Methods such as NSGA-II (Non-dominated Sorting Genetic Algorithm II) and SPEA2 (Strength Pareto Evolutionary Algorithm 2) are popular examples of this approach.

Defining multi-objective optimization problems and understanding Pareto-dominance are fundamental to face the challenges of finding solutions that balance different conflicting objectives. The search for the Pareto-optimal set of solutions is a complex task but essential for making informed decisions in diverse areas, from engineering and economics to social sciences. Continued progress in research into multi-objective optimization algorithms and approaches will continue to enable effective resolution of real-world problems where optimal solutions are not unique but rather a collection of optimal trade-offs.

4.4.3. Trade-offs and Pareto-optimal Frontier

In traditional optimization, a problem is formulated with a single objective to be maximized or minimized (Coello, et al., 2007). However, many real-world situations involve multiple goals that often conflict (Aarts & Lenstra, 1997). A multiobjective optimization problem seeks to find a set of solutions that offer a balance between these conflicting objectives (Ishibuchi, et al., 2002). Each solution in the set is known as a Pareto-optimal solution, and the collection of all these solutions forms the Pareto-optimal frontier (Ehrgott, 2005).

Trade-offs are inherent in multi-objective optimization problems (Coello, et al., 2007). As it is not possible to optimize all objectives simultaneously without sacrificing any of them, ideal solutions are often not achievable. Rather, decisions involve trade-offs, where improving one objective may result in worsening another (Aarts & Lenstra, 1997).

The Pareto-optimal frontier is a graphical representation of Pareto-optimal solutions (Coello, et al., 2007). It illustrates the relationship between goals, showing solutions where no goal can be improved without making at least one of the other goals worse. Each point on the Pareto-optimal frontier represents a unique solution, where it is not possible to make improvements without harming some aspect (Ehrgott, 2005).

The Pareto-optimal frontier offers crucial information for making informed decisions on complex problems (Coello, et al., 2007). By exploring Pareto-optimal solutions, decision-makers can better understand the trade-offs involved and choose the solution that best aligns with their specific preferences and requirements (Aarts & Lenstra, 1997). This approach helps to avoid looking for solutions that focus excessively on a single objective, to the detriment of other relevant factors (Ishibuchi, et al., 2002).

Finding the Pareto-optimal frontier can be a computationally intense challenge, especially in complex problems with multiple goals and constraints (Coello, et al., 2002). Several methods are used to address this issue:

- **Weighting-based methods:** Assign weights to the objectives to transform the multiobjective problem into a single optimization problem. However, this approach is sensitive to the choice of weights and may not adequately capture relationships between objectives (Slowinski & Teghem, 2000).
- **Aggregation-based methods:** Combine multiple objectives into a single aggregate function. However, the choice of the aggregate function can be subjective and affect the results (Steuer, 1999).
- **Dominance-based methods:** Evaluate the dominance relationship between solutions. One solution dominates another if it is equally good or better in all objectives and better in at least one. These methods ensure an accurate representation of the Pareto-optimal frontier (Ishibuchi, et al., 2001).
- **Genetic and evolutionary algorithms:** Use approaches inspired by natural selection to explore the solution space and converge to the Pareto-optimal frontier (Goldberg & Holland, 1988).

Multi-objective optimization and the Pareto-optimal frontier concept have applications in a wide range of disciplines. In engineering, for example, they help design products that meet multiple performance criteria, such as efficiency, cost, and durability (Aarts & Lenstra, 1997). In the economy, they help in the selection of investments that seek to maximize profits and minimize risks. When making environmental decisions, they consider the balance between economic growth, resource conservation, and environmental impacts (Coello, et al., 2007).

Multi-objective optimization and the trade-offs associated with the Pareto-optimal frontier are crucial concepts that address the challenges of making informed decisions in complex and conflicting environments (Steuer, 1986). The Pareto-optimal frontier reveals trade-offs between objectives, allowing decisions to be based on a thorough understanding of available options (Ishibuchi, et al., 2002). Ultimately, the search for Pareto-optimal solutions represents a realistic and effective approach to dealing with real-world problems, where choices are never simple but can be guided by careful analysis of the complex relationships between objectives (Coello, et al., 2007).

4.4.4. Methods for Addressing Multiple Objectives

A multiobjective optimization problem is characterized by having multiple objectives that are usually contradictory or competing with each other (Deb, 2011; Coello, et al., 2007). Each objective seeks to optimize a specific measure of performance, and a solution that is optimal in relation to one objective may not be optimal in relation to others. For example, when designing a car, objectives might include minimizing fuel consumption and maximizing passenger safety - two criteria that are often in conflict (Haftka, et al., 2006).

The solution to a multiobjective optimization problem is not a single point, as in single objective problems, but a set of solutions called the Pareto frontier (Deb, 2011; Coello, et al., 2007). The Pareto frontier represents solutions where it is not possible to improve one objective without worsening another. Finding the Pareto frontier is a challenge, as it involves exploring a multidimensional solution space in search of non-dominated solutions (Deb, et al., 2014).

There are several approaches to dealing with multiobjective optimization problems (Ehrgott, 2005). Some of the main approaches include:

- The aggregation approach aims to transform multiple objectives into a single weighted objective (Deb, 2011). In the weighted sum, each objective is multiplied by a weight that reflects its relative importance, and the weighted objectives are added together to form a single value. However, this approach can be problematic, as the choice of weights can be subjective and significantly influence the final solution (Bazaraa, et al., 2010).

- An alternative is the Tchebycheff method, which finds the solution that minimizes a linear combination of deviations from individual objectives, using a vector of weights (Deb, 2011). This allows exploring different trade-offs between objectives along the Pareto frontier (Bazaraa, et al., 2010).
- Lexicographic methods involve a sequential prioritization of objectives (Deb, 2011). The first objective is optimized, and then the second objective is optimized considering the already optimal solutions for the first one. This process continues for subsequent goals. These methods are simple to understand and implement, but can lead to solutions that are heavily influenced by the prioritization order (Bazaraa, et al., 2010).
- Epsilon-dominance is a set-based approach that looks for solutions that are dominated by a limited value (epsilon) relative to the other goals (Deb, 2011). This allows solutions close to the Pareto frontier to be selected. Epsilon-dominance is especially useful when the number of solutions in the Pareto set is too large to manage (Deb, et al., 2002).

In conclusion, multiobjective optimization is a complex and vital area for decision making in situations where there are conflicting objectives (Deb, et al., 2014). Aggregation methods, lexicographic methods, and epsilon-dominance are some of the approaches that can be used to deal with multiobjective optimization problems (Bazaraa, et al., 2010). The choice of approach depends on the nature of the objectives, constraints, and preferences of the decision maker (Deb, 2011). Understanding these methods and applying them appropriately is essential to finding realistic and effective solutions to real-world problems (Ehrgott, 2005).

5. CASE STUDY AND DEVELOPMENT OF THE MULTI-OBJECTIVE OPTIMIZATION MODEL FOR SUSTAINABLE ROBOTIC PROCESS AUTOMATION IMPLEMENTATION

5.1. Introduction

In this section, we introduce the context and relevance of our study. We address the need to investigate and develop a multi-objective optimization model for sustainable RPA implementation. Throughout this chapter, we will delve into a detailed description of the issue at hand, presenting the case study that will serve as the foundation for our research. The essential characteristics of this case study will be outlined, highlighting its significance in the broader context of our research. Furthermore, we will discuss the methodology used for data collection, including the chosen data source and the questionnaire strategy employed. The results obtained from this questionnaire will be analysed and discussed, providing crucial recommendations for defining user requirements. Through an in-depth analysis of the involved stakeholders, we will explore how sustainable RPA implementation can be viable. The section will also present the brainstorming process that led to the identification of crucial requirements. Based on this process, we will move on to propose our multi-objective optimization model, which presents itself as an innovative and sustainable solution. Finally, the mathematical formulation of our model will be outlined, detailing the decision variables, objective functions, and constraints. By concluding this chapter, we will have established a solid foundation for our research, and the next steps of our investigation will be delineated.

5.2. Problem Description and Case Study Presentation

In this section, we delve deeper into the description of the central problem of our research while introducing the case study that will serve as the basis for our analysis. Initially, we comprehensively contextualize the problem we aim to address, emphasizing its relevance in the domains where RPA is applied. Subsequently, we proceed to precisely identify the case study that will guide our research. This case was chosen due to its representativeness and relevance in relation to our goal of sustainable RPA implementation. Throughout this section, we examine the specific characteristics of this case study, highlighting aspects crucial to our investigation. The detailed analysis of these characteristics will contribute to a deeper understanding of the context in which our multi-objective optimization model will be applied. In this way, we will be prepared to advance to the next stage of the research, the data collection from the case study. The thorough exploration of this case will serve as a solid foundation for the final conclusions and recommendations of our study.

5.2.1. Problem Contextualization

In the current era, where digital transformation shapes the business landscape, it is evident that organizations are relentlessly seeking innovative strategies to optimize their processes and enhance their operational efficiency. In this context, RPA emerges as one of the most promising solutions destined to revolutionize the way repetitive and standardized tasks are handled. This technology, aimed at replacing manual actions with automated ones, has proven to be a powerful tool for boosting productivity and minimizing errors.

However, the adoption of RPA is not without its challenges. With the increasing integration of this technology into enterprises, significant hurdles arise that require in-depth analysis. RPA implementation involves a substantial change in established work methods, directly impacting team dynamics and organizational structures. Moreover, the inherent complexity of certain administrative tasks and the diversified nature of business operations can further complicate the process of RPA integration. These obstacles are particularly noticeable when it comes to activities that, while repetitive, require careful analysis and decisions based on human criteria. The intricate interplay between RPA and human decisions is a factor that cannot be ignored and, in turn, raises questions about the effectiveness of sustainable RPA implementation.

In this regard, the focal issue revolves around the pursuit of fully realizing the benefits of RPA while grappling with the inherent challenges of its implementation. The present investigation, therefore, aims to scrutinize the impact of RPA in the corporate context, with a specific focus on the sustainable implementation of this technology. The study will not only examine the tangible advantages of robotic automation but also identify the barriers that may hinder its seamless integration into a company's day-to-day operations.

Throughout this section, a detailed analysis of the challenges arising during RPA implementation will be conducted. Financial, technological, and organizational obstacles will be explored in depth, with the objective of comprehending the complete landscape within which our case study is situated. Thus, we will be well-equipped to proceed with the identification of the case study that will serve as the foundation for our research, addressing these issues in a concrete and informed manner.

5.2.2. Case Study Identification

In this section, we will shift our focus towards the meticulous identification and selection of the case study that will become the centrepiece of our investigations. The chosen company for the case study presents itself as a prominent player in its industry, and it is this prominence that makes it an ideal candidate for our in-depth analysis.

The company in question, holding a leadership position in the market, faces a complex operational dynamic and an increasing challenge in terms of managing repetitive and standardized tasks. The decision to implement RPA in its administrative department stemmed from the need to optimize internal operations and align with contemporary expectations of efficiency and precision. The company's strategic approach to opting for robotic automation stands as a testament to its dedication to shaping the future of its operations by eliminating time-consuming and error-prone manual processes.

The selection of this case study is motivated by its uniqueness and relevance, extending beyond its prominent market position. The company encountered specific challenges associated with the nature of its administrative tasks, ranging from data processing to report generation and document management. The complexity of these activities, many of which involved analysis and subjective decision-making, emphasized the importance of a carefully planned RPA implementation. This intricate context will enable an in-depth analysis of the challenges encountered and the solutions developed.

Furthermore, the company grappled with a diverse set of stakeholders, including managers, administrative teams, and employees who would directly interact with the automated processes. This aspect is crucial for understanding the impact and acceptance of RPA across all layers of the organization. Harmonizing the needs and perspectives of all stakeholders became a significant goal for the company, thus shaping how the implementation was carried out.

The identification of this case study also rests on the iterative approach adopted by the company to address real-time challenges as the implementation process progressed. The adaptations and adjustments made during this period offer valuable insights into the evolving dynamics of RPA integration and the strategic decisions required to overcome unexpected obstacles.

Through a meticulous analysis of this case, we shall be able to extract valuable lessons regarding the practical implications of RPA implementation, considering various angles: financial, operational, and human. The combination of specific challenges faced by this company and its strategic responses will provide a solid and realistic case study to inform the development of our multi-objective optimization model.

5.2.3. Relevant Characteristics of the Case Study

In this section, we focus on delineating the essential features of the chosen case study, grounding its relevance and uniqueness in the context of our research. The selected company for analysis represents a complex and multifaceted scenario, providing fertile ground for exploring the interactions between RPA and operational challenges.

A central feature of the case study is the wide range of administrative activities that the company used to perform manually before the RPA implementation. From data processing to report generation and document management, each of these tasks played a critical role in daily operations. The repetitive nature of these activities made them ideal targets for automation, with the aim of freeing up human resources for more strategic and cognitively intensive functions. The variety and complexity of these tasks contributed to a challenging RPA implementation, requiring an adaptive and personalized approach.

Another distinctive aspect of the case study is the coexistence of purely automatable tasks with those that require human decisions and subjective analysis. This mix of activities, with varying levels of complexity, drove the need for a carefully balanced integration of RPA. The challenge was not only in automating tasks but also in ensuring that the interaction between robotic actions and human interventions was smooth and efficient. This unique dynamic enriches the analysis by revealing the complexity of collaboration between RPA and human decision-making capabilities.

Additionally, the company emphasized the importance of considering the needs and perspectives of stakeholders throughout the implementation process. Company managers, the administrative team, and employees were involved in discussions and defining the parameters for RPA integration. This inclusive approach contributed to a change environment that was understood and embraced at all levels of the organization. Proactive engagement of stakeholders adds a human dimension to the case study, highlighting the interplay between technology and human factors.

The resolution of inherent challenges in RPA implementation also stood out as a relevant feature of the case study. The company adopted a pragmatic and flexible approach, adapting to emerging demands and unforeseen obstacles. The agility demonstrated in addressing real-time issues exemplifies the organization's ability to learn and continuously improve during the integration process. This willingness to confront challenges head-on and evolve based on lessons learned is a crucial facet of the success of RPA implementation.

By closely examining these characteristics of the case study, we will be equipped with a deep understanding of the operational environment in which our multi-objective optimization model will be applied. The diversity of activities, interactions between technology and human factors, and the problem-solving approach of the company will serve as fundamental pillars for the subsequent stages of our research. Understanding these relevant characteristics paves the way for the formulation of a robust and adaptable model that addresses the challenges and needs of the scenario under analysis.

5.3. Data Collection for the Case Study

Data collection is a crucial step in any research or case study. In this section, we will thoroughly explore the data collection process conducted to address a specific issue within the company under study, using questionnaires as the primary instrument. The main objective was to gather data for the case study in order to better understand the problem and construct a model capable of finding solutions for this particular case.

The company in question, with the determination to implement RPA in its administrative department, faced a significant and characteristic challenge. One of the main challenges faced by this company was the high cost associated with RPA implementation. However, it became clear that even with the automation of various processes, it was necessary to optimize and efficiently manage the resources associated with RPA. With this goal in mind, the choice was made to use a questionnaire as the data collection method, due to its effectiveness in obtaining information quickly and comprehensively.

Before commencing data collection, it was essential to develop a detailed questionnaire that addressed various aspects related to the problem at hand. The questionnaire was designed to address issues such as identifying user requirements within the context of stakeholders, which affect decision-making regarding the feasibility of RPA, as well as how these requirements influence the efficiency of sustainable RPA implementation. Additionally, a dedicated section of the questionnaire was aimed at the RPA team, containing questions about the total number of activities automated by RPA, average execution time, daily resource costs, and details of each machine acquired by the company. These questions were directed at the RPA team, as other employees from different teams may not have the necessary knowledge to answer such questions.

The next step involved defining the target audience for data collection. In this case, all users within the context of stakeholders who influence decisions regarding the feasibility of RPA in the company were considered participants in the questionnaire. For the sample, 30 employees from the company were selected, including 10 from the RPA team (1 RPA Manager, 2 Business Analysts, 5 RPA Developers, and 2 RPA Support Technicians), and 20 employees from the technical teams where RPA projects were implemented (including Business Line Directors, Managers, and Technicians).

After developing the questionnaire, distribution took place. For this purpose, a paper format was chosen. Employees received the paper questionnaire at the company's premises, along with clear instructions on how to fill it out.

The importance of confidentiality and anonymity in the employees' responses was emphasized. Participants were informed that their responses would be treated strictly confidentially, and their identities would be protected. It was stressed that the purpose of the questionnaire was to obtain honest and constructive feedback without any negative impact on their careers.

A specific deadline was set for responding to the questionnaire to ensure efficient data collection. One week was allocated for employees to complete it. Additionally, if any doubts arose during the questionnaire completion, employees could ask the person responsible for distributing the questionnaires for clarification on related issues. This ensured a more comprehensive and enlightening data collection process.

After the response deadline, the collected data were compiled and organized for analysis. A quantitative data analysis was performed.

Based on the results of the data analysis, a detailed report was prepared. This report highlighted how user requirements within the context of stakeholders affect decision-making regarding the feasibility of RPA, as well as how they influence the efficiency of sustainable RPA implementation.

The report was shared with the company's senior management and the RPA team with the aim of being discussed in meetings. The requirements to be implemented were identified, and an action plan was developed to analyse, at the end of the work, the before and after implementation of these requirements.

Data collection through questionnaires proved to be an effective approach for obtaining valuable recommendations regarding the problem studied in the company. The use of questionnaires allowed for a comprehensive understanding of employees' perceptions and opinions, contributing to a deeper understanding of the problem and providing important information for decision-making and the sustainable implementation of RPA.

Furthermore, the questionnaire-based data collection method facilitated the identification of key recommendations and trends through the analysis of quantitative data. The responses provided a comprehensive insight into the challenges and requirements associated with RPA implementation, enabling the identification of areas for improvement and informed decision-making.

When engaging a diverse range of participants, including stakeholders and the RPA team, the questionnaire captured various perspectives and experiences related to the problem at hand. This comprehensive approach ensured that the collected data reflected the global organizational context and provided valuable recommendations on various aspects of RPA implementation.

Ensuring confidentiality and anonymity in questionnaire responses was crucial to promoting honest and impartial feedback from participants. By emphasizing identity protection and the non-negative impact on careers, employees felt more comfortable providing candid responses, leading to a more accurate representation of their thoughts and opinions.

The timely distribution of the questionnaire and the provision of clear instructions further facilitated an efficient data collection process. The designated response deadline and the opportunity for participants to seek clarification ensured a comprehensive and well-founded set of responses.

Compiling and organizing the collected data allowed for a systematic analysis, enabling the identification of patterns, trends, and correlations. This quantitative analysis provided valuable insights into the relationships between user requirements, decision-making, and the efficiency of RPA implementation. The analysis laid the groundwork for the development of a detailed report summarizing the findings and presenting concrete recommendations.

The report, shared with the company's senior management and the RPA team, served as the basis for informed discussions and decision-making. It provided a clear understanding of the challenges and opportunities associated with RPA implementation, allowing for the identification of specific requirements and the formulation of an action plan. The analysis of "before and after" implemented requirements would serve as a measure of success and provide valuable feedback on the effectiveness of the implemented solutions.

In conclusion, the data collection process through questionnaires proved to be an effective and efficient method for obtaining valuable insights into the issue studied in the company. The comprehensive recommendations obtained from questionnaire responses facilitated a deeper understanding of the problem, informed decision-making, and support for sustainable RPA implementation. The combination of a quantitative approach with confidentiality and anonymity assurance resulted in a robust analysis and high-quality recommendations that will serve as a solid foundation for the subsequent stages of research.

5.3.1. Data Source Used

The data source used in this research played a crucial role in obtaining valuable information to understand the focal problem and develop suitable solutions for the case study. The choice of the data source aimed primarily to gather a comprehensive and in-depth view of the various perspectives and elements involved in sustainable RPA implementation.

The central instrument used for data collection was the questionnaire. This approach was selected based on its effectiveness in efficiently and comprehensively capturing a diverse range of information. The questionnaire was designed to address specific issues related to the problem at hand, including user requirements identification, the influence of stakeholders on RPA feasibility decisions, and factors affecting the efficiency of sustainable RPA implementation.

The choice of a questionnaire as the data collection instrument offered several advantages. Firstly, it allowed for the rapid and systematic collection of information from a large number of participants. This was especially relevant considering that data was needed from various teams within the organization, including the RPA team and the technical teams where RPA projects were implemented.

Additionally, the questionnaire provided a standardized approach to collecting information. This ensured that the same questions were presented to all participants, promoting comparability and data consistency. Standardization also facilitated subsequent analysis, allowing for the identification of patterns and trends in responses.

The selection of questions for the questionnaire was based on their relevance to the research objectives. Questions were carefully crafted to address specific topics, such as the financial impact of RPA implementation, user requirements in different contexts, and the dynamics between the RPA team and other technical teams.

The data collection approach was complemented by careful consideration of the participants to be included in the questionnaire. The selected employees represented a variety of perspectives and roles, including members of the RPA team, managers, and technical team members. This ensured that the voices of all relevant stakeholders were heard, contributing to a holistic analysis of the problem.

Furthermore, adopting a questionnaire-based data collection approach allowed for a quantitative analysis of the results. This involved tabulating and organizing the collected data in numeric formats, facilitating the identification of patterns, correlations, and trends. The quantitative analysis provided a solid foundation for understanding the relationships between variables and for drawing data-driven conclusions.

In summary, the data source used in this research, through questionnaires, played a central role in obtaining comprehensive and detailed information about the issue under analysis. The standardized and efficient approach of the questionnaire enabled the collection of data from various stakeholders, promoting a more complete understanding of the dynamics involved in sustainable RPA implementation. The quantitative analysis of the data collected through questionnaires further enriched the research, providing a solid basis for the conclusions and recommendations presented in the subsequent sections.

5.3.2. Data Collection Methodology

The data collection methodology adopted in this study played a crucial role in obtaining detailed and meaningful information about the problem under analysis. The careful choice and implementation of the methodology ensured the acquisition of reliable and representative data, enabling an in-depth analysis of the challenges and needs associated with the sustainable implementation of RPA.

The data collection methodology was structured into multiple phases, each designed to ensure the effectiveness and comprehensiveness of the process. The approach taken took into consideration the complex and multifaceted nature of the problem, as well as the diversity of perspectives from the involved stakeholders.

The first phase of the methodology involved detailed questionnaire planning. This included identifying the key thematic areas to be addressed, selecting relevant questions, and organizing the questions logically and coherently. Thoughtful questionnaire development was crucial to ensure that the collected data provided accurate insights aligned with the research objectives.

Following the questionnaire planning, the instrument development phase ensued. The questions were formulated clearly and concisely, ensuring they were understandable to the participants. The sequence of questions was carefully thought out to facilitate a logical flow of responses and prevent confusion. Additionally, open-ended and closed-ended questions were strategically combined to obtain a comprehensive view of participants' perceptions and opinions.

Questionnaire validation was also a crucial step. The instrument underwent a review process by experts and was tested with a pilot group of participants. This helped identify potential ambiguities or comprehension issues and allowed for adjustments before final distribution.

The questionnaire distribution phase involved physically delivering the instrument to the participants. A paper-based approach was chosen, allowing employees to complete the questionnaire on-site at the company's facilities. Clear instructions were provided to ensure that participants knew how to respond to the questions appropriately and thoroughly.

Emphasizing the confidentiality and anonymity of responses was an important consideration throughout the process. Participants were informed that their responses would be treated strictly confidentially, and their identities would be protected. This encouraged honesty and sincerity in responses, contributing to the quality of the collected data.

Once the questionnaires were distributed and completed by the participants, the data collection phase transitioned into the analysis stage. The collected data was compiled and organized to enable quantitative analysis. Data tabulation allowed for the identification of patterns, trends, and correlations among variables.

The data collection methodology used in this study provided a comprehensive and structured approach to obtaining meaningful information about the sustainable implementation of RPA. The well-crafted questions, along with the emphasis on confidentiality and questionnaire validation, resulted in high-quality data.

The effectiveness of the data collection methodology also manifested in the adopted sampling approach. Careful selection of participants ensured a diverse representation of stakeholders involved in the sustainable implementation of RPA. The inclusion of RPA team members, managers, and technical team technicians provided a variety of perspectives and experiences, enriching the overall understanding of the issue.

A fundamental consideration throughout the process was ensuring the quality of the collected data. This involved validating the questionnaire before distribution, adopting measures to promote honesty and sincerity in responses, and conducting rigorous analysis of the results. The rigorous approach contributed to the reliability of the data and the validity of the conclusions drawn from them.

The data collection methodology also aligned with the research objectives, which aimed to understand user requirements, stakeholder influence, and factors affecting the sustainable implementation of RPA. The selected questions addressed these aspects in detail and allowed for an in-depth analysis of organizational dynamics and challenges faced.

The data collection approach through questionnaires, combined with quantitative and qualitative analysis of the results, proved to be a comprehensive and robust method for obtaining meaningful recommendations regarding the studied issue. The implemented methodology ensured the collection of accurate and reliable data, enabling an in-depth analysis of various dimensions of the case study and serving as a solid foundation for the subsequent stages of research.

In conclusion, the data collection methodology adopted in this study played a crucial role in obtaining detailed and representative information about the sustainable implementation of RPA in the company under study. The structured approach, careful question selection, emphasis on confidentiality, and quantitative and qualitative analysis of the results contributed to the quality of the collected data and a profound understanding of the issue. This methodology strengthened the basis for subsequent analysis and the formulation of data-driven recommendations.

5.3.3. Questionnaire

Questionnaires are a widely used research instrument for collecting data from a large number of people. They are a versatile tool that can be used to gather information on a variety of topics, including attitudes, beliefs, behaviours, and demographics (Dillman, 2014; Oppenheim, 2016).

A questionnaire is a structured set of questions that are used to collect data from respondents. The questions are typically designed to be answered in a written format, but they can also be administered in a face-to-face or online setting (Dillman, 2014).

Questionnaires can be classified into a number of different types, including:

- **Self-administered questionnaires:** These are the most common type of questionnaire. Respondents are given the questionnaire to complete on their own.
- **Interviewer-administered questionnaires:** These questionnaires are administered by an interviewer who reads the questions to the respondent and records the answers.
- **Online questionnaires:** These questionnaires are administered via the internet. Respondents can access the questionnaire from any computer with an internet connection (Dillman, 2014).

The design and development of a questionnaire is an important step in ensuring that the data collected is accurate and reliable. Factors to consider include:

- **The purpose of the research:** Questions should be designed to collect the necessary data to address the research question.
- **The target population:** Questions should be appropriate for the target population.
- **The level of measurement:** Questions should collect data at the appropriate level of measurement.
- **The wording of the questions:** Questions should be clear, concise, and unambiguous.
- **The order of the questions:** Questions should be ordered logically.

The pre-testing of the questionnaire: The questionnaire should be pre-tested with a small sample of respondents to identify any potential problems (Oppenheim, 2016).

Once a questionnaire has been designed and developed, it can be administered to the target population. Considerations during administration include:

- **The mode of administration:** It should be appropriate for the target population.
- **The timing of the administration:** The questionnaire should be administered at a convenient time for the target population.
- **The instructions:** Instructions for completing the questionnaire should be clear and concise.
- **The follow-up:** Respondents who do not return the questionnaire should be followed up with (Dillman, 2014).

The data collected from a questionnaire can be analysed using various statistical methods, depending on the type of data and research question. Data should be interpreted in the context of the research question and the study's limitations (Tourangeau, et al., 2010).

Questionnaires are a valuable research tool for collecting data from a large number of people. Proper design, administration, and analysis are crucial for ensuring the accuracy and reliability of the collected data.

The questionnaire played a fundamental role in obtaining valuable recommendations on the complexities of sustainable RPA implementation in the context of the company under study. Its design was guided by the aim of capturing a wide range of information related to user requirements, stakeholder influence, and challenges faced in RPA implementation. The careful design of the questionnaire allowed for a comprehensive and structured approach to data collection.

The distribution and completion of the questionnaire were carefully coordinated. Delivering the questionnaires in physical format (Appendix 2) in the workplace provided convenience to participants, allowing them to respond at their own pace and in their own environment. Emphasis on confidentiality and anonymity encouraged participants to provide honest responses without fear of negative repercussions.

Questions 1 through 5 were answered exclusively by the RPA Manager in order to provide data related to the company's RPA activities, costs, and machine details.

1. How many RPA activities are currently implemented?

Answer: **44 RPA activities.**

2. What is the average execution time for each RPA activity?

Answer: The answer to this question is presented through a graph where we can analyze the times, in minutes, of the company's respective RPA activities.

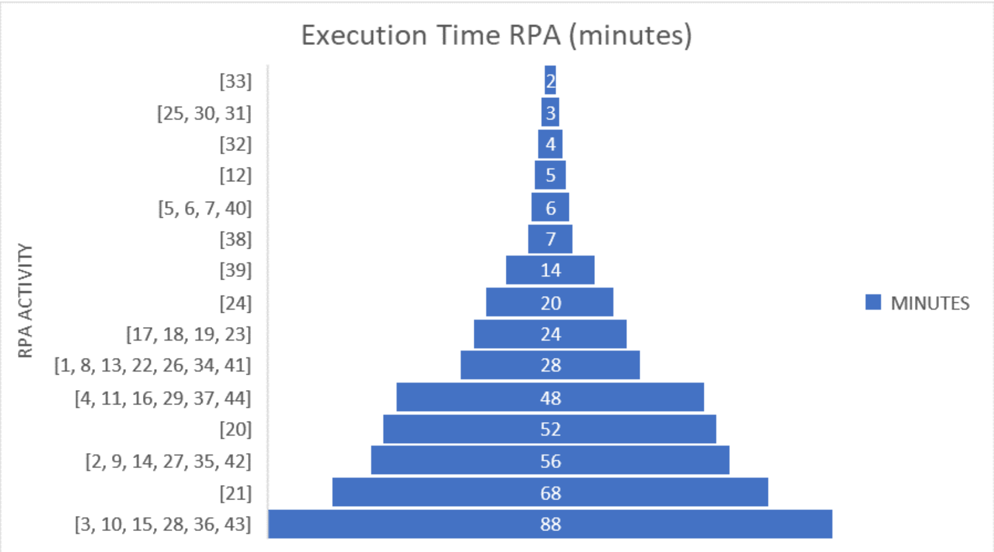

Figure 22 - Execution times of RPA activities.

Figure 2. Execution Times of RPA Activities.

3. What is the daily cost spent on total RPA resources?

Answer: **3000 monetary units (U. m.).**

4. How many RPA machines has the company acquired?

Answer: **4 RPA machines.**

5. What is the daily availability and cost of each RPA machine?

Answer: The answer to this question is presented through a table with the cost and availability of each RPA machine.

Table 21 - Daily Cost and Daily Availability of RPA Machines.

	RPA Machines Cost per Day (Monetary Units)	**Availability RPA Machines per Day (minutes)**
Machine 1	0.7	480
Machine 2	1.4	600
Machine 3	2.1	960
Machine 4	2.8	1440

From question 6 onward, all participants responded to the questions. In other words, the questionnaire distributed to individuals began with question 6.

6. Are you part of the RPA team in the company?

a) Yes **(10)**

b) No **(20)**

7. Regarding costs, how important is this factor in RPA implementation?

a) Extremely important. **(20)**

b) Important. **(5)**

c) Neutral. **(5)**

d) Less important.

e) Not important.

8. How would you rate the energy efficiency of RPA solutions compared to manual/traditional processes?

a) RPA solutions are more energy-efficient. **(22)**

b) RPA solutions are less energy-efficient.

c) RPA solutions have similar energy efficiency to manual/traditional processes.

d) I don't know enough to answer. **(8)**

9. What could be the possible impacts on employees with the implementation of RPA in the company?

a) Reduction in the number of employees. **(2)**

b) Redirecting employees to more strategic tasks. **(10)**

c) Improvement in working conditions. **(8)**

d) I don't know enough to answer. **(10)**

10. In what ways can RPA automation help reduce paper consumption in the company?

a) Eliminating the need for printed documents. **(5)**

b) Automating processes to reduce waste.

c) Minimizing errors leading to rework and unnecessary resource use. **(5)**

d) All of the above options. **(20)**

11. Do you believe that sustainable RPA implementation can improve team productivity?

a) Yes, definitely. **(20)**

b) Maybe, depending on the context.

c) No, I don't believe there is a direct correlation. **(2)**

d) I'm not sure. **(8)**

12. How would you rate the current process of allocating RPA projects to machines in terms of effectiveness?

a) Highly effective.

b) Moderately effective. **(2)**

c) Ineffective. **(13)**

d) I'm not sure. **(15)**

13. What is the importance of minimizing the time required to complete automation projects?

a) Very important to ensure efficiency and agility in operations. **(24)**

b) Important, but not the most critical factor. **(1)**

c) Neutral, as project completion time does not significantly affect results. **(2)**

d) I'm not sure about the importance of project completion time. **(3)**

14. What is the primary goal of RPA implementation in an organization?

a) Completely replace employees with robots to reduce costs. **(3)**

b) Improve operational efficiency by automating repetitive tasks. **(23)**

c) Increase complexity of business processes to achieve advanced results.

d) Expand the current workforce by hiring robots. **(4)**

15. How would you assess employees' resistance to RPA implementation in the company?

a) Very strong.

b) Moderate. **(8)**

c) Weak. **(15)**

d) I don't have enough information to answer. **(7)**

16. What is your perception of the level of training provided to employees to work with RPA solutions?

a) Very adequate.

b) Adequate. **(18)**

c) Insufficient. **(6)**

d) I can't evaluate. **(6)**

17. What are the main areas in which RPA has demonstrated effectiveness in the company?

a) Data processing. **(15)**

b) Report generation. **(10)**

c) Document management. **(5)**

d) Internal communication. **(5)**

e) Other areas (please specify): ______________________________

18. Regarding the integration of RPA with existing systems in the company, how would you rate the results achieved so far?

a) Very well integrated. **(2)**

b) Moderately integrated. **(15)**

c) Poorly integrated. **(5)**

d) I can't evaluate. **(8)**

19. How do you assess the degree of alignment of RPA projects with the overall company strategy?

a) Completely aligned. **(5)**

b) Partially aligned. **(17)**

c) Poorly aligned. **(5)**

d) I can not evaluate. **(3)**

20. What are the main performance indicators that the company considers when evaluating the success of RPA implementation?

a) Reduction in operational costs. **(19)**

b) Increased productivity. **(5)**

c) Improved process accuracy. **(5)**

d) Customer satisfaction. **(1)**

e) Other indicators (please specify): ____________________________

21. In your opinion, what are the major obstacles faced in integrating RPA with existing processes?

a) Difficulty in adapting existing processes. **(1)**

b) Resistance from employees to change. **(14)**

c) Technical complexity. (15)

d) Lack of leadership support.

e) Other obstacles (please specify): ____________________________

22. What types of activities do you consider most suitable for automation through RPA?

a) Highly repetitive tasks. **(20)**

b) Tasks involving complex decisions.

c) Tasks requiring creativity. **(5)**

d) Highly collaborative tasks. **(5)**

23. How would you rate the collaboration between the RPA team and the rest of the company teams?

a) Highly collaborative. **(25)**

b) Moderately collaborative. **(5)**

c) Not very collaborative.

d) I do not have enough information to answer.

24. In terms of maintaining RPA solutions, what is your perception of the need for frequent updates?

a) Extremely necessary. **(15)**

b) Necessary. **(10)**

c) Occasionally necessary. **(5)**

d) I do not consider it necessary.

25. How would you describe the overall perception of employees about RPA in the company?

a) Very positive. **(15)**

b) Neutral. **(10)**

c) Mixed. **(5)**

d) Negative.

26. What criteria are considered when selecting processes for automation through RPA?

a) Task volume. **(15)**

b) Task complexity. **(8)**

c) Potential for error reduction. **(7)**

d) Potential for increased productivity.

27. What are the main metrics used to evaluate the efficiency of RPA activities?

a) Task completion rate. **(20)**

b) Average execution time. **(15)**

c) Error rate. **(5)**

d) Resource usage.

e) Other metrics (please specify): ______________________________

28. In your opinion, what are the main factors that can ensure the sustainability of RPA implementation in the long term?

a) Leadership commitment. **(10)**

b) Adoption of best automation practices. **(10)**

c) Ongoing training and team development. **(9)**

d) Adaptation to changes in business needs. **(1)**

29. How do you assess the current capacity of the RPA team to handle potential future challenges?

a) Very capable. **(18)**

b) Capable. **(12)**

c) Partially capable.

d) Not prepared for future challenges.

30. What kind of support or additional resources do you consider necessary to maximize the benefits of sustainable RPA implementation?

a) Increased investment in technology. **(12)**

b) Ongoing team training. **(18)**

c) Greater leadership involvement.

d) Improved internal communication.

e) Other resources (please specify): ______________________________

This set of questions was designed with the intention of exploring participants' perceptions on various aspects related to RPA implementation and its implications. By dividing the questions between those answered exclusively by the RPA Manager and those answered by all participants, the research could address both the specific characteristics of RPA activities and the general opinions of those involved.

The responses to these questions provided valuable data that contributed to a more comprehensive understanding of the case study. Details regarding the number of implemented RPA activities, associated costs, and RPA machine characteristics allowed for a more precise grasp of the scale and complexity of the implementation. Furthermore, participants' opinions on factors such as costs, energy efficiency, employee impacts, and implementation goals revealed relevant perspectives that influenced the conclusions of this study.

5.3.4. Discussion of Questionnaire Results

The aim of this questionnaire was to gather information about the implementation of Robotic Process Automation (RPA) in the company and employees' perceptions of this technology.
Here is a discussion of the questionnaire results:

- **Participation in the RPA Team (Question 6):**

The majority of participants (20) are not part of the RPA team, suggesting that RPA implementation may involve different departments within the company.

- **Importance of Costs in RPA Implementation (Question 7):**

Most participants (20) consider costs extremely important in RPA implementation. This indicates that expense management is a critical consideration for the company.

- **RPA Energy Efficiency (Question 8):**

The majority of participants (22) believe that RPA is more energy-efficient compared to manual/traditional processes. This could be a motivating factor for RPA adoption.

- **Employee Impact (Question 9):**

Responses vary, but the majority (10) believe that RPA implementation may result in employees being redirected to more strategic tasks, which can be seen as a positive opportunity.

- **Reduction in Paper Consumption (Question 10):**

Most (20) agree that RPA automation can help reduce paper consumption, highlighting the importance of environmental sustainability.

- **Productivity Improvement with RPA (Question 11):**

Most (20) believe that sustainable RPA implementation can enhance team productivity, which is a positive goal for many companies.

- **Effectiveness in Allocating RPA Projects (Question 12):**

The majority (15) rate the allocation of RPA projects as ineffective. This may be an area for improvement to ensure the efficiency of the RPA team.

- **Importance of Swift Project Completion (Question 13):**

Most (24) consider minimizing the time required to complete automation projects very important, emphasizing the need for operational efficiency.

- **Primary Goal of RPA Implementation (Question 14):**

The majority (23) believe that the primary goal of RPA implementation is to improve operational efficiency, while a few less relevant responses mention replacing employees with robots (3).

- **Employee Resistance (Question 15):**

The majority (15) perceive moderate employee resistance to RPA implementation. This underscores the importance of addressing employee concerns during the implementation process.

- **Perception of Training (Question 16):**

Most (18) consider the training provided to employees adequate, which is positive for effective RPA adoption.

- **Areas of RPA Effectiveness (Question 17):**

The majority (15) identify data processing as the primary area where RPA is effective, followed by report generation (10).

- **Integration of RPA with Systems (Question 18):**

Most (15) rate the integration of RPA with existing systems as moderately integrated, indicating room for improvement.

- **Alignment with Company Strategy (Question 19):**

The majority (17) see RPA projects as partially aligned with the overall company strategy. This may be an opportunity to improve strategic alignment.

- **Performance Indicators (Question 20):**

Reducing operational costs (19) is considered the most important performance indicator for evaluating the success of RPA implementation.

- **Obstacles in RPA Integration (Question 21):**

Employee resistance (14) and technical complexity (15) are the main obstacles mentioned, highlighting critical areas to address during implementation.

- **Suitable Tasks for Automation (Question 22):**

The majority (20) consider highly repetitive tasks as the most suitable for automation by RPA.

- **Collaboration between RPA Team and Other Teams (Question 23):**

Most (25) perceive highly effective collaboration between the RPA team and other company teams, which is essential for success.

- **Maintenance of RPA Solutions (Question 24):**

The majority (15) believe that frequent updates are extremely necessary to maintain effective RPA solutions.

- **Employee Perception of RPA (Question 25):**

Most (15) perceive an overall positive employee perception of RPA in the company.

- **Criteria for Selecting Processes for Automation (Question 26):**

The volume of tasks (15) is the most important criterion considered when selecting processes for automation.

- **RPA Efficiency Metrics (Question 27):**

Task completion rate (20) and average execution time (15) are the most commonly used metrics to assess the efficiency of RPA activities.

- **Sustainability of RPA Implementation (Question 28):**

Leadership commitment (10) and adopting best automation practices (10) are key factors mentioned to ensure the sustainability of RPA implementation.

- **Preparedness for Future Challenges (Question 29):**

Most (18) believe that the RPA team is well-equipped to handle potential future challenges.

- **Resources Needed to Maximize Benefits (Question 30):**

Additional resources considered necessary to maximize the benefits of sustainable RPA implementation include ongoing team training (18) and increased leadership involvement (indicated as a relevant need but not specified).

The implementation of RPA is seen as a strategy to enhance operational efficiency and reduce costs.

Employee resistance, technical complexity, and integration with existing systems are significant challenges to overcome.

Collaboration between the RPA team and other teams is regarded as a strength.

Metrics such as operational cost reduction and energy efficiency are crucial for assessing the success of RPA.

Additional resources, such as ongoing training and leadership involvement, are deemed necessary to maximize the long-term benefits of RPA.

5.4. User Requirements Definition in the Stakeholder Context

The definition of user requirements plays an essential role in crafting a multi-objective optimization model for the sustainable implementation of RPA (Robotic Process Automation). These requirements capture the needs, desires, and expectations of stakeholders involved in the process, providing clear guidance for model development. In this section, we will elaborate on the characterization of stakeholders, discussing their roles, interests, and influence in the context of sustainable RPA implementation. Subsequently, we will delve into the methodology employed for requirements elicitation, highlighting the collaborative approach adopted to ensure the comprehensiveness and relevance of identified requirements.

5.4.1. Stakeholder Characterization

Stakeholders are individuals or groups with a direct or indirect interest in the outcome of RPA implementation within the organization. They play critical roles in decision-making and directly influence the outcomes achieved. In this context, key stakeholders include senior management of the company, the RPA team, employees who interact with RPA solutions, and the end users who benefit from optimized processes.

Senior Management: Senior management plays a pivotal role in making strategic decisions and allocating resources for RPA implementation. Their primary focus includes analysing the cost, efficiency, and sustainability benefits brought about by RPA adoption. Additionally, leadership is responsible for setting organizational priorities and ensuring alignment of the overall strategy with RPA implementation.

RPA Team: The RPA team comprises professionals specialized in process automation and RPA technologies. They play a fundamental role in the implementation, development, and maintenance of RPA solutions. Their technical perspective is essential for evaluating the feasibility and effectiveness of proposed solutions.

Employee Users of RPA: Employees who directly interact with RPA solutions offer valuable insights into usability, effectiveness, and efficiency of implemented solutions. They have a practical view of RPA solutions in action and can highlight improvement opportunities.

End Users: End users are the direct beneficiaries of processes optimized by RPA. Their needs and experiences must be considered to ensure that implemented solutions meet their expectations and enhance their satisfaction.

5.4.2. Methodology for Requirements Elicitation for Sustainable Robotic Process Automation Implementation Feasibility

Requirement's elicitation is a crucial step to ensure that the multi-objective optimization model can address the real needs of stakeholders and align with the objectives of sustainable RPA implementation. To achieve this, a structured methodology was employed, based on a participatory process involving stakeholders at various stages.

Definition of Questions and Hypotheses: The methodology commenced with the definition of questions and hypotheses in a meeting with Business Line Directors and the RPA Manager. These questions served as a starting point to identify areas of interest and focus in sustainable RPA implementation.

Questionnaire and Responses: The questions were incorporated into a questionnaire and answered by participants, providing insights, expectations, and priorities related to RPA. Responses played a central role in the requirements elicitation process.

Brainstorming for Response Analysis: Following the collection of responses, a brainstorming session was conducted with Business Line Directors and the RPA Manager. They collectively analysed the responses and explored the recommendations provided.

Identification of Requirements: Relevant requirements for the feasibility of sustainable RPA implementation were identified based on the responses and discussions during the brainstorming session. These requirements encompassed areas such as project allocation, cost minimization, reduction of makespan, and average workload.

Justification of Selected Requirements: Each selected requirement was justified based on the responses to the questionnaire. For example, the relevance of efficient project allocation was supported by responses to the question about the effectiveness of the current allocation.

The participatory requirements elicitation methodology has several implications and benefits. The use of brainstorming allowed key stakeholders to collectively analyse questionnaire responses, enriching the understanding of identified requirements. Collaboration among stakeholders generated innovative insights and valuable contributions that may not have been considered otherwise.

Furthermore, active stakeholder involvement promoted engagement, mutual understanding, and consensus building. Brainstorming discussions clarified doubts, deepened understanding, and resolved potential conflicts, ensuring that the selected requirements accurately reflected needs and expectations.

The participatory approach also ensures that the multi-objective optimization model aligns with stakeholders' actual perspectives and the peculiarities of the organizational context. This contributes to the validity and relevance of the model, increasing the likelihood that proposed solutions are feasible and effective in practice.

In summary, stakeholder characterization and the participatory requirements elicitation methodology strengthen the foundation of sustainable RPA implementation. By actively involving stakeholders at every stage, from defining questions to justifying selected requirements, we ensure that their voices are heard and their perspectives are integrated into model development. This promotes transparency, legitimacy, and acceptance of proposed solutions, while maximizing the utility and effectiveness of the model.

The participatory approach also enables comprehensive consideration of the pillars of sustainability - economic, social, and environmental. By analysing the responses to the questionnaire and discussing them during brainstorming sessions, requirements were selected based on their influences on the different pillars. For instance, the importance of cost minimization is directly related to the economic pillar, while reducing the average workload influences the social pillar.

Collaboration among stakeholders and joint analysis of responses strengthen informed decision-making. Divergent perspectives can be explored and understood, allowing for the formulation of more balanced and sustainable solutions. Analysing responses in a collaborative context facilitates the identification of patterns, trends, and gaps, guiding the selection of the most relevant and impactful requirements.

The use of brainstorming to analyse questionnaire responses provides a creative environment where innovative ideas can emerge. Interaction among stakeholders fosters the generation of alternatives and approaches to meet identified requirements. This innovative approach results in more comprehensive and effective solutions that address the challenges of RPA implementation sustainably.

Furthermore, the use of a participatory approach contributes to strengthening relationships among stakeholders. Collaboration and mutual engagement create a sense of ownership and commitment, promoting an atmosphere of cooperation and alignment with RPA implementation objectives. This is essential for creating an environment where proposed solutions are accepted and successfully implemented.

In conclusion, stakeholder characterization and the participatory requirement gathering methodology play a fundamental role in defining user requirements in the context of stakeholders for the feasibility of sustainable RPA implementation. This approach promotes comprehensive consideration of stakeholder perspectives and needs, ensuring that proposed solutions align with organizational objectives and sustainability dimensions. Collaboration and joint analysis of questionnaire responses through brainstorming enrich the requirement selection process, enabling the formulation of more innovative, effective, and acceptable solutions. The participatory approach is a cornerstone in building a multi-objective optimization model that truly addresses the challenges and opportunities of sustainable RPA implementation.

5.4.3. Brainstorming

Brainstorming is a group creativity technique by which efforts are made to find a conclusion for a specific problem by gathering a list of ideas spontaneously contributed by its members (Osborn, 1957). The brainstorming method is frequently used in businesses to generate new ideas and solutions to problems (Paulus & Brown, 2007). It is also used in education to promote creative thinking and problem-solving skills (Weisbord, 1990).

Brainstorming was first introduced by Alex Faickney Osborn in 1939 (Osborn, 1957). Osborn was a creative director at advertising agency BBDO, and he developed brainstorming as a way to improve the creativity of his team. Osborn's original brainstorming method was based on four principles:

- **Quantity over quality:** The goal of brainstorming is to generate as many ideas as possible, regardless of their quality (Osborn, 1957).
- **No criticism:** During brainstorming, all ideas are accepted, even if they seem far-fetched or impractical (Osborn, 1957).
- **Free association:** Participants are encouraged to think freely and to build on each other's ideas (Osborn, 1957).
- **Record-keeping:** All ideas are recorded so that they can be evaluated later (Osborn, 1957).

There are many different types of brainstorming, each with its own advantages and disadvantages. Some common types of brainstorming include:

- **Traditional brainstorming:** This is the most common type of brainstorming, and it is the method that Osborn originally described (Paulus & Brown, 2007).
- **Reverse brainstorming:** This type of brainstorming involves starting with a solution and then working backwards to identify the problem (Paulus & Brown, 2007).
- **Brainwriting:** This type of brainstorming is done individually, and participants write down their ideas on paper or on a computer (Paulus & Brown, 2007).

- **Group brainstorming:** This is the most common type of brainstorming, and it involves a group of people working together to generate ideas (Paulus & Brown, 2007).

Brainstorming can be a valuable tool for generating new ideas and solutions to problems. Some of the benefits of brainstorming include:

Increased creativity: Brainstorming can help people to think outside the box and to come up with new and innovative ideas (Paulus & Brown, 2007).

Improved problem-solving: Brainstorming can help people to identify and solve problems more effectively (Paulus & Brown, 2007).

Increased team collaboration: Brainstorming can help to build teamwork and communication skills (Weisbord, 1990).

Brainstorming is not a perfect tool, and it has some limitations. Some of the limitations of brainstorming include:

- **Groupthink:** Groupthink can occur in brainstorming sessions, where the group becomes so focused on reaching consensus that it fails to consider alternative ideas (Paulus & Brown, 2007).
- **Evaluation bias:** Ideas that are generated early in a brainstorming session may be more likely to be accepted, even if they are not the best ideas (Paulus & Brown, 2007).
- **Time constraints:** Brainstorming sessions can be time-consuming, and it can be difficult to generate a large number of ideas in a short amount of time (Paulus & Brown, 2007).

Brainstorming is a valuable tool that can be used to generate new ideas and solutions to problems. However, it is important to be aware of the limitations of brainstorming and to take steps to mitigate these limitations. When used effectively, brainstorming can be a powerful tool for creativity and problem-solving.

The brainstorming process plays a pivotal role in the requirement gathering stage for the feasibility of sustainable RPA implementation. Brainstorming is a widely recognized and used technique for generating ideas, problem-solving, and fostering group creativity. It was developed by Alex Osborn in the 1930s as a method to promote the generation of innovative ideas through collective collaboration. The goal of brainstorming is to create an environment that encourages the free expression of thoughts and perspectives, allowing participants to explore a wide range of possibilities.

The basic methodology of brainstorming involves a group session where participants are invited to contribute ideas without any initial judgment or criticism. During the session, a moderator or facilitator records the ideas on a board or some visible medium for everyone to see. The emphasis is on the quantity and diversity of generated ideas rather than seeking an immediate solution. The combination of different perspectives often leads to the creation of more creative and innovative solutions.

Brainstorming offers a series of significant benefits when applied to the context of sustainable RPA implementation. Among these benefits are:

- **Stimulating Creativity:** By providing a criticism-free environment, brainstorming encourages participants to think more creatively and explore various approaches to the challenges at hand.
- **Diversity of Perspectives:** Involving stakeholders from different areas and hierarchical levels ensures the contribution of diverse perspectives. This enriches the analysis of questionnaire responses and the identification of more comprehensive requirements.
- **Generating Innovative Ideas:** The freedom to express ideas without prior restrictions can lead to the generation of innovative solutions that might not have been considered in traditional approaches.
- **Active Collaboration:** Brainstorming promotes collaboration and active engagement of participants, creating a conducive environment for discussion and idea exchange.
- **Identifying Relevant Requirements:** Joint analysis of questionnaire responses during brainstorming allows for the identification of requirements that reflect the true needs and expectations of stakeholders.
- **Consensus and Acceptance:** Open discussion and consideration of various perspectives facilitate consensus building and acceptance of proposed solutions, increasing the likelihood of successful implementation.
- **Rapid Analysis Process:** Brainstorming allows for real-time analysis of questionnaire responses, identifying patterns, gaps, and relevant insights quickly.
- **Promoting Sustainability:** Collaboration among stakeholders and joint analysis of questionnaire responses enable the identification of requirements aligned with the economic, social, and environmental dimensions of sustainability.

In the context of sustainable RPA implementation, brainstorming plays a crucial role in selecting the requirements that will influence the construction of the optimization model. Involved stakeholders, including Business Line Directors and the RPA Manager, analyze questionnaire responses and collaborate to identify the most relevant and impactful requirements.

The collaborative approach allows for a deeper exploration of the implications and interconnections of the responses, identifying emerging patterns and valuable recommendations. This assists in formulating requirements that consider influences and synergies across different areas and dimensions.

Active stakeholder participation during brainstorming strengthens commitment to proposed solutions and increases the likelihood of successful adoption and implementation. The diversity of perspectives enriches the requirement selection process, allowing different voices to be heard and considered.

Brainstorming is a powerful tool in identifying requirements for sustainable RPA implementation viability. Its collaborative approach, encouragement of creativity, and comprehensive consideration of questionnaire responses provide a solid foundation for building solutions that meet stakeholders' needs and promote sustainability in economic, social, and environmental dimensions. Through brainstorming, stakeholders' voices are amplified, and their contributions translate into tangible and impactful requirements for multi-objective optimization model development.

5.4.4. Discussion of Brainstorming Results

In the brainstorming process conducted with stakeholders, a critical step was the classification of each question under the most suitable sustainability pillar for the company. To accomplish this task, stakeholders carefully considered the potential impacts of RPA implementation on the organization's economic, environmental, and social aspects. They not only assigned each question to a specific pillar but also provided robust arguments to justify their choices, demonstrating a profound understanding of RPA's potential effects across each sustainability dimension. Furthermore, stakeholders aligned these analyses with the strategic objectives they deemed most relevant, ensuring that sustainable RPA implementation aligned with the company's overall vision and desired outcomes in terms of efficiency, environmental responsibility, and employee well-being. This meticulous and participatory approach by stakeholders laid a solid foundation for discussing brainstorming results and formulating sustainable RPA-related strategies.

The distribution of questionnaire questions across the pillars of economic, environmental, and social sustainability is essential for analysing how the implementation of Robotic Process Automation (RPA) affects each of these aspects. Let us analyse each question individually and justify its assignment to a specific pillar:

Question 6: Are you part of the company's RPA team?

Pillar: Social

Justification: This question addresses employees' participation in the RPA team, highlighting the social impact of process automation in terms of employment and employee engagement.

Question 7: In terms of costs, how important is this factor in RPA implementation?

Pillar: Economic

Justification: This question directly addresses the economic aspect of RPA implementation, as it relates to the costs associated with process automation.

Question 8: How would you rate the energy efficiency of RPA solutions compared to manual/traditional processes?

Pillar: Environmental

Justification: Energy efficiency is a fundamental environmental aspect as it addresses energy consumption associated with RPA solutions compared to manual processes.

Question 9: What could be the potential impacts on employees with the implementation of RPA in the current company?

Pillar: Social

Justification: This question assesses the social impact of RPA implementation, including employment issues, satisfaction, and working conditions of employees.

Question 10: In what ways can RPA automation help reduce paper consumption in the company?

Pillar: Environmental

Justification: The reduction of paper consumption is an environmental measure as it relates to the reduction of natural resource usage and waste minimization.

Question 11: Do you believe that sustainable RPA implementation can improve team productivity?

Pillar: Economic

Justification: This question links sustainable RPA implementation to productivity improvements, which is a fundamental economic objective.

Question 12: How would you rate the current process of allocating RPA projects to machines in terms of effectiveness?

Pillar: Economic

Justification: This question focuses on the effectiveness of project allocation processes, which are directly related to efficiency and resource savings.

Question 13: What is the importance of minimizing the time required to complete automation projects?

Pillar: Economic

Justification: Minimizing project completion time is directly related to efficiency and economic performance of RPA implementation.

Question 14: What is the main goal of RPA implementation in an organization?

Pillar: Economic

Justification: This question aims to identify the primary goal of RPA implementation, which is often related to efficiency and cost reduction, fundamental economic aspects.

Question 15: How do you assess employees' resistance to RPA implementation in the company?

Pillar: Social

Justification: Employee resistance is directly related to the social aspect as it affects the workplace dynamics and environment.

Question 16: What is your perception of the level of training provided to employees to work with RPA solutions?

Pillar: Social

Justification: Employee training is an important social aspect to ensure successful RPA implementation.

Question 17: What are the main areas where RPA has demonstrated effectiveness in the company?

Pillar: Economic

Justification: This question aims to identify areas where RPA can bring economic benefits, such as operational efficiency and cost reduction.

Question 18: Regarding the integration of RPA with existing systems in the company, how would you rate the results achieved so far?

Pillar: Economic

Justification: The integration of RPA with existing systems affects efficiency and resource economy, making it a relevant economic issue.

Question 19: How do you assess the alignment of RPA projects with the overall company strategy?

Pillar: Economic

Justification: Alignment with the overall company strategy is essential to ensure effective resource allocation, thus an economic aspect.

Question 20: What are the main performance indicators that the company considers when evaluating the success of RPA implementation?

Pillar: Economic

Justification: The mentioned performance indicators are generally related to economic results, such as task completion rate and average execution time.

Question 21: In your opinion, what are the main obstacles faced in integrating RPA with existing processes?

Pillar: Social and Environmental

Justification: Obstacles can be related to employee resistance (social aspect) and process adaptation (environmental aspect).

Question 22: What types of activities do you consider most suitable for automation through RPA?

Pillar: Economic

Justification: This question relates to efficiency and resource economy, highlighting activities suitable for automation.

Question 23: How would you rate the collaboration between the RPA team and the other teams in the company?

Pillar: Social

Justification: Collaboration between teams is an important social aspect for the success of RPA implementation.

Question 24: In terms of maintaining RPA solutions, what is your perception of the need for frequent updates?

Pillar: Economic

Justification: The need for frequent updates is related to maintenance and operational costs, making it an economic aspect.

Question 25: How would you describe employees' overall perception of RPA in the company?

Pillar: Social

Justification: Employees' perception of RPA directly impacts the social environment and the acceptance of technology in the workplace.

Question 26: What criteria are considered when selecting processes for automation through RPA?

Pillar: Economic and Environmental

Justification: Process selection considers criteria such as task volume (economic) and potential error reduction (environmental).

Question 27: What are the main metrics used to assess the efficiency of RPA activities?

Pillar: Economic

Justification: Efficiency metrics are generally related to economic results, such as task completion rate and average execution time.

Question 28: In your opinion, what are the main factors that can ensure the long-term sustainability of RPA implementation?

Pillar: Economic, Social, and Environmental

Justification: Long-term sustainability involves leadership commitment (social), adoption of best practices (economic), and consideration of environmental implications.

Question 29: How do you assess the current team's capacity to deal with potential future challenges?

Pillar: Economic and Social

Justification: The team's ability to address future challenges is related to their technical competence (economic) and adaptability (social).

Question 30: What kind of support or additional resources do you consider necessary to maximize the benefits of sustainable RPA implementation?

Pillar: Economic and Social

Justification: Additional resources may include technology investment (economic) and ongoing team training (social) to maximize the benefits of sustainable RPA implementation.

This distribution of questions across sustainability pillars allows for a comprehensive analysis of the economic, social, and environmental impacts of RPA implementation in the company. It facilitates the understanding of brainstorming results and their relationship with sustainability.

Table 22 - Identification of the pillars of sustainability in each question in the questionnaire

	Pillar		
	Social	Environment	Economic
Q. 6	x		
Q. 7			x
Q. 8		x	
Q. 9	x		
Q. 10		x	
Q. 11			x
Q. 12			x
Q. 13			x
Q. 14			x
Q. 15	x		
Q. 16	x		
Q. 17			x
Q. 18			x
Q. 19			x
Q. 20			x
Q. 21	x	x	
Q. 22			x
Q. 23	x		
Q. 24			x
Q. 25	x		
Q. 26		x	x
Q. 27			x
Q. 28	x	x	x
Q. 29	x		x
Q. 30	x		x
	40%	20%	64%

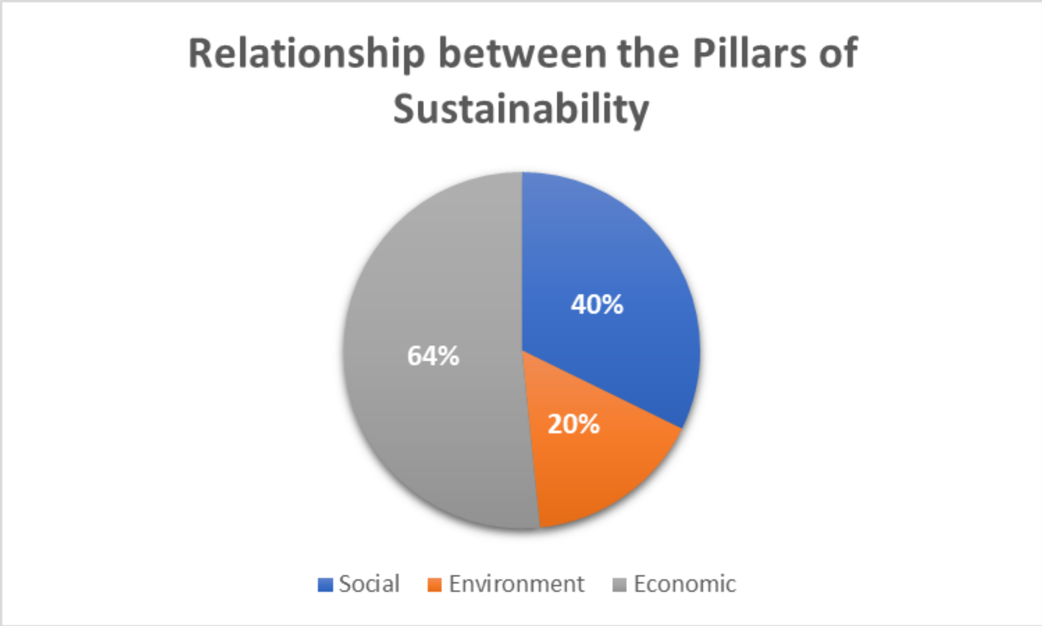

Figure 23 - Relationship between the pillars of sustainability.

The present questionnaire was developed as part of a comprehensive research on sustainable RPA implementation in organizations. The aim of this study is to analyse the perception and opinions of professionals involved in the RPA field regarding various aspects, including costs, energy efficiency, employee impact, and strategic alignment. Furthermore, we seek to understand how companies are leveraging the potential of RPA to improve the sustainability of their operations.

Analysing the responses to these questions, we have identified four main objectives that are directly related to the pillars of sustainability: economic, environmental, social, and strategic. These objectives help guide sustainable RPA implementation and align organizational practices with corporate responsibility principles.

Objective 1: Efficient allocation of RPA projects to machines

This objective aligns with the economic and environmental pillars of sustainability. Efficient allocation of RPA projects can increase productivity, reduce operational costs, and minimize resource usage, such as energy. This contributes to the organization's financial efficiency and reduces environmental impact.

Objective 2: Cost minimization in RPA implementation

Minimizing costs related to RPA implementation is crucial for the economic pillar of sustainability. When resources are allocated efficiently, the organization can direct funds toward sustainable initiatives in other areas. Additionally, cost reduction can enable job retention and improved working conditions, addressing the social aspect of sustainability.

Objective 3: Minimization of Automation Project Completion Time

This objective is directly intertwined with the economic and environmental pillars of sustainability. Reducing the time required to complete automation projects can enhance operational efficiency, diminish costs, and decrease the utilization of natural resources, such as energy and paper. This, in turn, contributes to the financial well-being of the organization and the reduction of its environmental footprint.

Objective 4: Minimization of Average Employee Workload

The minimization of the average employee workload aims to enhance employee well-being and satisfaction, aligning with the social pillar of sustainability. Furthermore, this can bolster team productivity, resulting in a more effective allocation of the organization's financial resources.

These objectives have been identified based on the study participants' responses and are pivotal in establishing a sustainable RPA implementation model. The analysis of additional questions in the questionnaire will also yield valuable insights into specific areas of attention and challenges faced by organizations in their RPA implementation journey.

Aligning RPA practices with sustainability principles is imperative to ensure that organizations not only attain operational efficiency but also promote corporate responsibility in economic, environmental, social, and strategic terms. Sustainable RPA implementation is not solely a pursuit of efficiency but also a commitment to a more sustainable future for businesses and society at large.

In conclusion of this brainstorming process, it is evident that stakeholders have identified crucial objectives related to the economic, environmental, and social sustainability of RPA implementation within the company. These objectives reflect a concern for balancing operational efficiency with environmental responsibility and employee well-being. To translate these objectives into concrete actions, a multi-objective optimization model will be developed, taking into account the various dimensions of sustainability. This model will enable informed decision-making, seeking to maximize economic benefits, minimize environmental impacts, and promote an appropriate workplace environment. Thus, sustainable RPA implementation will be guided by a strategic and balanced approach, aligned with the company's values and goals, contributing to a more sustainable and effective future.

5.5. Proposal for the Multi-objective Optimization Model for Sustainable Robotic Process Automation Implementation

In this section, we will present our model for sustainable RPA implementation, taking into consideration the four main objectives identified, related to the pillars of sustainability: economic, environmental, social, and strategic. We will begin with a brief summary of the objectives to provide a clear overview of what will be discussed, followed by a dedicated section for each objective, detailing how they relate to the pillars of sustainability and how they can be achieved, including examples and case studies when applicable. Furthermore, we will emphasize the importance of sustainability in business and how the sustainable implementation of RPA can contribute to corporate responsibility goals and long-term value creation.

Summary of Identified Objectives:

- **Efficient Allocation of RPA Projects to Machines:** This objective aims to maximize economic efficiency and reduce environmental impact. Efficient allocation of RPA projects can increase productivity, reduce operational costs, and minimize resource usage, such as energy and paper.

- **Cost Minimization in RPA Implementation:** Cost minimization is related to the economic pillar of sustainability. Reducing costs associated with RPA implementation is crucial for financial efficiency, enabling the reallocation of resources to sustainable initiatives.

- **Minimization of Project Automation Completion Time:** This objective is directly linked to the economic and environmental pillars of sustainability. Reducing the time required to complete automation projects can enhance operational efficiency, reduce costs, and decrease the use of natural resources.

- **Minimization of Average Employee Workload:** Minimizing the average employee workload aims to improve employee well-being and satisfaction, aligning with the social pillar of sustainability and contributing to a healthy work environment.

Below we present the relationship between the objectives and the pillars of sustainability.

- **Efficient Allocation of RPA Projects to Machines:**
  - Relationship with the Economic Pillar: Efficient allocation reduces operational costs.
  - Relationship with the Environmental Pillar: Fewer resources consumed, reducing environmental impact.

    Example: Automated task allocation based on workload and energy efficiency.

- **Cost Minimization in RPA Implementation:**
  - Relationship with the Economic Pillar: Reduction of direct and indirect costs.

    Example: Use of open-source tools to reduce licensing costs.

- **Minimization of Project Automation Completion Time:**
  - Relationship with the Economic Pillar: Time savings result in greater efficiency.
  - Relationship with the Environmental Pillar: Less runtime translates to lower energy consumption.

    Example: Automation of document approval processes to reduce completion time.

- **Minimization of Average Employee Workload:**
  - Relationship with the Social Pillar: Enhances employee quality of life.

Example: Automation of repetitive tasks to free up employees' time for higher-value tasks.

Sustainability in business is essential for building a positive reputation, complying with environmental and social regulations, and generating long-term value. Sustainable RPA implementation is not just about efficiency but also corporate responsibility and a commitment to a more sustainable future for businesses and society. By aligning RPA objectives with the pillars of sustainability, organizations can reap economic, environmental, and social benefits, contributing to a more balanced and responsible world.

Here we present our proposal for a multi-objective mathematical optimization model aimed at addressing the production planning and scheduling problem within the context of efficient implementation of Robotic Process Automation technology.

The described model is specifically focused on the planning and scheduling of production for independent parallel machines, with machine and job sequence setup times being independent. The objective is to minimize three objective functions, taking into account the requirements of stakeholders, an RPA team in an administrative de-partment. The three objectives we present include the minimization of machine cost, minimization of makespan (total execution time), and minimization of machine workload balance.

To verify the results of this model, we utilized the Excel Solver based on the mathematical model presented below.

In an approach to problem solving, it is essential to follow a well-defined flowchart that allows you to identify, analyse and optimize processes effectively. This process involves several crucial steps that aim to achieve sustainable results and maximize operational efficiency.

The first step is to identify the problem. It is essential to clearly understand the challenge at hand, defining it precisely and comprehensively. Once the problem has been identified, it is necessary to assess whether there are repetitive processes that contribute to its persistence.

This is where the second stage comes in, which is the analysis of existing processes. This analysis allows you to determine whether there are technological solutions available to automate or improve these processes. Technology can be a powerful ally in optimizing repetitive tasks and reducing human errors.

However, if there are no technological solutions readily available, it is crucial to move on to the third step: evaluating alternative technologies. In this context, RPA (Robotic Process Automation) can be a valuable solution. RPA enables the automation of manual tasks, saving time and resources.

After implementing technologies, it is necessary to ensure that their use is sustainable and optimized. This is the fourth step of the process. To this end, it is essential to continually evaluate the performance and effectiveness of the implemented technology. If optimization is not achieved satisfactorily, it is important to identify the resources needed to improve the process.

The fifth step involves defining clear objectives for optimizing resources. This definition can be carried out through tools such as questionnaires and brainstorming, which allow collecting valuable information and ideas from employees involved in the process.

Finally, the sixth and final step consists of creating an implementation model. This model must reflect the planned improvements and ensure a smooth transition to the new way of operating. After implementation, it is crucial to evaluate the results to ensure that optimization objectives have been achieved.

In summary, the flowchart for problem solving and process optimization begins with identifying the problem, going through the analysis of repetitive processes, evaluation of technological solutions, sustainable implementation, definition of objectives and, finally, evaluation of results. This structured and meticulous process aims to ensure efficiency and excellence in task and resource management.

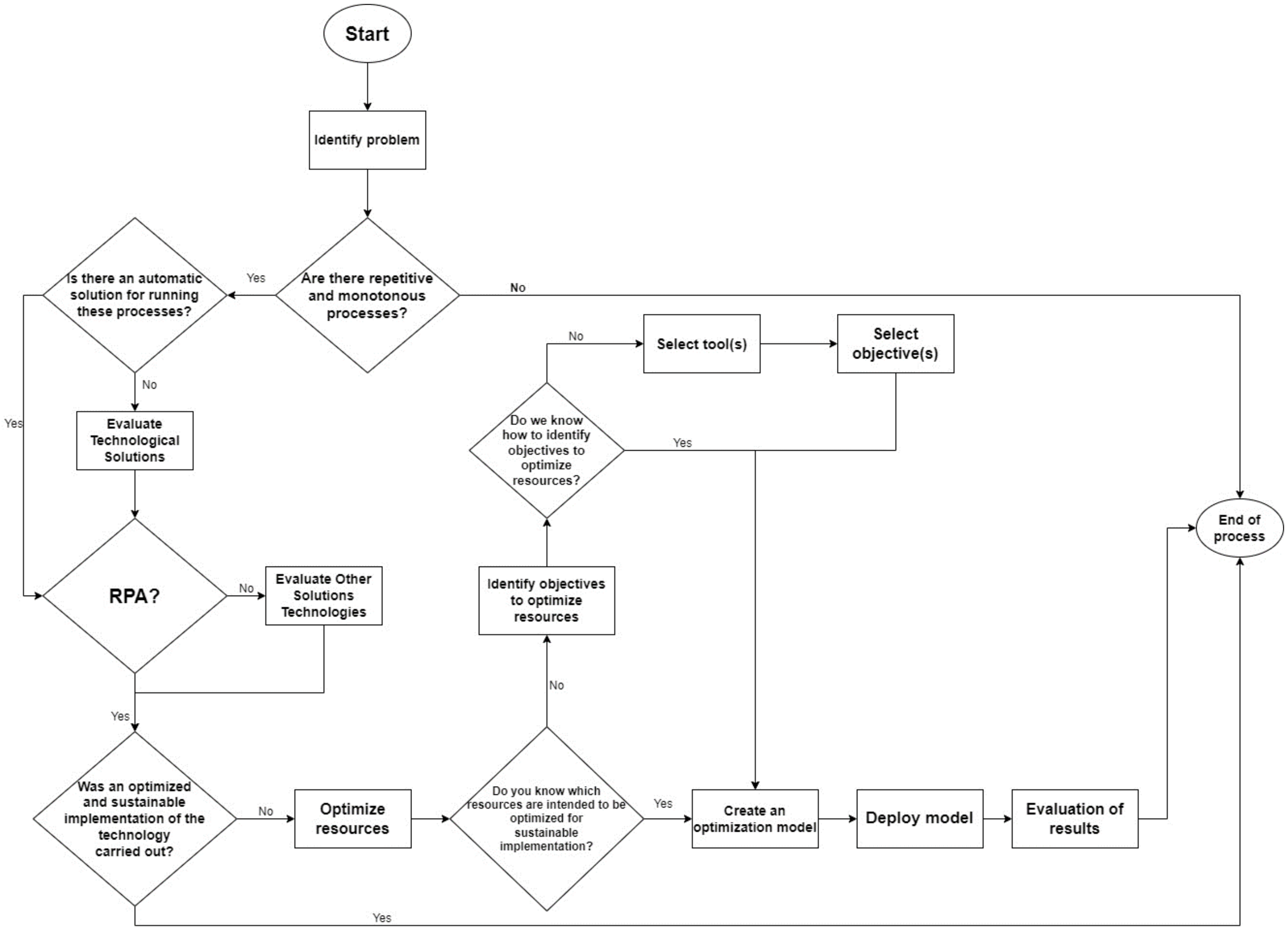

Figure 24 -Flowchart relating to the work developed.

5.6. Mathematical formulation of the model

This subsection presents some mathematical formulation for building the model that we propose to develop here.

5.6.1. Decision variables

- n - total number of tasks;
- m - total number of machines;
- T(i,j) - time of task i on machine j;
- C(i,j) – cost of task i on machine j;
- X(i,j) - binary variable indicating if task i is scheduled on machine j (1 if the task is scheduled, 0 otherwise);
- Makespan - variable representing the makespan (total completion time of all tasks).

5.6.2. Model (constraints and objective functions)

Constraints:

1. Each task must be scheduled on exactly one machine:

$$\sum_{j=1}^{m} x_{ij} = 1, \forall\, i \in \{1, 2, \dots, n\} \qquad (1)$$

2. Each machine can execute only one task at a time:

$$\sum_{i=1}^{n} x_{ij} \leq 1, \forall\, i \in \{1, 2, \dots, m\} \qquad (2)$$

Objective functions:

3. The variable makespan is defined as the total completion time of tasks:

$$Minimize\ makespan: \sum_{i=1}^{n}\sum_{j=1}^{m} x_{ij} \times T_{ij} \tag{3}$$

4. The cost variable is defined as the sum of costs of all scheduled tasks:

$$Minimize\ cost: \sum_{i=1}^{n}\sum_{j=1}^{m} x_{ij} \times C_{ij} \tag{4}$$

5. The average workload is defined as:

$$Minimize\ average\ workload:$$
$$\sum_{j=1}^{m}\left(\sum_{i=1}^{n} x_{ij} \times T_{ij}\right) + (total\_machine\_time - defined\_value) \tag{5}$$

5.7. Conclusion

Chapter 5 thoroughly explored the data collection phase and user requirement definition within the context of stakeholders for the sustainable implementation of RPA. By analysing the responses from a meticulously crafted questionnaire and conducting brainstorming sessions with key stakeholders, valuable insights were gained, and fundamental requirements for the development of the multi-objective optimization model were identified.

The data collection, carried out through the questionnaire, allowed for a deep understanding of stakeholders' perceptions regarding various aspects of sustainable RPA implementation. The responses provided information about the significance attributed to factors such as costs, energy efficiency, team productivity, and social impact. Through this analysis, the four main objectives guiding the model's development were identified: RPA project allocation to machines, cost minimization, makespan minimization, and average workload minimization.

However, it was the brainstorming that added a collaborative and enriching dimension to the requirement definition process. Bringing stakeholders together to collectively examine questionnaire responses enabled the exploration of the interplay between different requirements and their implications. The collaborative approach sparked the generation of innovative ideas, leading to a deeper understanding of requirements and their impact on the economic, social, and environmental dimensions of sustainability.

Brainstorming proved to be a valuable technique for holistic requirement identification, capitalizing on the diversity of perspectives and knowledge among stakeholders. By fostering active collaboration, the technique not only strengthened commitment to the selected requirements but also facilitated the establishment of a robust consensus around proposed solutions.

Overall, Chapter 5 served as a solid foundation for the subsequent phase of the study, in which the identified requirements will be incorporated into the multi-objective optimization model. The participatory and collaborative approach adopted during data collection and requirement definition will contribute to the development of solutions aligned with stakeholders' actual needs and sustainability principles. The chapter not only underscored the importance of stakeholder interaction but also demonstrated the capability of the data collection and brainstorming process to create a solid groundwork for advancing research.

6. APPLICATION OF THE MULTI-OBJECTIVE OPTIMIZATION MODEL FOR THE SUSTAINABLE IMPLEMENTATION OF ROBOTIC PROCESS AUTOMATION TO THE CASE STUDY

6.1. Introduction

Robotic Process Automation has emerged as a transformative approach to optimizing and enhancing organizational process efficiency across various industries. However, the successful implementation of RPA is by no means a trivial task, as it encompasses a myriad of technical and operational challenges, increasingly pertinent sustainability concerns. This chapter is dedicated to addressing these concerns by applying a multi-objective optimization model to our case study, with the aim of achieving a sustainable implementation of RPA.

Within this chapter, we will delve into two distinct perspectives (Scenario 1 and Scenario 2) within our case study, each presenting its unique challenges and variables. Our objective is to find solutions that optimize multiple goals, including operational efficiency, resource savings, and environmental impact reduction. Furthermore, we will consider context-specific factors in each scenario that may influence the application of the model and the outcomes achieved.

In Scenario 1, we will represent the application of the model using the weighted sum method. This approach enables us to weigh objectives according to their relative importance, seeking to optimize the right combination of cost, execution time, and average workload for RPA implementation in this specific context.

In Scenario 2, we will address the application of the model to the case study using the Tchebycheff method. This method offers a different approach, allowing us to find solutions that approximate the best possible compromise among conflicting objectives. By applying the model to this scenario, we will explore the feasibility of sustainable RPA implementation from a distinct perspective.

Throughout this chapter, we will provide a detailed analysis of the model application strategies in both scenarios, highlighting the methods and algorithms employed. Additionally, we will present the results obtained in each scenario and discuss the practical implications of these findings.

The mathematical model developed was executed using Microsoft Excel from Office LTSC, following the same configuration as a computer with an Intel CORE i7 vPro 2.2GHz processor and 8GB of memory. The model's implementation was carried out within an Excel spreadsheet, where both the data file and the model itself were developed. To perform the calculations and find the optimal solution for the problem, the Excel Solver tool was employed.

The data required for the problem were input into a data spreadsheet, organized according to problem specifications and identified constraints. Model implementation occurred within the Excel spreadsheet, where variables and constraints were defined based on the problem's requirements. Mathematical formulas were developed accordingly, taking into account problem specifications and identified constraints.

To ensure solution quality and efficiency, specific configurations were adopted in the Excel Solver. The Solver was set with a maximum time limit of 30 seconds for calculation execution. A constraint precision of 0.000001 was required, meaning constraints needed to be satisfied with a very small margin of error. Furthermore, an ideal quality integer value of 1 was defined, indicating that optimal solutions should be integers. Automatic rounding was enabled to ensure compliance with this constraint.

For Solver convergence, a criterion of 0.0001 was established, indicating that the algorithm should converge to a solution sufficiently close to the optimal. Derivatives were calculated in an advanced manner, and a population size of 100 was specified. The random seed value was set to 0. The Solver was configured to impose variable bounds and establish a mutation rate of 0.075. The LP Simplex resolution method was used for selection. Unrestricted variables were defined as non-negative.

These settings were applied during the execution of the mathematical model using Excel Solver. Multiple tests were conducted to ensure the model's robustness and efficiency, and the results were analysed and validated to meet the expectations and requirements of the problem under study.

The use of Microsoft Excel and the Solver tool with these specific configurations provided a practical and flexible environment for the development and execution of the mathematical model, ensuring the attainment of reliable and accurate solutions to the problem at hand.

To visualize and communicate the results obtained from the execution of the mathematical model, graphs were developed using the powerful charting capabilities available in Microsoft Excel. The Excel charting tool offered a wide range of visualization options, allowing for clear and precise representation of results. Advanced formatting and customization features were employed to create engaging and highly informative visualizations.

These graphs played a vital role in communicating the results and supporting decision-making based on the information derived from the implemented mathematical model.

Ultimately, this chapter aims to contribute to the development of more sustainable and effective approaches in RPA implementation, recognizing the importance of balancing multiple objectives in a dynamic and environmentally conscious business environment.

This introduction sets the context for the chapter, presents the objectives, and underscores the significance of addressing sustainability in RPA implementation across different scenarios. You can customize it according to the specific details of your study and thesis.

6.2. Scenario 1

6.2.1. Contextualization of Scenario 1

In Scenario 1 of our investigation, we delve into the application of the multi-objective optimization model for sustainable RPA implementation, utilizing the weighted sum method. This meticulous and rigorous approach aims to deepen our understanding of the complex interplay among multiple objectives, namely cost, execution time, and average workload, concerning the implementation of RPA in a dynamic organizational environment.

To shed light on the relevance and effectiveness of the weighted sum method, it is imperative to conduct a comprehensive state-of-the-art review to examine its evolution over time, applications in various contexts, and contributions to multi-objective problem resolution.

The weighted sum method, also known as the weighted linear aggregation method, is a well-established technique in multi-objective optimization dating back to the roots of multi-criteria decision theory (MCDM) (Bates, et al., 1988). This method is grounded in the principle of assigning weights to each objective, reflecting their relative importance in decision-making. The weighted sum of these objectives results in a single scalar value, representing an aggregated measure of solution quality with respect to all considered objectives (Armstrong, 2006).

The initial application of the weighted sum method was primarily in the context of engineering and planning decisions, but its versatility has made it widely applicable across various disciplines, such as economics, logistics, social sciences, and more recently, in the field of RPA.

One notable advantage of the weighted sum method is its ability to handle conflicting objectives, enabling decision-makers to attain solutions that balance the inherent trade-offs among these objectives (Hyndman & Athanasopoulos, 2018). This flexibility is particularly relevant in our investigation, as the successful implementation of RPA often necessitates optimizing multiple criteria that may conflict with each other.

Furthermore, over the years, the weighted sum methodology has been enriched with technical advancements, including approaches for determining objective weights, ranging from subjective methods based on decision-maker preferences to more sophisticated multi-criteria analysis techniques.

These objective weighting techniques are pivotal for the application of the weighted sum method, as improper weight assignments can lead to suboptimal or distorted results (Hyndman& Khandakar, 2008). Therefore, careful consideration of weight allocation in our sustainable RPA implementation context is crucial.

The relevance of our investigation lies in applying this well-established method to a rapidly evolving research domain, Robotic Process Automation. The inherent complexity of managing resources, operational costs, and environmental impacts in the context of RPA makes the weighted sum method an attractive tool for exploring effective and balanced solutions (Chatfield, 1996).

Thus, in this scenario, our approach is based on the critical review and adaptation of the weighted sum method, considering the dynamics of our case study and its implications for sustainable RPA implementation. We will explore different weight combinations to assess how they impact the model's performance, aiming to gain valuable insights and robust solutions.

In the next segment, we will discuss the practical application of the weighted sum method to our case study and how it aligns with our broader goal of achieving sustainable RPA implementation.

Continuing with the contextualization of Scenario 1, we will now address the practical application of the weighted sum method to the case study:

Now that we have established a solid foundation with our comprehensive review of the weighted sum method, we can proceed to apply this method to our specific case study (Makridakis, at al., 1998). Our objective is to employ a methodical and rigorous approach to find solutions that balance the competing objectives of cost, execution time, and average workload, resulting in sustainable RPA implementation.

The implementation of the model begins with creating a set of trials that represent the context of RPA implementation in our study organization. Each trial is defined by specific values for cost, execution time, and average workload, reflecting realistic scenarios that may occur.

For the application of the weighted sum method, we assign weights to each of these objectives, reflecting their relative importance. The choice of weights is a critical step as it directly influences the solutions obtained. Therefore, we will use carefully considered approaches, taking into account expert preferences, multi-criteria analysis, and context-specific RPA criteria.

Once the weights are assigned to the objectives, we will use the multi-objective optimization model to calculate optimal solutions for each scenario, considering the defined weights. The goal is to find a set of solutions that represent effective compromises among the objectives, considering their respective relevance.

During this process, we will explore a variety of weight combinations to assess how different weightings affect the model's performance. This will allow us to identify solutions that excel in terms of operational efficiency, resource savings, and environmental sustainability in RPA implementation.

It is important to emphasize that the application of the weighted sum method is iterative and requires careful analysis of the results. As we explore different scenarios and weightings, we will have the opportunity to adjust our approaches and refine our decision criteria to achieve desired objectives.

In summary, Scenario 1 represents a detailed and well-founded exploration of the weighted sum method in the context of sustainable RPA implementation. By applying this methodology, we are seeking not only optimal solutions but solutions that balance conflicting objectives and meet the complex demands of successful RPA implementation in a dynamic environment. In the next segment, we will discuss the obtained results and the practical implications of this application in Scenario 1.

The weights were determined based on the relative importance of each objective and the goal of minimizing cost, execution time, and average workload. By testing different combinations, we were able to assess the model's performance under various objective weightings.

The weights were assigned incrementally, ranging from 0 to 1 in increments of 0.10. This approach allowed us to explore a total of 66 possible combinations of weights for the three objectives. Each line in the table represents one of the examples of weight combinations. The total sum should equal 1. For example, we observed the allocation of a weight of 1 to one of the objectives and 0 to the other two objectives. Then, the total value of 1 is distributed among the weights of each of the objectives. The table below (Table 19) illustrates the tested combinations, where "Objective 1 weight," "Objective 2 weight," and "Objective 3 weight" represent the weights assigned to the cost, execution time, and average workload objectives, respectively:

Table 23 - Details of Weight.

weight objective 1	weight objective 2	weight objective 3
0	0	1
0.1	0	0.9
0.2	0	0.8
0.3	0	0.7
0.4	0	0.6
...	...	...
1	0	0
0.9	0.1	0
0.8	0.2	0
...	...	...
0	1	0
0.1	0.9	0
0.2	0.8	0
...	...	...

These combinations of weights facilitate a comprehensive analysis of results, allowing us to identify the most efficient solutions for each individual objective as well as the overall set of objectives.

In the next subchapter, we will present the application of the model, followed by the results obtained by applying the multi-objective model using the previously mentioned weight combinations. We will highlight the non-dominated solutions that were found and provide performance evaluation graphs to further illustrate the results.

6.2.2. Model application

Multi-objective optimization is a fundamental approach for solving complex problems that involve searching for optimal solutions considering multiple criteria or objectives. A widely used tool for this purpose is Microsoft Excel, which offers optimization functionality through the Solver add-in. In this text, we will detail all the steps involved in implementing a multi-objective optimization model in Excel's Solver, with a focus on presenting Scenario 1 of the implemented model.

Step 1: Definition of Objectives and Constraints

The first step in implementing a multi-objective optimization model is to clearly define the objectives to be achieved and the constraints to be respected. This involves a detailed analysis of the problem at hand, identifying which criteria should be optimized and which limitations should be considered.

Step 2: Modelling in Excel

After defining the objectives and constraints, it's time to start modelling in Excel. This involves creating a spreadsheet that represents the problem to be solved. Decision variables should be clearly defined, and formula cells should be used to represent objective functions and constraints.

Step 3: Solver Configuration

The next step is to configure the Solver in Excel. To do this, go to the "Data" tab and select "Solver" in the "Analysis" section. The Solver window will open, and this is where you will define the optimization parameters. It is important to note that we are dealing with multi-objective optimization, so you should select "Minimize" for each objective, depending on the problem.

Step 4: Specification of Variable and Objective Cells

In the Solver, you should specify the cells representing decision variables and the cells representing objectives. Make sure that the Solver is configured to optimize all objective functions simultaneously by checking the "Solve for Multiple Objectives" option.

Step 5: Definition of Constraints

It is crucial to define the problem's constraints in the Solver. This involves including all constraints from your mathematical model, such as resource limitations, capacity constraints, etc. The Solver will ensure that all these constraints are respected during optimization.

Step 6: Setting Resolution Options

The Solver has various resolution options that can be configured according to the problem's needs. It is important to review these options to ensure that the optimization is performed adequately and efficiently.

Step 7: Problem Resolution

After configuring all options, click "Solve" in the Solver. Excel will use optimization algorithms to find optimal solutions that meet the defined objectives and constraints. Depending on the problem's complexity, this may take some time (Appendix 3).

To illustrate (Appendix 4) the successful implementation of the multi-objective optimization model in Excel's Solver, we will now present figures that demonstrate Scenario 1 of the model. These figures will show the obtained results, including the values of decision variables and the optimized objective values.

In summary, implementing a multi-objective optimization model in Excel's Solver is a process that involves the careful definition of objectives and constraints, modelling in Excel, Solver configuration, and problem resolution. This approach is extremely useful for dealing with complex problems where it is necessary to consider multiple decision criteria. With the right tools and proper analysis, Excel's Solver can be a valuable ally in the quest for optimal solutions in multifaceted scenarios.

6.2.3. Results obtained

After successfully implementing a multi-objective optimization model in Excel's Solver and conducting the optimization process, it is essential to present the results. This section provides a comprehensive overview of the outcomes achieved in Scenario 1 of the model.

In Scenario 1, the multi-objective optimization aimed to minimize specific objectives simultaneously.

These objective values represent the optimized outcomes that were achieved by considering multiple criteria simultaneously. It is important to note that the specific meaning and units of these objectives should be provided for a comprehensive understanding of the results. The results obtained in Scenario 1 reflect the trade-offs and compromises made while optimizing multiple objectives.

	Weighted o1	Weighted o2	Weighted o3	Cost	Makespan	Average workload
1	0,00	0,00	1,00	2682,4	850,5	0
2	0,10	0,00	0,90	2432,5	1140,3	1
3	0,20	0,00	0,80	2378,6	1209,6	10
4	0,30	0,00	0,70	2377,9	1180,2	8
5	0,40	0,00	0,60	2372,3	1190,7	10
6	0,50	0,00	0,50	2394	1260	11
7	0,60	0,00	0,40	2377,2	1209,6	11
8	0,70	0,00	0,30	2370,9	1194,9	11
9	0,80	0,00	0,20	2372,3	1199,1	11
10	0,90	0,00	0,10	2375,8	1205,4	11
11	1,00	0,00	0,00	2373,7	1199,1	11
12	0,00	0,10	0,90	2599,8	758,8	0
13	0,10	0,10	0,80	2515,1	831,6	1
14	0,20	0,10	0,70	2489,2	840	0
15	0,30	0,10	0,60	2512,3	875,7	0
16	0,40	0,10	0,50	2406,6	1087,8	0
17	0,50	0,10	0,40	2372,3	1190,7	10
18	0,60	0,10	0,30	2378,6	1218	11
19	0,70	0,10	0,20	2373,7	1201,2	11
20	0,80	0,10	0,10	2370,9	1194,9	11

Figure 25 - Scenario 1 Objective results (1-20).

	Weighted	Weighted	Weighted	Cos	Makesp	Average worklo
21	0,90	0,10	0,00	2375,8	1205,4	11
22	0,00	0,20	0,80	2594,9	771,4	0
23	0,10	0,20	0,70	2601,2	767,2	0
24	0,20	0,20	0,60	2527,7	816,9	2
25	0,30	0,20	0,50	2500,4	863,1	1
26	0,40	0,20	0,40	2515,8	835,8	2
27	0,50	0,20	0,30	2522,8	823,2	2
28	0,60	0,20	0,20	2497,6	894,6	0
29	0,70	0,20	0,10	2370,9	1194,9	11
30	0,80	0,20	0,00	2372,3	1199,1	11
31	0,00	0,30	0,70	2608,2	770	1
32	0,10	0,30	0,60	2611	778,4	0
33	0,20	0,30	0,50	2599,1	765,8	1
34	0,30	0,30	0,40	2489,2	840	0
35	0,40	0,30	0,30	2568,3	785,4	1
36	0,50	0,30	0,20	2529,1	821,1	1
37	0,60	0,30	0,10	2501,8	871,5	2
38	0,70	0,30	0,00	2495,5	842,1	6
39	0,00	0,40	0,60	2599,8	761,6	1
40	0,10	0,40	0,50	2604,7	764,4	1

Figure 26 - Scenario 1 Objective results (21-40).

	Weighted	Weighted	Weighted	Cos	Makesp	Average worklo
41	0,20	0,40	0,40	2597,7	786,8	1
42	0,30	0,40	0,30	2613,8	772,8	1
43	0,40	0,40	0,20	2625	770	2
44	0,50	0,40	0,10	2534	833,7	1
45	0,60	0,40	0,00	2496,9	848,4	4
46	0,00	0,50	0,50	2601,2	756	1
47	0,10	0,50	0,40	2576,7	788,2	1
48	0,20	0,50	0,30	2615,9	777	1
49	0,30	0,50	0,20	2606,8	764,4	1
50	0,40	0,50	0,10	2522,8	834,4	1
51	0,50	0,50	0,00	2497,6	834,4	5
52	0,00	0,60	0,40	2617,3	774,9	1
53	0,10	0,60	0,30	2603,3	775,6	1
54	0,20	0,60	0,20	2602,6	764,4	1
55	0,30	0,60	0,10	2601,9	772,8	1
56	0,40	0,60	0,00	2589,3	767,2	7
57	0,00	0,70	0,30	2604	775,6	1
58	0,10	0,70	0,20	2597,7	763	0
59	0,20	0,70	0,10	2608,9	791	1
60	0,30	0,70	0,00	2594,9	772,8	7

Figure 27 - Scenario 1 Objective results (41-60).

	Weighted	Weighted	Weighted	Cos	Makesp	Average worklo
61	0,00	0,80	0,20	2601,2	770	1
62	0,10	0,80	0,10	2609,6	761,6	2
63	0,20	0,80	0,00	2601,2	756	6
64	0,00	0,90	0,10	2601,9	764,4	1
65	0,10	0,90	0,00	2604	760,2	3
66	0,00	1,00	0,00	2602,6	760,2	5

Figure 28 - Scenario 1 Objective results (61-66).

6.3. Scenario 2

6.3.1. Contextualization of Scenario 2

In Scenario 2 of our investigation, we continue our journey in applying the multi-objective optimization model for the sustainable implementation of RPA. However, in this scenario, we have adopted a distinct and enriching approach by employing the Tchebycheff method as a key technique in the pursuit of optimal and balanced solutions.

Before delving into the practical application of the Tchebycheff method to our case study, it is imperative to conduct a comprehensive review of the state-of-the-art to grasp the significant role of this method in multi-objective optimization problems.

The Tchebycheff method, also known as Tchebicheff method or Chebyshev method, is a well-established technique in multicriteria decision-making (MCDM) and the resolution of multi-objective problems. Originating from the theory of Tchebycheff polynomials, this method boasts a long history of application across various disciplines, including engineering, economics, logistics, and now at the forefront of RPA.

The distinguishing feature of the Tchebycheff method is its ability to find the optimal solution that minimizes the worst possible outcome for each individual criterion. This is achieved by assigning different weights to each criterion and calculating the weighted distance of each option to a known reference point called the ideal point or utopia point. This approach enables decision-makers to explore their individual preferences and strike a balance between criteria, resulting in well-founded and balanced decisions.

The Tchebycheff method is highly versatile and applicable to complex decision-making problems that involve multiple factors to be considered. It enables the exploration of diverse scenarios and provides a solid foundation for balanced decisions.

In this scenario, we will apply the Tchebycheff method to our specific case study, seeking solutions that effectively optimize the criteria of cost, execution time, and average workload, considering the defined weights. This approach will allow us to assess the model's performance from this unique perspective and identify solutions that balance conflicting objectives, contributing to a sustainable implementation of RPA.

The model we are going to present here used scalarizing methods. First, we apply the weighting sum method, and finally, we present the Tchebycheff method. We proceed to a brief explanation of these methods. Initially, the weighting sum method is applied, and then we evolve the model with the application of the Tchebycheff method.

The weighted sum method, also known as the weighting method, is a widely used approach in multi-criteria decision-making. In this method, each criterion is assigned a weight that reflects its relative importance compared to other criteria (Hwang & Masud, 1979; Miettinen, 1999). The formula associated with this method is relatively simple, where the total score of an option is calculated by summing the product of each criterion by its respective assigned weight (Ercan, et al., 2016; Steuer &Choo, 1983). Mathematically, the formula can be expressed as Eq. (1):

$$\sum(Criterion\_i \times Weight\_i) \qquad (1)$$

In equation 1, "Criterion_i" represents the value of the option in the specific criterion, and "Weight_i" is the weight assigned to that criterion. Through this process of weighted summation, it is possible to obtain an overall view of the evaluated alternatives, thus ena-bling a more informed and justified decision-making process based on the preferences of the decision-makers.

In this work, the Tchebycheff (Dächert, et al., 2012) method is applied to solve the multi-objective optimization model. The Tchebycheff method, also known as Tchebicheff or Chebyshev method, is a technique used in multi-criteria decision-making. In this method, the goal is to find the optimal solution that minimizes the worst possible outcome for each criterion. This is achieved by applying different weights to each criterion and then calculating the weighted distance of each option to a known reference point called the ideal point or utopia point. The Tchebycheff method allows decision-makers to explore their individual preferences and strike a compromise between the criteria, leading to a balanced and well-founded decision. It is a widely applied approach in complex decision-making problems involving multiple factors to be considered. The Tchebycheff method can be formulated and presented in Eq. (2):

$$\min \max[w_i|f_i(x) - z_i^*|] \qquad (2)$$

It has been verified that the weighting coefficients for objective i (wi) and the components of a reference point (zi) assume a small positive value. Then it also presents Eq. (3) associated with the method:

$$\begin{aligned} & \min \lambda \\ \text{s.t.} \quad & w_i(f_i(x) - z_i^*) - \lambda \leq 0 \end{aligned} \qquad (3)$$

In this study, we utilized the optimization problem to address a multi-objective optimization problem as described.

In the next segment, we will discuss the practical application of the Tchebycheff method to Scenario 2 and examine the results obtained, as well as their implications within the context of our study.

6.3.2. Model application

Multi-objective optimization is a fundamental approach for solving complex problems that involve seeking optimal solutions considering multiple criteria or objectives. A widely used tool for this purpose is Microsoft Excel, which offers optimization functionality through the Solver add-in. In this text, we will detail all the steps involved in implementing a multi-objective optimization model in Excel's Solver, with a focus on presenting the scenario where the Tchebycheff method was applied.

Step 1: Definition of Objectives and Constraints

The initial step in implementing a multi-objective optimization model is the clear definition of the objectives to be achieved and the constraints to be adhered to. This necessitates a detailed analysis of the specific problem, identifying which criteria should be optimized and what limitations should be considered.

Step 2: Modelling in Excel

Following the definition of objectives and constraints, the next stage is to commence modelling in Excel. This entails creating a spreadsheet that will represent the problem to be resolved. Decision variables should be clearly defined, and formula cells should be used to represent objective functions and constraints.

Step 3: Configuration of the Solver

The subsequent step involves configuring the Solver in Excel. To achieve this, navigate to the "Data" tab and select "Solver" in the "Analysis" section. The Solver window will open, where you will define the optimization parameters. It is crucial to note that we are dealing with multi-objective optimization, so you must choose "Minimize" for each objective, depending on the problem.

Step 4: Specification of Variable and Objective Cells

In the Solver, you must specify the cells that represent the decision variables and the cells that represent the objectives. Ensure that the Solver is configured to optimize all objective functions simultaneously by selecting the "Solve for Multiple Objectives" option.

Step 5: Definition of Constraints

Defining the problem's constraints in the Solver is of utmost importance. This involves incorporating all constraints from your mathematical model, such as resource limitations, capacity constraints, etc. The Solver will ensure that all these constraints are adhered to during optimization.

Step 6: Configuration of Resolution Options

The Solver offers various resolution options that can be configured according to the problem's requirements. It is essential to review these options to ensure that the optimization is executed appropriately and efficiently.

Step 7: Problem Resolution

After configuring all options, click "Solve" in the Solver. Excel will employ optimization algorithms to discover optimal solutions that meet the defined objectives and constraints. Depending on the problem's complexity, this process may take some time (Appendix 5).

To illustrate (Appendix 6) the successful implementation of the multi-objective optimization model in Solver, we will now present figures that demonstrate Scenario 2, where the Tchebycheff method was applied. These figures will display the results obtained, including the values of decision variables and the optimized objective values.

In summary, the implementation of a multi-objective optimization model in Excel's Solver involves a meticulous definition of objectives and constraints, Excel modelling, Solver configuration, and problem resolution. This approach is highly valuable for addressing complex problems where multiple decision criteria must be considered. With the right tools and proper analysis, Excel's Solver can be a valuable ally in the pursuit of optimal solutions in multifaceted scenarios, such as those utilizing the Tchebycheff method.

6.3.3. Results obtained

After successfully implementing a multi-objective optimization model in Excel Solver and conducting the optimization process, it is essential to present the results. This section provides a comprehensive overview of the results achieved in Scenario 2 of the model.

In Scenario 2, multi-objective optimization aimed to minimize specific objectives simultaneously. These objective values represent the optimized results that were achieved by considering multiple criteria simultaneously. It is important to note that the specific meaning and units of these objectives must be provided for a comprehensive understanding of the results. The results obtained in Scenario 2 reflect the compromises and balances reached during the optimization of multiple objectives.

	Weighted	Weighted	Weighted	Cos	Makesp	Average worklo
1	0,00	0,00	1,00	2892	1050	0
2	0,10	0,00	0,90	2404	1134	3
3	0,20	0,00	0,80	2409	1239	9
4	0,30	0,00	0,70	2398	1247	11
5	0,40	0,00	0,60	2388	1235	10
6	0,50	0,00	0,50	2399	1243	11
7	0,60	0,00	0,40	2381	1178	7
9	0,80	0,00	0,20	2375	1184	9
10	0,90	0,00	0,10	2396	1241	9
11	1,00	0,00	0,00	2407	1088	9
12	0,00	0,10	0,90	2374	1193	10
13	0,10	0,10	0,80	2615	769	1
14	0,20	0,10	0,70	2483	876	8
15	0,30	0,10	0,60	2502	1021	3
16	0,40	0,10	0,50	2498	1088	8
17	0,50	0,10	0,40	2433	1008	8
18	0,60	0,10	0,30	2545	1012	7
20	0,80	0,10	0,10	2423	1065	7

Figure 29 - Scenario 2 Objective results (1-20).

	Weighted	Weighted	Weighted	Cos	Makesp	Average worklo
21	0,90	0,10	0,00	2451	1187	9
22	0,00	0,20	0,80	2417	1056	8
23	0,10	0,20	0,70	2612	764	1
24	0,20	0,20	0,60	2507	832	5
25	0,30	0,20	0,50	2484	872	5
26	0,40	0,20	0,40	2472	945	7
27	0,50	0,20	0,30	2493	1065	6
28	0,60	0,20	0,20	2447	983	7
29	0,70	0,20	0,10	2475	1113	9
30	0,80	0,20	0,00	2434	1025	7
31	0,00	0,30	0,70	2611	762	0
32	0,10	0,30	0,60	2526	815	6
33	0,20	0,30	0,50	2535	868	8
34	0,30	0,30	0,40	2480	867	7
35	0,40	0,30	0,30	2477	897	5
36	0,50	0,30	0,20	2516	1025	7
37	0,60	0,30	0,10	2457	937	6
38	0,70	0,30	0,00	2491	1067	6
39	0,00	0,40	0,60	2610	762	1
40	0,10	0,40	0,50	2574	811	5

Figure 30 - Scenario 2 Objective results (21-40).

	Weighted	Weighted	Weighted	Cos	Makesp	Average worklo
41	0,20	0,40	0,40	2510	829	8
42	0,30	0,40	0,30	2489	846	6
43	0,40	0,40	0,20	2480	867	9
44	0,50	0,40	0,10	2505	935	8
45	0,60	0,40	0,00	2472	893	7
46	0,00	0,50	0,50	2601	761	1
47	0,10	0,50	0,40	2723	862	5
48	0,20	0,50	0,30	2528	822	6
49	0,30	0,50	0,20	2501	837	6
50	0,40	0,50	0,10	2608	857	7
51	0,50	0,50	0,00	2570	865	6
52	0,00	0,60	0,40	2714	817	1
53	0,10	0,60	0,30	2617	777	4
54	0,20	0,60	0,20	2537	815	4
55	0,30	0,60	0,10	2532	839	5
56	0,40	0,60	0,00	2521	859	6
57	0,00	0,70	0,30	2598	759	0
58	0,10	0,70	0,20	2585	776	5
59	0,20	0,70	0,10	2542	809	4
60	0,30	0,70	0,00	2514	827	7

Figure 31 - Scenario 2 Objective results (41-60).

	Weighted	Weighted	Weighted	Cos	Makesp	Average worklo
61	0,00	0,80	0,20	2605	760	1
62	0,10	0,80	0,10	2573	778	5
63	0,20	0,80	0,00	2545	803	5
64	0,00	0,90	0,10	2600	760	0
65	0,10	0,90	0,00	2566	783	1
66	0,00	1,00	0,00	2624	777	2

Figure 32 - Scenario 2 Objective results (61-66).

6.4. Conclusion

Chapter 6 represented a significant milestone in our pursuit of a sustainable implementation of RPA (Robotic Process Automation) through the application of a multi-objective optimization model. In this chapter, we delved into two distinct scenarios - Scenario 1, employing the method of weighted sums, and Scenario 2, utilizing the Tchebycheff method. Both approaches proved instrumental in gaining a comprehensive understanding of the challenges and opportunities involved in RPA implementation within a dynamic and environmentally-conscious business context.

In Scenario 1, we embarked on our model application journey by exploring the weighted sums method. This method proved to be a valuable tool for multicriteria decision analysis, enabling proper weighting of objectives, in this case, cost, execution time, and average workload. A review of the state of the art revealed its applicability across various disciplines, and its adaptation to the context of sustainable RPA implementation showed promise.

By applying the weighted sums method, we were able to explore different combinations of weights for the objectives, allowing for a detailed analysis of solutions in terms of operational efficiency and environmental impact. This approach underscored the importance of judiciously assigning weights as they directly influenced the solutions obtained.

Through carefully planned iterations and critical evaluation of results, we identified solutions that not only optimized each individual criterion but also achieved a global balance, effectively addressing the challenges of conflicting objectives.

In Scenario 2, we expanded our approach by employing the Tchebycheff method, a sophisticated multicriteria decision-making technique. This method stood out for its ability to find solutions that minimize the worst possible outcome for each criterion, while taking distinct weights into account. A detailed review of the state of the art revealed its applicability in complex contexts and its capacity to balance conflicting objectives.

The application of the Tchebycheff method to our case study allowed us to explore solutions from a unique perspective. By considering the worst possible outcome for each criterion, we were able to assess the robustness of solutions in the face of real-world uncertainties and variations. This approach provided valuable insights into making informed and balanced decisions in RPA implementation.

The successful application of these methods in Scenarios 1 and 2 enriched our understanding of sustainable RPA implementation. Our research contributed to a deeper insight into balancing multiple objectives in a dynamic business environment, considering critical factors such as cost, execution time, average workload, and environmental impact.

Furthermore, our analysis revealed that the choice of optimization method can have a significant impact on the solutions obtained. The weighted sums method stood out for its simplicity and transparent reflection of preferences. On the other hand, the Tchebycheff method offered a more robust approach to addressing uncertainty and dealing with conflicting objectives.

As a result of these findings, we are better equipped to make informed decisions in RPA implementation, taking into account not only operational efficiency but also environmental and sustainability concerns.

Chapter 6 was a rich and comprehensive exploration of the application of multi-objective optimization methods to sustainable RPA implementation. Through Scenarios 1 and 2, we demonstrated the ability to balance conflicting objectives and find solutions that meet the complex demands of this ever-evolving landscape.

As we progress in our research, we will continue to refine our approaches, considering new methods and enhancing our understanding of the dynamics of RPA implementation. This research represents a significant step toward a more efficient and sustainable future for robotic process automation, contributing to the ongoing evolution of the field and excellence in business practices.

In the next chapter, we will delve deeper into our analysis by presenting the obtained results in detail and discussing the practical implications of these findings in the context of our investigation into sustainable RPA implementation.

7. RESULTS AND DISCUSSION

7.1. Results

Now, this section explains the results obtained from the application of the multi-objective model using the aforementioned weight combinations. In this section, we will discuss the advantages of the evaluation methods employed, namely the weighted sum method and the Tchebycheff method, and address the suitability of each of these methods for the problem at hand.

The use of different evaluation methods is crucial in providing a comprehensive view of the performance of the multi-objective model. The weighted sum method is widely employed and enables the consideration of multiple objectives by weighting them with as-signed weights. On the other hand, the Tchebycheff method is an approach based on an aggregation function that seeks to minimize the maximum distance between the obtained solution and an ideal reference point.

The weighted sum method offers flexibility in assigning weights to objectives, allowing decision-makers to emphasize the relative importance of each one. This is particularly relevant in the context of task allocation in machines, where cost, makespan, and average workload can have different weights based on the needs and priorities of stakeholders.

On the other hand, the Tchebycheff method, by minimizing the maximum distance, provides a robust approach and helps identify more balanced solutions in terms of all the considered objectives. It is an efficient technique for finding compromise solutions in multi-objective problems.

By exploring these two evaluation methods, we are able to gain valuable insights into the performance of the multi-objective model and identify high-quality solutions, taking into account the defined objectives.

In the following figures (Figure 41 and Figure 42), we will present the results achieved with each method, comparing their characteristics and evaluating their suitability for the problem at hand. This will allow for a deeper understanding of the advantages and limitations of each method and contribute to the selection of the most appropriate approach in task allocation in machines, considering the objectives of the involved stakeholders.

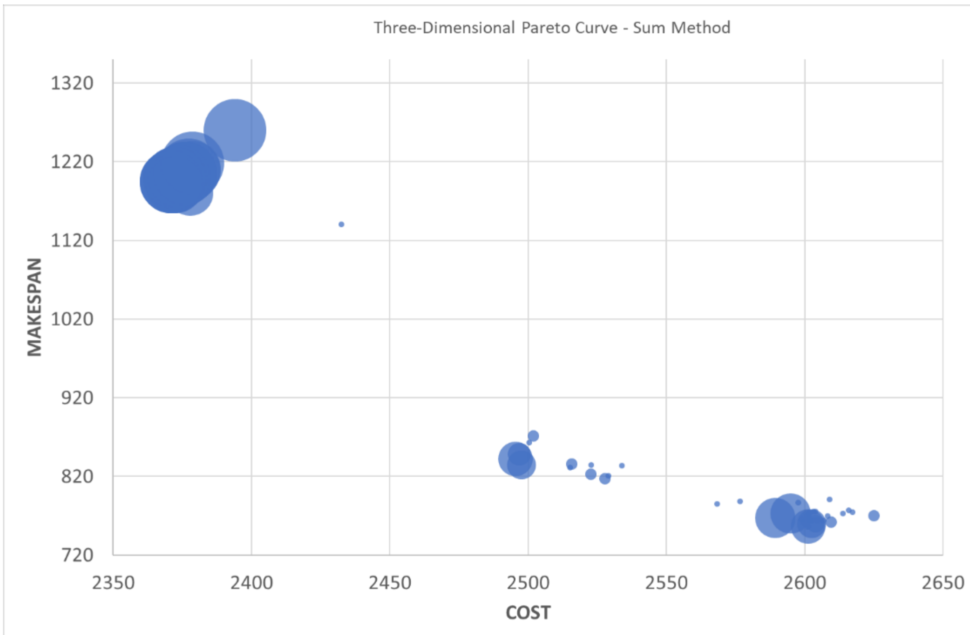

Figure 33 - Three-Dimensional Pareto Curve about Weighted Sum Method.

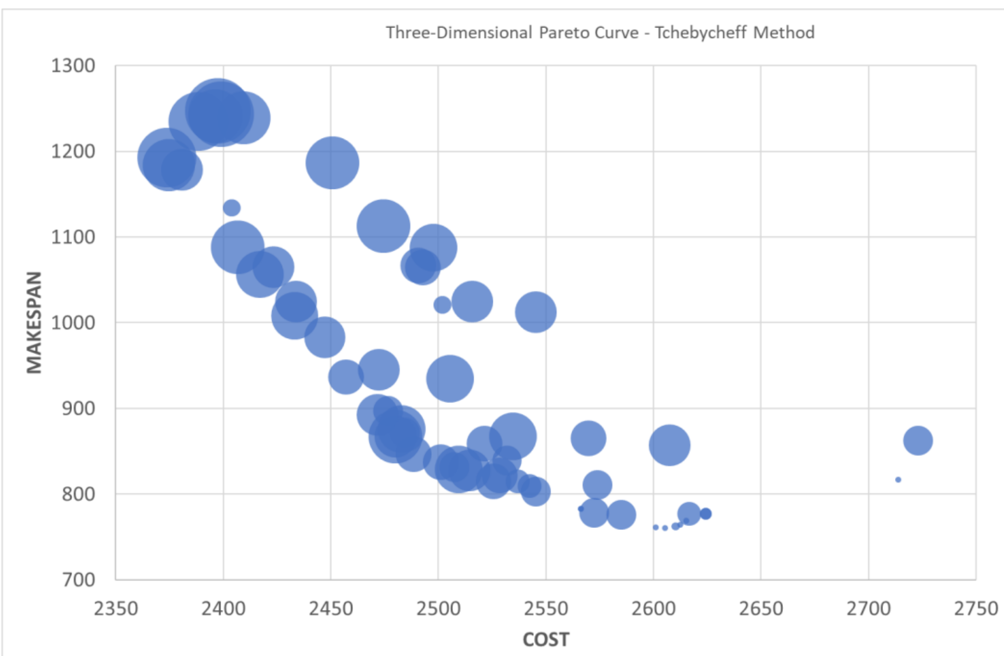

Figure 34 - Three-Dimensional Pareto Curve about Tchebycheff Method.

The three-dimensional Pareto curve consists of three axes: cost, availability, and makespan value. In this case, the x-axis represents cost, the y-axis represents the makespan value, and the size of the points represents the average workload.

By analysing the three-dimensional Pareto curve, it is possible to identify points that represent different combinations of cost, makespan value, and average workload. Larger points indicate better results, while smaller points indicate less favourable results.

It is recommended to increase the size of the points corresponding to the best objectives, making them more visible on the graph. This facilitates the identification of the most promising solutions in relation to the three objectives considered.

Considering the values of the points:

Table 24 - Point values of the Weighted Sum method.

	Weighted Sum		
	cost	makespan	average workload
Point 1	2394	1260	11
Point 2	2379	1218	11
Point 3	2377	1210	11
Point 4	2376	1205	11
Point 5	2374	1201	11
Point 6	2374	1199	11
Point 7	2372	1199	11
Point 8	2371	1195	11

In Table 24, it is possible to analyse the data referring to the Weighted Sum method. Additionally, for each of these data points, cost and makespan. It is worth noting that, for all points presented in this table, the value of the average workload the same at 11.

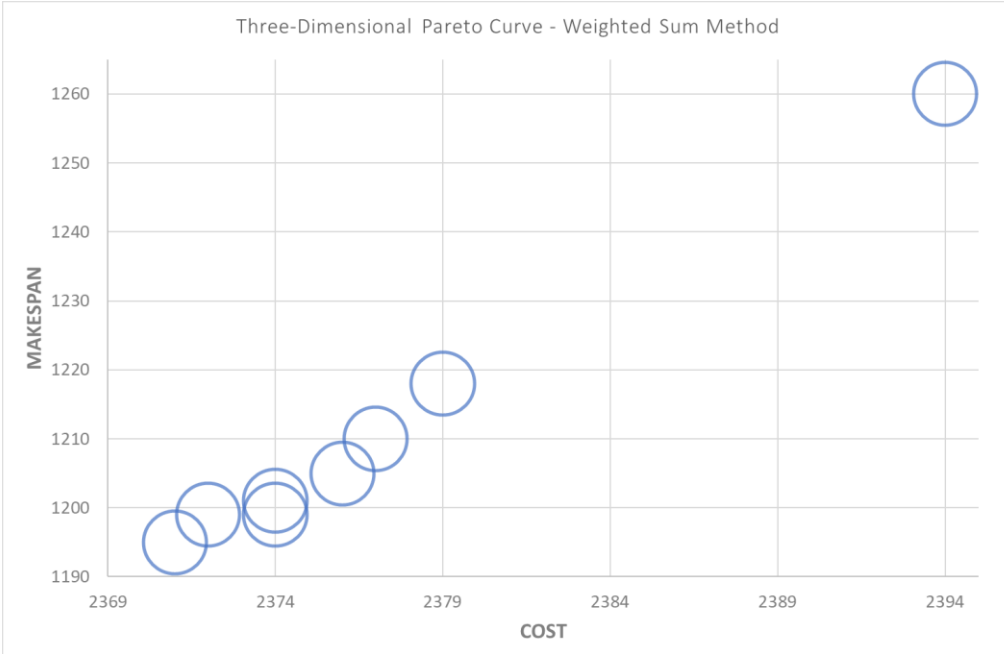

Figure 35 - Point values of Three-Dimensional Pareto Curve about Weighted Sum Method.

For the Weighted Sum method:

- The cost values range from 2371 to 2394, with Point 8 having the lowest cost.
- The makespan values range from 1195 to 1260, with Point 8 having the low-est makespan.
- The average workload is consistently 11 for all points.

Table 25 - Point values of the Tchebycheff method.

	Tchebycheff		
	cost	makespan	average workload
Point 1	2480	867	9
Point 2	2475	1113	9
Point 3	2451	1187	9
Point 4	2409	1239	9
Point 5	2407	1088	9
Point 6	2399	1243	11
Point 7	2398	1247	11
Point 8	2396	1241	9
Point 9	2388	1235	10

Point 10	2375	1184	9
Point 11	2374	1193	10

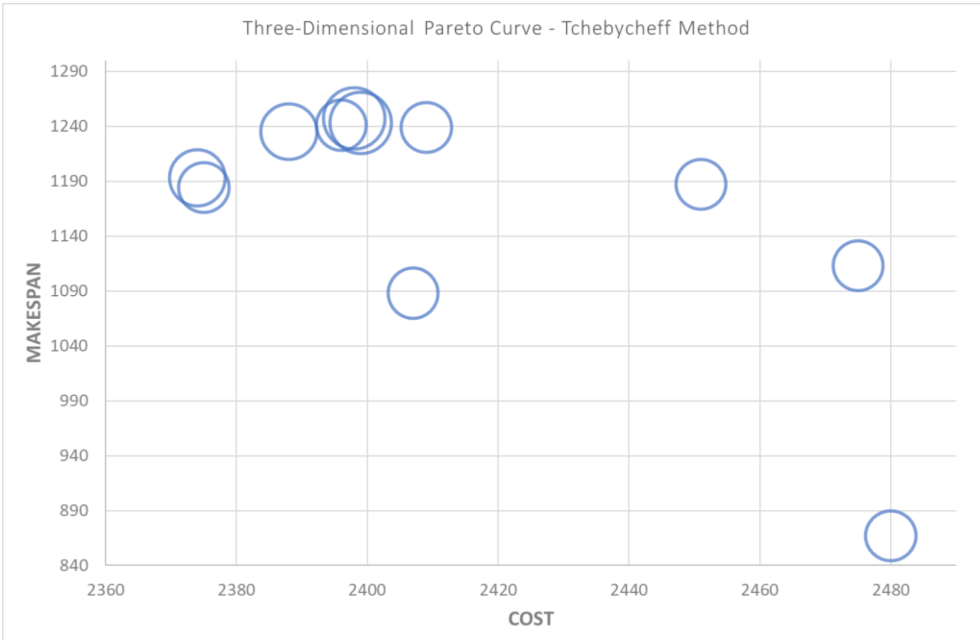

Figure 36 - Point values of Three-Dimensional Pareto Curve about Tchebycheff Method.

For the Tchebycheff method:

- The cost values range from 2374 to 2480, with Point 11 having the lowest cost.
- The makespan values range from 867 to 1247, with Point 1 having the lowest makespan.
- The average workload is consistently 9 for most points, except for Points 6, 7, and 8, which have a workload of 11, and Points 9 and 11, which have a workload of 10.

7.2. Discussion

In order to compare the results obtained by the Weighted Sum and Tchebycheff methods, we performed a simple statistical analysis of the presented data. Measures such as mean, standard deviation, median, maximum and minimum values were considered for each of the metrics: cost, makespan, and average workload.

Table 26 - Statistical analysis of the Weighted Sum method.

	Weighted Sum				
Metric	Mean	Standard Deviation	Median	Maximum	Minimum
Cost	2520.3	95.3	2531.6	2682.4	2371
Makespan	904.6	180.7	822.2	1260.0	756.0
Average workload	3.8	4.2	1.0	11.0	0.0

Table 27 - Statistical analysis of the Tchebycheff method.

	Tchebycheff				
Metric	Mean	Standard Deviation	Median	Maximum	Minimum
Cost	2516.4	92.9	2506.4	2891.7	2374
Makespan	934.9	154.4	867.4	1247.4	758.8
Average workload	5.7	2.9	6.0	11.0	0.0

Upon analysing the results, we observed differences between the two methods regarding the cost, makespan and average workload metrics. Let us discuss each of these metrics individually:

Cost:

The Weighted Sum method had an average cost of 2520.3, while the Tchebycheff method had an average of 2516.4.

The minimum cost found by the Weighted Sum method was 2371, whereas the Tchebycheff method achieved a minimum of 2374.

Compared to the initial value of 3000 monetary units, we can calculate the percentage reduction in cost:

For the Weighted Sum method: ((3000 - 2371) / 3000) * 100 = 21.10%

For the Tchebycheff method: ((3000 - 2374) / 3000) * 100 = 20.90%

Therefore, both methods managed to reduce the cost, with the Weighted Sum method being slightly more efficient in this aspect.

Makespan:

The Weighted Sum method had an average makespan of 904.6, while the Tchebycheff method had an average of 934.9.
The minimum makespan found by the Weighted Sum method was 756.0, whereas the Tchebycheff method achieved a minimum of 758.8.
Comparing the averages, we can observe that the Weighted Sum method had a lower makespan compared to the Tchebycheff method.
This indicates that the Weighted Sum method is more efficient in distributing tasks in order to reduce the total time required to complete them.

Average Workload:

The Weighted Sum method had an average workload of 3.8, while the Tchebycheff method had an average of 5.7.
However, the Tchebycheff method exhibited a greater variation in the average workload values. indicating a less uniform distribution of tasks.
In terms of stakeholder objectives, we can consider the Weighted Sum method more suitable, as it achieved superior results in terms of cost reduction, lower makespan, and a more uniform distribution of tasks (average workload close to the desired value).

Regarding the sustainable implementation of RPA technology, it is important to consider the three pillars: economic, environmental, and social.
The implementation of the model in the organization can bring benefits in terms of organizational sustainability, such as:

- **Economic:** The reduction in the cost of operational activities, as evidenced by the decrease in the cost obtained through evaluation methods, will result in financial savings for the organization. This can allow the reallocation of resources to strategic areas and in-vestments in other projects.
- **Environmental:** Task allocation optimization can lead to better resource utilization, reducing execution time and minimizing energy consumption. This contributes to environmental sustainability by reducing the organization's carbon footprint and environmental impact.
- **Social:** The implementation of RPA technology and task allocation optimization can positively impact employees by freeing them from repetitive and monotonous

tasks. This can provide greater job satisfaction, improve work-life balance, and enable employees to focus on more strategic and value-added activities.

The suitability of the evaluation methods used, Weighted Sum and Tchebycheff, depends on the specific needs and objectives of the problem at hand. Both methods have their advantages and limitations.

Weighted Sum: This method allows for assigning different weights to metrics and weighting their relative importance. This offers flexibility to reflect the preferences and priorities of stakeholders. However, weight assignment can be subjective and requires careful analysis to avoid distortions in the results.

Tchebycheff: This method aims to identify the worst performance in each metric and find a balance among them. It is useful when seeking a robust solution that minimizes the impact of the worst performance. However, it can result in more conservative solutions where all metrics are treated with equal importance, without considering specific stakeholder preferences.

In the context of this task allocation problem, the choice of evaluation method will depend on the objectives and priorities of the stakeholders. If the main goal is to minimize the makespan, the Weighted Sum method may be more suitable as it allows assigning greater weight to this metric. On the other hand, if there is a need to find a balance among all metrics, the Tchebycheff method may be a more appropriate option.

Regarding the proposed solution for task allocation to machines, based on the results obtained, we identified that the optimal point in terms of cost minimization, makespan and average workload occurred with the Weighted Sum method.

At this point, the cost was reduced to 2371 monetary units, representing a 21.10% de-crease compared to the initial value of 3000 monetary units. This cost reduction can bring significant financial benefits to the organization, enabling better utilization of available resources.

Additionally, the makespan was reduced to 1195-time units, indicating a shorter to-tal time required for task completion. This can result in greater operational efficiency and reduced waiting time for product or service delivery.

As for the average workload, the Weighted Sum method achieved a value close to the desired value of 11. This indicates a more balanced distribution of tasks among ma-chines, avoiding excessive overload or idleness.

In summary, the results obtained from the comparison of evaluation methods highlight the superiority of the Weighted Sum method in terms of cost minimization, makespan and average workload. The sustainable implementation of RPA technology can bring economic, environmental and social benefits to the organization. The choice of evaluation method will depend on stakeholder priorities and specific problem objectives.

We identified 3 possible solution sets for the Weighted Sum method. We present the weights assigned to each of the objectives in the following solutions:

Table 28 - Values of weighted Sum method solution sets.

	Weighted Sum		
	Weight cost	Weight makespan	Weight average workload
Solution 1	0.70	0.00	0.30
Solution 2	0.80	0.10	0.10
Solution 3	0.70	0.20	0.10

Table 29 - Solution Set 1.

	Solution 1		
	Activity	Total Activity	Occupancy (%)
Machine 1	[2, 4, 6, 12, 15, 17, 18, 24, 25, 26, 30, 35, 38, 40, 42, 44]	16	100%
Machine 2	[3, 7, 9, 10, 16, 21, 23, 28, 33, 39, 41, 43]	12	100%
Machine 3	[5, 11, 13, 14, 20, 22, 27, 29, 31, 34, 37]	11	42%
Machine 4	[1, 8, 19, 32, 36]	5	12%

Table 30 - Solution Set 2.

	Solution 2		
	Activity	Total Activity	Occupancy (%)
Machine 1	[1, 2, 5, 6, 7, 8, 12, 15, 17, 18, 19, 21, 22, 25, 26, 30, 32, 33, 34, 38, 39]	21	100%
Machine 2	[3, 4, 9, 10, 13, 16, 20, 28, 29, 35]	10	100%
Machine 3	[11, 14, 23, 24, 27, 31, 36, 37, 40, 41, 42, 43, 44]	13	60%
Machine 4	-	0	0%

Table 31 - Solution Set 3.

	Solution 3		
	Activity	Total Activity	Occupancy (%)
Machine 1	[2, 5, 6, 7, 8, 15, 17, 18, 19, 21, 22, 23, 25, 26, 30, 31, 32, 33, 34, 38, 39, 40]	22	100%
Machine 2	[1, 3, 4, 9, 11, 13, 14, 16, 24, 29, 35, 41, 44]	13	100%
Machine 3	[10, 12, 20, 27, 28, 36, 37, 42, 43]	9	60%
Machine 4		0	0%

From a practical standpoint, the potential solution deemed as the one to implement in the company would be Solution 1, given that it allocates the number of projects to all resources. This can be a significant advantage in terms of day-to-day practicality because not only are the resources being utilized, but it is also possible to maintain uniformity among the machines. In other words, no machine remains completely idle, enabling consistent updates across all machines. This ensures that all machines are in the same configured conditions.

8. CLOSING REMARKS

In the present chapter, we will address the final considerations of this study. Initially, we will present the conclusions reached throughout our investigation, summarizing the key findings. Following that, we will discuss the limitations identified during the development of this study, acknowledging the areas that may benefit from future research and improvements. Lastly, we will put forth a proposal for future work, outlining potential directions that can be explored to expand and deepen the knowledge in this field. This chapter concludes our analysis and provides a comprehensive overview of what has been achieved thus far, as well as the prospects that open up for subsequent research.

8.1. Conclusions

The present research aimed at analysing the relationship between user needs and the sustainable viability of RPA implementation, integrating them into a multi-objective model to evaluate its efficiency. We concluded that user needs have a significant impact on RPA viability, and their integration into a multi-objective model enables a more precise and efficient evaluation. Through this investigation, we were able to address the central research question and research hypotheses:

Central Research Question: How do user needs, within the context of stakeholders, influence decisions regarding the sustainable viability of RPA, and how can this relationship be incorporated into a multi-objective optimization model to assess the effectiveness of sustainable RPA implementation?

The answer to the Central Research Question reveals that user needs, when considered within the stakeholder context, have a substantial impact on decisions related to the sustainable viability of RPA. This research demonstrated that integrating user needs into a multi-objective optimization model provides a more accurate and effective assessment of sustainable RPA implementation. This study offers valuable recommendations on how user needs can be incorporated into a decision-making model, contributing to more efficient implementation aligned with organizational goals.

Research Hypothesis 1: What are the user requirements within the context of stakeholders that impact decisions concerning the sustainable viability of RPA systems?

Our findings confirm Research Hypothesis 1, identifying specific user requirements within the stakeholder context that directly influence decisions related to the sustainable viability of RPA systems. These requirements include the allocation of RPA activities based on each machine's characteristics, cost minimization, runtime minimization (makespan), and average workload minimization. This in-depth understanding of user requirements is essential for developing effective RPA implementation strategies that meet stakeholder needs.

Research Hypothesis 2: Considering user requirements within the context of stakeholders significantly affects the decision about the sustainable viability of RPA systems?

Our research confirms Research Hypothesis 2, showing that considering user requirements within the stakeholder context has a significant impact on decisions related to the sustainable viability of RPA systems. Integrating these requirements into a multi-objective model allows for a more efficient assessment of the effectiveness of sustainable RPA implementation. This means that organizations that take into account user needs when making decisions about RPA are more likely to achieve sustainable and effective results.

Research Hypothesis 3: Identifying and analysing user requirements within the context of stakeholders enables a more precise evaluation of the sustainable viability of RPA systems?

Our findings confirm Research Hypothesis 3, demonstrating that the identification and analysis of user requirements within the context of stakeholders enable a more precise assessment of the sustainable viability of RPA systems. By considering these requirements, organizations can make more informed decisions aligned with their strategic objectives, resulting in more effective and sustainable RPA implementations. A detailed understanding of these requirements is essential for an accurate assessment of RPA's sustainable viability in any organization.

Research Hypothesis 4: Incorporating the relationship between user requirements and stakeholders in a multi-objective model permits a comprehensive assessment of the efficiency of sustainable RPA system implementation?

Our research has shown that incorporating the relationship between user requirements and stakeholders into a multi-objective model indeed enables a comprehensive evaluation of the efficiency of sustainable RPA system implementation. This is because this model allows for the consideration of multiple objectives and perspectives, resulting in a more thorough and balanced assessment of RPA implementation efficiency. The results of this study confirm that the multi-objective approach is highly beneficial for assessing the efficiency of sustainable RPA system implementation and can be effectively applied in other organizational contexts beyond RPA.

Research Hypothesis 5: Identifying and analysing the primary challenges and obstacles users encounter when adopting RPA enables the development of tailored solutions to meet their needs?
Our findings support Research Hypothesis 5, demonstrating that identifying and analysing the key challenges and obstacles faced by users when adopting RPA are essential for the development of customized solutions. By understanding the specific challenges users encounter, organizations can tailor their RPA implementation strategies to address individual needs. This not only enhances implementation efficiency but also increases user satisfaction and, consequently, the overall success of RPA within the organization.

Research Hypothesis 6: Will the proposed guidelines for sustainable and efficient RPA implementation, based on the case study results and data analysis, prove beneficial for organizations seeking to adopt RPA in an economical and sustainable manner?
Based on our research, we confirm that the proposed guidelines for sustainable and efficient RPA implementation, derived from the case study results and data analysis, have the potential to be highly beneficial for organizations seeking to adopt RPA in an economical and sustainable manner. These guidelines offer practical, evidence-based guidance that can help organizations plan, implement, and manage RPA more efficiently and sustainably. By following these guidelines, organizations can expect tangible benefits, including cost reduction, improved operational efficiency, and alignment with sustainable practices.

Research Hypothesis 7: Will the research findings and contributions to the scientific community and industry professionals yield significant benefits in advancing the field of RPA?
Our research validates Research Hypothesis 7, as the outcomes of this investigation and its contributions signify a significant advancement in the field of RPA. By scrutinizing the interplay between user needs, stakeholders, and the sustainable viability of RPA, we have pioneered an innovative model with broad applicability across various organizational contexts. Furthermore, the proposed guidelines for the sustainable implementation of RPA represent a valuable addition to both the scientific community and industry professionals, offering a practical roadmap for the

successful adoption of RPA. We anticipate that this research will inspire future studies and foster ongoing growth and evolution in the realm of RPA, resulting in substantial benefits for all stakeholders involved.

Having addressed the research questions in this study, we have determined that the proposed guidelines for effective and sustainable RPA implementation will be of great value to organizations seeking to adopt this technology in a sustainable manner. These guidelines furnish practical insights for RPA planning, implementation, and management, taking into account user needs, stakeholder engagement, efficient task allocation, and economically viable, environmentally responsible solutions.

The model we are presenting distinguishes itself by encompassing a variety of key aspects for sustainable RPA implementation within a single framework. Our model addresses RPA implementation, such as within an administrative department, facilitating the identification of benefits derived from sustainable implementation. Additionally, it aids in the selection of RPA tools, analysing the costs of different available options, enabling assessment. It also assists in evaluating RPA funding by comparing resource expenditures before and after model application and supports RPA monitoring by allocating RPA activities to machines, thereby enhancing project monitoring efficiency and effectiveness.

The primary strength and innovation of this model lie in its ability to encompass all these topics within a unified framework while addressing a novel aspect for RPA technology, which is project allocation. Specifically, we can observe that our model, in response to RPA implementation, tackles issues such as energy efficiency analysis, paperless RPA automation, workforce impact, ethical considerations (such as data privacy and security), engagement of all stakeholders, cost-benefit analysis, and scalability and flexibility (choosing a scalable and adaptable RPA solution to meet evolving business needs). By considering these environmental, social, and economic facets, organizations can ensure that RPA implementation aligns with sustainable practices and positively contributes to the overall well-being of companies and their stakeholders.

In the case study, we observed significant differences among evaluation methods, underscoring the superiority of the Weighted Sum method in cost reduction, execution time, and balanced workload distribution. This sustainable RPA implementation can bring economic, environmental, and social benefits to the organization.

We recommend the adoption of Solution 1, which enables efficient and uniform resource allocation, facilitating machine maintenance and updates. This solution will yield practical benefits for the company in terms of resource utilization efficiency and a more stable working environment. This solution also resulted in a 21.10% reduction in the initial cost associated with RPA implementation.

We consider this study to be relevant as it emphasizes the importance of taking into account the needs of users and stakeholders in the implementation of RPA. Based on the results, we suggest that organizations utilize these guidelines to implement RPA sustainably, reaping economic, environmental, and social benefits.

This doctoral thesis represents a significant effort to deeply comprehend the relationship between user needs, within the context of stakeholders, and the sustainable viability of Robotic Process Automation (RPA) implementation. Throughout this study, we meticulously investigate how the incorporation of these needs into a multi-objective optimization model can influence the effectiveness of sustainable RPA implementation.

The findings of this study hold fundamental importance and have several implications that extend beyond academic research into the realm of business and society at large. Some of the key contributions and advantages of this study are highlighted as follows:

Enhanced Understanding of User Needs: This study has revealed that user needs play a critical role in determining the success of RPA implementation. By identifying and analysing these needs, organizations can make informed decisions and tailor their strategies to meet user expectations.

Innovative Multi-Objective Approach: The development of a multi-objective optimization model that incorporates user and stakeholder needs represents a significant innovation. This approach enables a balanced evaluation of different goals and objectives, ensuring that RPA implementation is efficient and aligned with the interests of all involved parties.

Practical Guidelines for Sustainable Implementation: The guidelines proposed in this study offer practical, evidence-based guidance for organizations seeking to adopt RPA sustainably. These guidelines encompass everything from the efficient allocation of activities to the consideration of economic and environmental impacts, providing a clear roadmap for the planning and implementation of RPA projects.

Contribution to Advancing the RPA Field: This study significantly contributes to the field of RPA by promoting a more holistic and sustainable approach to the adoption of this technology. Furthermore, the conclusions and guidelines presented here can serve as a valuable starting point for future research and practices in the field.

Economic, Environmental, and Social Benefits: Sustainable RPA implementation, as demonstrated in this study, can result in substantial benefits for organizations. These include reduced operational costs, energy efficiency, minimized environmental impact, and improved working conditions, among others.

Corporate Social Responsibility Promotion: When considering the social and environmental aspects of RPA implementation, organizations can demonstrate a genuine commitment to corporate social responsibility, contributing to a positive impact on society and the environment.

Stakeholder Engagement Emphasis: This study underscores the importance of involving stakeholders in decision-making regarding RPA. By actively engaging all parties involved, organizations can ensure that RPA implementation is transparent, ethical, and aligned with the interests of all stakeholders.

In summary, this doctoral thesis comprehensively addressed the central research question and validated research hypotheses, providing a deeper understanding of the influence of user needs and stakeholders on the sustainable viability of RPA. The practical implications of this study are significant and can assist organizations in adopting RPA more effectively and sustainably, maximizing its economic, environmental, and social benefits.

This study not only fills a gap in academic literature but also provides practical guidance applicable in the real business environment. It is expected that organizations adopting the proposed guidelines may reap the rewards of a successful RPA implementation, benefiting from increased efficiency, resource savings, and contributions to environmental and social sustainability. Furthermore, this research promotes a broader dialogue on corporate social responsibility and the importance of considering the impact of emerging technologies on society.

As we advance in the field of RPA and technology, it is crucial to continue exploring ways to promote efficiency and sustainability in all areas of implementation. This doctoral thesis represents a significant step in this direction and offers a solid foundation for future studies and business practices seeking a more sustainable and effective future in RPA adoption.

In this section, we will summarize the overall contribution of this doctoral study, highlighting its importance and relevance to the field of RPA, as well as to society and organizations.

This study makes a significant contribution to the field of RPA and related areas, addressing critical sustainability and efficiency issues in RPA implementation. The key contributions can be summarized as follows:

Integration of User Needs: This study unequivocally demonstrates that user needs play a fundamental role in the sustainable viability of RPA. The integration of these needs into a multi-objective optimization model offers an innovative approach to assess and enhance RPA implementation.

Comprehensive Multi-Objective Model: Creating a multi-objective model that considers not only user requirements but also stakeholder goals results in a more comprehensive and balanced evaluation of RPA effectiveness. This represents a significant contribution to both literature and practice.

Practical Guidelines: The proposed guidelines in this study offer evidence-based and practical guidance for organizations seeking to adopt RPA sustainably. These guidelines are a valuable resource for professionals and managers aiming for successful RPA implementation.

Holistic Approach: This study addresses RPA implementation holistically, considering not only economic but also social and environmental aspects. This promotes corporate social responsibility and the adoption of more ethical and sustainable business practices.

Sustainability Promotion: By emphasizing sustainability in RPA implementation, this study contributes to responsible business practices and reduces the environmental impact of organizations.

Economic, Environmental, and Social Benefits: The research highlights the economic, environmental, and social benefits of sustainable RPA implementation, including cost reduction, operational efficiency, and improved working conditions.

Relevance to Society: Besides its implications for the business world, this study is also relevant to society as a whole, as it promotes the responsible adoption of emerging technologies.

At the heart of the technological revolution that shapes the business world, an acronym emerges as the protagonist: RPA, or Robotic Process Automation. This technological innovation is not just a tool, but a promise of balance between companies' efficiency and people's quality of life. By embracing RPA, companies are paving the way to a more sustainable future, not only from an economic point of view, but also environmentally and socially.

RPA is much more than automating repetitive tasks; it is the materialization of technological evolution, a symbiosis between the human mind and the machine. By delegating monotonous tasks to machines, we free up time for creativity, innovation and the development of unique human skills. The people who use RPA in companies are not merely machine operators, but conductors of digital orchestras, conductors of complex processes.

However, the true potential of RPA goes far beyond operational efficiency. It is a tool that can boost sustainability in several dimensions. Economically, RPA reduces operational costs, increases productivity and allows for more strategic investment in key areas. This not only guarantees the survival of companies, but also creates space for a more equitable distribution of resources.

In environmental terms, the automation promoted by RPA minimizes waste, optimizes resource consumption and reduces organizations' carbon footprint. Replacing manual processes with digital solutions reduces the need for physical travel and paper, contributing to the preservation of our planet. It is a small step towards a greener future, but every step counts.

Socially, RPA has the potential to create more meaningful and fulfilling jobs. By relieving workers of tedious and repetitive tasks, it allows them to focus on activities that require empathy, creativity and human judgement. This not only improves workers' quality of life, but also strengthens the social fabric as companies become more socially aware and responsible.

However, perhaps the most profound impact of RPA is its potential to reduce stress in people. Modern life is marked by tight deadlines, frenetic paces and constant pressure to do more with less. RPA can be an ally in the fight against stress. By taking on tasks that take up time and energy, it allows us to regain balance between work and personal life. People who use RPA can enjoy more time with their family, pursue hobbies, exercise, and even simply relax.

Thinking about future generations, RPA represents a promise of a more balanced world. As children are born into this technological environment, they will have the opportunity to develop in a world where work is more rewarding and life is more sustainable. Technology will not just be a tool, but an ally in building a better future.

In a world facing complex challenges, RPA is one of the answers. As we embrace this technology, we must do so with a deep commitment to sustainability, empathy and quality of life. RPA is not just a business tool; It is an opportunity to redefine the relationship between technology and humanity, to create a balance that benefits everyone. It is the silent revolution that will lead us to a brighter future.

RPA technology has been gaining more and more relevance in the business world, being a powerful tool for automating repetitive and manual tasks. However, it is important that the use of this technology is done in a sustainable way, to ensure that the balance between economic development and environmental preservation is not put at risk.

One of the main benefits of using RPA is the freeing up of time and human resources for more complex and strategic tasks. This allows companies to improve their productivity and efficiency, which can lead to increased competitiveness and profits. However, it is important that this freeing up of time is used for activities that are truly beneficial to society, such as innovation and the development of new products and services.

The use of RPA can also contribute to environmental sustainability. For example, automating tasks involving the transport of goods and documents can help reduce greenhouse gas emissions. Additionally, using robots to perform repetitive tasks can help save energy and natural resources.

At a social level, the use of RPA can contribute to improving people's quality of life. For example, automating tasks that are considered dangerous or unhealthy can help protect workers. Furthermore, the use of RPA can create new job opportunities, particularly in the area of developing and maintaining RPA systems.

Regarding the impact of RPA on unborn children, it is important to note that this technology has the potential to provide them with a better world. For example, automating tasks that are currently performed by humans can help free up time and resources for children to focus on their education and personal development. Additionally, using RPA can help create a more sustainable world, which is essential for children's futures.

In short, RPA technology can be a powerful tool to promote the balance between economic development and environmental preservation. However, it is important that the use of this technology is done in a responsible and sustainable way, to ensure that its benefits are maximized and its negative impacts are minimized.

Concrete examples of how RPA technology can contribute to sustainability:

- **Reducing greenhouse gas emissions:** Automating tasks involving the transport of goods and documents can help reduce greenhouse gas emissions. For example, a company that uses robots to sort orders can reduce the number of truck trips needed to transport orders to customers.
- **Saving energy and natural resources:** Using robots to perform repetitive tasks can help save energy and natural resources. For example, a company that uses robots to clean offices can reduce the consumption of water and cleaning products.
- **Improving worker safety and health:** Automating tasks that are considered dangerous or unhealthy can help protect workers. For example, a company that uses robots to perform welding tasks in confined spaces can reduce the risk of workplace accidents.
- **Creation of new job opportunities:** The use of RPA can create new job opportunities, particularly in the area of developing and maintaining RPA systems. For example, a

company that invests in RPA technology needs to hire engineers and technicians to develop and maintain RPA systems.

In addition to the economic and environmental benefits, RPA technology can also contribute to improving people's quality of life. For example, automating tasks that are considered dangerous or unhealthy can help protect workers. Furthermore, the use of RPA can create new job opportunities, particularly in the area of developing and maintaining RPA systems.

Automating repetitive and manual tasks can free up time and human resources so that people can focus on more complex and strategic tasks. This can lead to increased job satisfaction, as people feel more valued and motivated when they are challenged and can use their skills to the fullest.

Reducing stress at work is another important benefit of using RPA. Repetitive and manual tasks can be a source of stress for workers, as they can be monotonous and tiring. Automating these tasks can help reduce stress and improve workers' mental health.

RPA technology also has the potential to contribute to improving people's quality of life outside of work. For example, automating household tasks can free up time for people to pursue their hobbies and interests. Additionally, using RPA can help people save money as it can reduce labour costs.

RPA technology has the potential to provide a better world for unborn children. For example, automating tasks that are currently performed by humans can help free up time and resources for children to focus on their education and personal development.

Children who grow up in a world where RPA technology is widely used will have access to a more personalized and effective education. Teachers will have more time to focus on each student's individual needs, and children will have the opportunity to learn in new ways, using innovative technologies.

Additionally, using RPA can help create a more sustainable world, which is essential for children's futures. For example, automating tasks involving the transport of goods and documents can help reduce greenhouse gas emissions.

RPA technology has the potential to be a powerful tool to promote sustainable development and create a better world for children. However, it is important that the use of this technology is done in a responsible and sustainable way, to ensure that its benefits are maximized and its negative impacts are minimized.

As we enter this new paradigm driven by RPA, it is essential to highlight how this technology can be a tool to foster empathy and concern for the future, especially for future generations. RPA is not just a technological revolution, but also a cultural evolution that invites us to rethink our values and priorities.

Empathy, the ability to understand and share the feelings of others, is a fundamental human quality that often is obscured in the hustle and bustle of the corporate world. With the automation of routine tasks, workers have more time to focus on interpersonal relationships and customer service. This not only improves the quality of these interactions, but also allows companies to better meet their customers' needs by strengthening empathy as a core value.

Furthermore, RPA also contributes to social sustainability by creating more meaningful employment opportunities. As mechanical tasks are automated, workers are encouraged to engage in activities that require creativity, compassion and interpersonal skills. This not only makes jobs more rewarding, but also promotes a fairer society where the focus is on creating human value.

When it comes to economic sustainability, RPA offers a path for companies to thrive in the competitive global landscape. By reducing operating costs, improving efficiency and directing resources to strategic areas, companies can become more resilient and prepared to face economic challenges. This financial stability is essential to guarantee a prosperous future for future generations.

However, perhaps the most inspiring aspect of RPA is its potential to shape a greener future. Process automation not only reduces waste and resource consumption, but also allows for more accurate and sustainable management of natural resources. This is essential to protect the planet we will leave to our children and grandchildren. RPA not only creates efficiencies in companies but also promotes environmental responsibility.

For children born into this increasingly digital world, RPA is an opportunity to inherit a healthier planet and a more equitable society. As technology becomes an ally in the search for a balance between efficiency and quality of life, these children will grow up in an environment where work is more rewarding, the environment is better preserved and empathy is more valued.

RPA is not just a technological tool; it is a catalyst for profound cultural and social change. It is the promise of a future where empathy and sustainability are core values, and where technology is an ally in the search for a more balanced and meaningful life. As we move forward on this journey, it is essential that we embrace RPA with a humanistic vision, seeking not only efficiency, but also the well-being of people and the preservation of our planet for future generations. It is a challenge worth facing, as the future we build today will shape the world of tomorrow.

In the age of globalization, companies face increasing challenges to remain competitive in an ever-dynamic and interconnected market. In this context, RPA has emerged as a powerful tool to boost operational efficiency, reduce costs, and enhance service quality. Furthermore, RPA can also play a pivotal role in promoting environmental sustainability, contributing to the preservation of the environment.

- **Operational Efficiency:** The automation of repetitive and routine tasks through RPA allows companies to save valuable time and resources. This is especially relevant in a globalized world where the speed of execution is essential to meet the demands of a constantly changing market.
- **Error Reduction:** Robotic process automation robots are highly precise and consistent in their operations. This helps minimize human errors, which can be costly in terms of time and resources, and maintains product and service quality in a global business environment.
- **Flexibility and Scalability:** RPA is highly flexible and scalable, enabling companies to adapt quickly to changes in global market demands. Automated processes can be adjusted and expanded as needed, providing agility and competitiveness.
- **Cost Reduction:** The automation of repetitive tasks reduces the need for human labour, resulting in significant operational cost savings. This is particularly beneficial in a globalized environment where the pressure to cut costs is constant.
- **Improved Customer Experience:** With process automation, companies can provide faster and more efficient customer service, which is crucial for competing in a global economy. This leads to greater customer satisfaction and brand loyalty.

In addition to economic benefits, RPA can also play a significant role in promoting environmental sustainability. Here are some ways in which RPA can contribute to environmental preservation:

- **Resource Consumption Reduction:** Process automation reduces the need for physical resources such as paper and electricity, which are often used in manual tasks. This helps decrease the ecological footprint of businesses.
- **Fewer Commutes:** With task automation, many employees can work remotely, reducing the need for daily commutes. This not only saves time and money but also

reduces carbon emissions associated with transportation.

- **Efficient Resource Management:** RPA systems can be programmed to optimize the use of resources like energy, water, and raw materials, thus contributing to sustainable resource management.
- **Waste Reduction:** Process automation can lead to more precise and efficient production, reducing the waste of materials and products. This is crucial for waste reduction and promoting recycling.
- **Cultural Shift:** The adoption of RPA can lead to a cultural shift within companies, with an increasing focus on efficiency and environmental responsibility. This can translate into more environmentally responsible business practices.

In summary, RPA is a powerful tool in the age of globalization, bringing numerous economic benefits to companies. Additionally, it also plays a relevant role in promoting environmental sustainability, contributing to environmental conservation and a more sustainable future. As companies embrace RPA, they not only become more globally competitive but also do their part in safeguarding the planet for future generations.

RPA technology has the potential to be a powerful tool to promote the balance between economic development and environmental preservation. However, it is important that the use of this technology is done in a responsible and sustainable way, to ensure that its benefits are maximized and its negative impacts are minimized.

8.2. Limitations to the study

While this thesis has achieved significant results and valuable contributions, it is important to acknowledge and address its limitations. Scientific research is an ongoing process, and understanding a complex field such as RPA is subject to inherent limitations. The key limitations of this study include:

- **Limited Generalizability:** The results of this study are based on a specific case study and may not be directly applicable to all organizations or contexts. The unique nature of the case studied may restrict the generalization of the conclusions.
- **Subjectivity in Weight Assignment:** The assignment of weights to objectives in the multi-objective model is a subjective task that can vary according to the preferences and goals of the organization. This can influence the results and effectiveness of the model.

- **Uncontrollable External Factors:** The business environment is subject to external factors such as regulatory changes, evolving economic conditions, and technology. These factors can affect the implementation of RPA in unpredictable ways.
- **Data Sample Limitations:** Limited data availability or data quality can affect the accuracy of the analyses conducted in this study. A larger and more diverse data sample could provide additional insights.
- **Focus on User Needs:** While this study has focused on user needs, other stakeholders, such as external regulators, can play a significant role in the sustainable viability of RPA and have not been fully explored.
- **Limited Time and Resources:** Time and resource constraints may have limited the depth of analysis in some areas. Future research may delve deeper into these analyses.

8.3. Future Work Proposal

This study has identified several areas warranting further investigation in the context of RPA and sustainability. Some proposals for future work include:

- **Multiple Case Studies:** Conducting additional case studies in different organizations and sectors to validate and generalize the findings of this study.
- **Development of Objective Weighting Models:** Researching more advanced and robust methods for assigning weights to objectives in multi-objective models, taking into account subjectivity and uncertainty.
- **Evaluation of External Impacts:** Investigating how external factors such as government regulations and technological advancements affect the sustainable implementation of RPA.
- **Inclusion of Other Stakeholders:** Exploring the role of other stakeholders, such as external regulators and interest groups, in the sustainable viability of RPA.
- **Long-Term Analysis:** Conducting longitudinal studies to assess the impact of sustainable RPA implementation over time.
- **Development of Decision Support Tools:** Creating decision support tools based on the models developed in this study to assist organizations in the sustainable implementation of RPA.
- **Assessment of Other Emerging Technologies:** Applying the principles and models

developed in this study to other emerging technologies to determine their applicability in different contexts.

Ultimately, this doctoral thesis represents a significant step in understanding the relationship between user needs, stakeholders, and the sustainable viability of RPA. However, there are many opportunities for future research to expand and deepen this knowledge, contributing to the ongoing evolution of the field of RPA and the promotion of more efficient, sustainable, and socially responsible business practices. Scientific research is a dynamic and continuous endeavour, and we hope that this study inspires and informs future efforts in this exciting and ever-evolving field.

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APPENDIX

APPENDIX 1

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Literature review of decision models for the sustainable implementation of Robotic Process Automation

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Abstract

Robotic Process Automation (RPA) is a rules-based system for automating business processes by software bots that mimic human interactions to relieve employees from tedious work. It was verified in the literature that there are few works related to RPA decision support models. This technology is in great growth and, therefore, it becomes important to study the evaluation of the implementation of RPA. The objective of this work is focused on a literature review for the identification and analysis of Robotic Process Automation implementation models. This work analyses some models or studies available in the literature and, in addition, analyses it from a perspective relating to the Triple Bottom Line (TBL) related to environmental, social and economic effects. Regarding the results obtained, it appears that there is still a lot of room to improve research in this field, for example, with regard to the development of an evaluation model for the implementation of the RPA, taking into account the TBL of the sustainability concept.

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Keywords: Robotic Process Automation (RPA); Sustainability; Decision Models; Literature review; Smart systems.

Figure 37 - Illustration of the article "Literature review of decision models for the sustainable implementation of Robotic Process Automation"

APPENDIX 2

Questionário sobre Robotic Process Automation (RPA)

As questões abaixo serão respondidas exclusivamente pelo RPA Manager com o objetivo de fornecer dados relacionados às atividades de RPA da empresa, custos e detalhes das máquinas.

1. Quantas atividades de RPA estão implementadas atualmente?

Responder:

2. Qual é o tempo médio de execução de cada atividade de RPA?

Responder:

3. Qual é o custo diário gasto no total de recursos de RPA?

Responder:

4. Quantas máquinas RPA a empresa adquiriu?

Responder:

5. Qual a disponibilidade diária e o custo de cada máquina RPA?

Responder:

O questionário foi distribuído a todos os participantes a partir da próxima questão.

1. Você faz parte da equipe de RPA da empresa?

a) Sim

b) Não

2. Em relação aos custos, qual a importância deste fator na implementação do RPA?

a) Extremamente importante.

b) Importante.

c) Neutro.

d) Menos importante.

e) Não é importante.

3. Como você avaliaria a eficiência energética das soluções RPA em comparação com processos manuais/tradicionais?

a) As soluções RPA são mais eficientes em termos energéticos.

b) As soluções RPA são menos eficientes em termos energéticos.

c) As soluções RPA têm eficiência energética semelhante aos processos manuais/tradicionais.

d) Não sei o suficiente para responder.

4. Quais poderiam ser os possíveis impactos aos colaboradores com a implementação do RPA na empresa?

a) Redução do número de funcionários.

b) Redireccionamento dos colaboradores para tarefas mais estratégicas.

c) Melhoria nas condições de trabalho.

d) Não sei o suficiente para responder.

5. De que forma a automação RPA pode ajudar a reduzir o consumo de papel na empresa?

a) Eliminação da necessidade de documentos impressos.

b) Automatizar processos para reduzir desperdícios.

c) Minimizar erros que levam ao retrabalho e ao uso desnecessário de recursos.

d) Todas as opções acima.

6. Você acredita que a implementação sustentável de RPA pode melhorar a produtividade da equipe?

a) Sim, definitivamente.

b) Talvez, dependendo do contexto.

c) Não, não acredito que haja uma correlação direta.

d) Não tenho certeza.

7. Como você avaliaria o processo atual de alocação de projetos de RPA para máquinas em termos de eficácia?

a) Altamente eficaz.

b) Moderadamente eficaz.

c) Ineficaz.

d) Não tenho certeza.

8. Qual é a importância de minimizar o tempo necessário para concluir projetos de automação?

a) Muito importante para garantir eficiência e agilidade nas operações.

b) Importante, mas não o fator mais crítico.

c) Neutro, pois o tempo de conclusão do projeto não afeta significativamente os resultados.

d) Não tenho certeza sobre a importância do tempo de conclusão do projeto.

9. Qual é o objetivo principal da implementação do RPA em uma organização?

a) Substituir completamente os funcionários por robôs para reduzir custos.

b) Melhorar a eficiência operacional automatizando tarefas repetitivas.

c) Aumentar a complexidade dos processos de negócios para alcançar resultados avançados.

d) Ampliar a força de trabalho atual com a contratação de robôs.

10. Como você avaliaria a resistência dos funcionários à implementação do RPA na empresa?

a) Muito forte.

b) Moderado.

c) Fraco.

d) Não tenho informações suficientes para responder.

11. Qual a sua perceção sobre o nível de formação oferecido aos

colaboradores para trabalharem com soluções RPA?

a) Muito adequado.

b) Adequado.

c) Insuficiente.

d) Não consigo avaliar.

12. Quais são as principais áreas em que o RPA demonstrou eficácia na empresa?

a) Processamento de dados.

b) Geração de relatórios.

c) Gestão de documentos.

d) Comunicação interna.

e) Outras áreas (especificar): ______________________________

13. Em relação à integração do RPA com os sistemas existentes na empresa, como você avaliaria os resultados alcançados até o momento?

a) Muito bem integrado.

b) Moderadamente integrado.

c) Mal integrado.

d) Não consigo avaliar.

14. Como você avalia o grau de alinhamento dos projetos de RPA com a estratégia geral da empresa?

a) Completamente alinhado.

b) Parcialmente alinhado.

c) Mal alinhado.

d) Não consigo avaliar.

15. Quais são os principais indicadores de desempenho que a empresa considera ao avaliar o sucesso da implementação do RPA?

a) Redução de custos operacionais.

b) Aumento da produtividade.

c) Maior precisão do processo.

d) Satisfação do cliente.

e) Outros indicadores (especificar): ____________________________

16. Na sua opinião, quais são os principais obstáculos enfrentados na integração do RPA com os processos existentes?

a) Dificuldade de adaptação dos processos existentes.

b) Resistência dos funcionários à mudança.

c) Complexidade técnica.

d) Falta de apoio da liderança.

e) Outros obstáculos (especificar): ____________________________

17. Que tipos de atividades você considera mais adequadas para automação por meio de RPA?

a) Tarefas altamente repetitivas.

b) Tarefas que envolvam decisões complexas.

c) Tarefas que exijam criatividade.

d) Tarefas altamente colaborativas.

18. Como você avaliaria a colaboração entre a equipe de RPA e o restante das equipes da empresa?

a) Altamente colaborativo.

b) Moderadamente colaborativo.

c) Pouco colaborativo.

d) Não tenho informações suficientes para responder.

19. Em termos de manutenção de soluções RPA, qual a sua perceção sobre a necessidade de atualizações frequentes?

a) Extremamente necessário.

b) Necessário.

c) Ocasionalmente necessário.

d) Não considero necessário.

20. Como você descreveria a perceção geral dos colaboradores sobre RPA na empresa?

a) Muito positivo.

b) Neutro.

c) Misto.

e) Negativo.

21. Quais critérios são considerados na seleção de processos para automação por meio de RPA?

a) Volume de tarefas.

b) Complexidade da tarefa.

c) Potencial de redução de erros.

d) Potencial para aumento de produtividade.

22. Quais são as principais métricas utilizadas para avaliar a eficiência das atividades de RPA?

a) Taxa de conclusão de tarefas.

b) Tempo médio de execução.

c) Taxa de erro.

d) Utilização de recursos.

e) Outras métricas (especifique): ______________________________

23. Na sua opinião, quais são os principais fatores que podem garantir a sustentabilidade da implementação do RPA no longo prazo?

a) Compromisso da liderança.

b) Adoção de melhores práticas de automação.

c) Formação contínua e desenvolvimento da equipe.

d) Adaptação às mudanças nas necessidades do negócio.

24. Como você avalia a capacidade atual da equipe de RPA para lidar com potenciais desafios futuros?

a) Muito capaz.

b) Capaz.

c) Parcialmente capaz.

d) Não preparado para desafios futuros.

25. Que tipo de apoio ou recursos adicionais você considera necessários para maximizar os benefícios da implementação sustentável do RPA?

a) Aumento do investimento em tecnologia.

b) Treinamento contínuo da equipe.

c) Maior envolvimento da liderança.

d) Melhor comunicação interna.

e) Outros recursos (especifique): ______________________________

APPENDIX 3

	A	B	C	D	E	F	G	H	I
1		Goal values	Weights						
2	Upper limit	3000							
3	Objective Function Min. Cost	2682,4	0	0					
4	bjective Function Min. Makespa	850,5	0	0					
5	ɔjective Function Min. Work Lo	0	1	0					
6	Variáveis	Headquarters		0					
7		RPA tasks	Machine 1	Machine 2	Machine 3	Machine 4			
8		1	0	0	1	0			1
9		2	0	0	1	0			1
10		3	0	0	1	0			1
11		4	0	1	0	0			1
12		5	0	0	0	1			1
13		6	1	0	0	0			1
14		7	0	0	0	1			1
15		8	0	0	1	0			1
16		9	0	0	0	1			1
17		10	0	0	0	1			1
18		11	0	0	1	0			1
19		12	1	0	0	0			1
20		13	0	0	1	0			1
21		14	0	1	0	0			1
22		15	0	0	1	0			1
23		16	0	1	0	0			1
24		17	0	0	0	1			1
25		18	0	1	0	0			1
26		19	0	0	0	1			1
27		20	0	0	0	1			1
28		21	0	1	0	0			1
29		22	1	0	0	0			1
30		23	0	0	0	1			1
31		24	0	0	1	0			1
32		25	0	0	0	1			1
33		26	1	0	0	0			1
34		27	0	1	0	0			1
35		28	1	0	0	0			1
36		29	0	1	0	0			1
37		30	0	0	1	0			1
38		31	0	0	0	1			1
39		32	0	0	1	0			1
40		33	1	0	0	0			1
41		34	1	0	0	0			1
42		35	0	1	0	0			1
43		36	1	0	0	0			1
44		37	1	0	0	0			1
45		38	0	0	0	1			1
46		39	0	0	1	0			1
47		40	0	1	0	0			1
48		41	0	1	0	0			1
49		42	0	1	0	0			1
50		43	1	0	0	0			1
51		44	1	0	0	0			1
52		Work load	11	11	11	11			
53									
54			Machine 1	Machine 2	Machine 3	Machine 4			
55			1	1	1	1			4

Figure 38 - Scenario 1 Demonstrator Configuration

Slack variable	0									
		0	0	0	0					
Parameters	Time it takes to execute each RPA task per machine									
	Tij	Machine 1	Machine 2	Machine 3	Machine 4		Machine 1	Machine 2	Machine 3	Machine 4
	1	28	28	28	28		0	0	28	0
	2	56	56	56	56		0	0	56	0
	3	88	88	88	88		0	0	88	0
	4	48	48	48	48		0	48	0	0
	5	6	6	6	6		0	0	0	6
	6	6	6	6	6		6	0	0	0
	7	6	6	6	6		0	0	0	6
	8	28	28	28	28		0	0	28	0
	9	56	56	56	56		0	0	0	56
	10	88	88	88	88		0	0	0	88
	11	48	48	48	48		0	0	48	0
	12	5	5	5	5		5	0	0	0
	13	28	28	28	28		0	0	28	0
	14	56	56	56	56		0	56	0	0
	15	88	88	88	88		0	0	88	0
	16	48	48	48	48		0	48	0	0
	17	24	24	24	24		0	0	0	24
	18	24	24	24	24		0	24	0	0
	19	24	24	24	24		0	0	0	24
	20	52	52	52	52		0	0	0	52
	21	68	68	68	68		0	68	0	0
	22	28	28	28	28		28	0	0	0
	23	24	24	24	24		0	0	0	24
	24	20	20	20	20		0	0	20	0
	25	3	3	3	3		0	0	0	3
	26	28	28	28	28		28	0	0	0
	27	56	56	56	56		0	56	0	0
	28	88	88	88	88		88	0	0	0
	29	48	48	48	48		0	48	0	0
	30	3	3	3	3		0	0	3	0
	31	3	3	3	3		0	0	0	3
	32	4	4	4	4		0	0	4	0
	33	2	2	2	2		2	0	0	0
	34	28	28	28	28		28	0	0	0
	35	56	56	56	56		0	56	0	0
	36	88	88	88	88		88	0	0	0
	37	48	48	48	48		48	0	0	0
	38	7	7	7	7		0	0	0	7
	39	14	14	14	14		0	0	14	0
	40	6	6	6	6		0	6	0	0
	41	28	28	28	28		0	28	0	0
	42	56	56	56	56		0	56	0	0
	43	88	88	88	88		88	0	0	0
	44	48	48	48	48		48	0	0	0
		319,9	691,6	850,5	820,4		457	494	405	293
	Number of machines	4								

Figure 39 - Data in Scenario 1 Demonstrator

Cost Machine 1	Cost Machine 2	Cost Machine 3	Cost Machine 4
0,7	1,4	2,1	2,8

Availability Machine 1	Availability Machine 2	Availability Machine 3	Availability Machine 4
480	600	960	1440

Figure 40 - Cost and Availability of Machines in the Scenario 1 Demonstrator.

APPENDIX 4

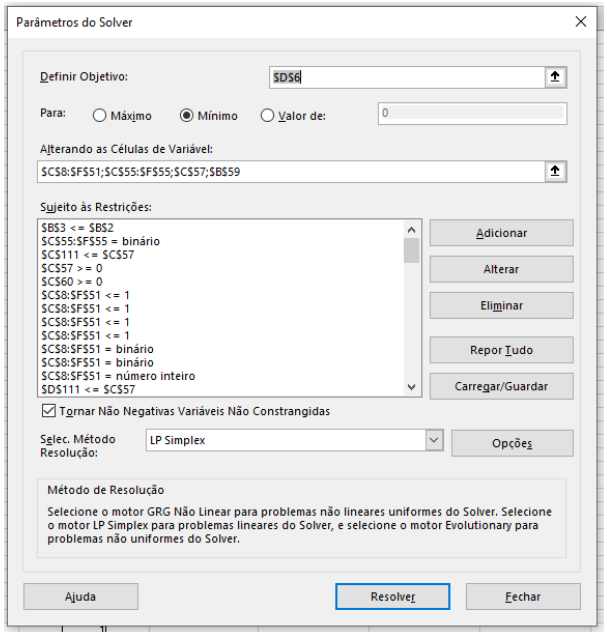


Figure 41 - Scenario 1 Demonstrator Solver Parameters.

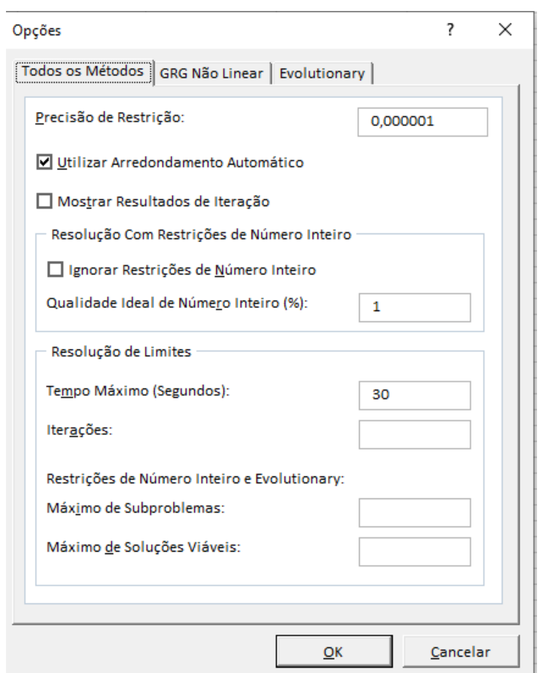
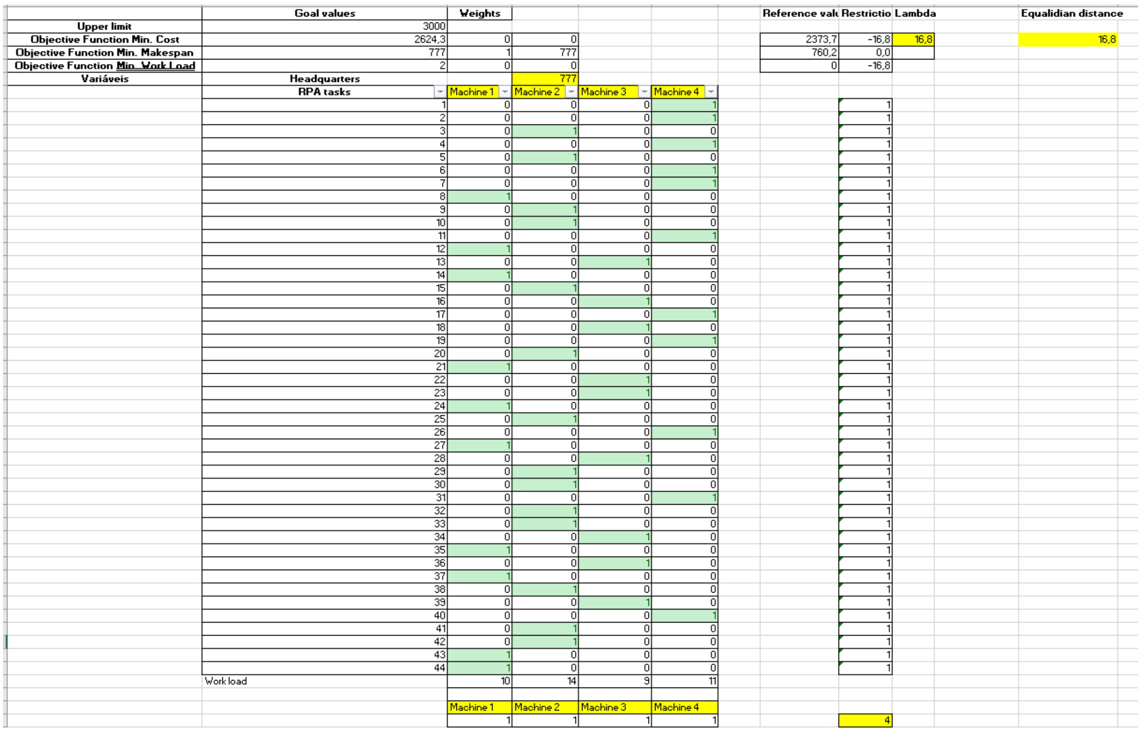


Figure 42 - Scenario 1 Demonstrator Solver Options.

APPENDIX 5



	Goal values	Weights				Reference valu	Restrictio	Lambda	Equalidian distance
Upper limit	3000								
Objective Function Min. Cost	2624,3	0	0			2373,7	-16,8	16,8	16,8
Objective Function Min. Makespan	777	1	777			760,2	0,0		
Objective Function Min. Work Load	2	0	0			0	-16,8		
Variáveis	Headquarters		777						
	RPA tasks	Machine 1	Machine 2	Machine 3	Machine 4				
	1	0	0	0	1		1		
	2	0	0	0	1		1		
	3	0	1	0	0		1		
	4	0	0	0	1		1		
	5	0	1	0	0		1		
	6	0	0	0	1		1		
	7	0	0	0	1		1		
	8	1	0	0	0		1		
	9	0	1	0	0		1		
	10	0	1	0	0		1		
	11	0	0	0	1		1		
	12	1	0	0	0		1		
	13	0	0	1	0		1		
	14	1	0	0	0		1		
	15	0	1	0	0		1		
	16	0	0	1	0		1		
	17	0	0	0	1		1		
	18	0	0	1	0		1		
	19	0	0	0	1		1		
	20	0	1	0	0		1		
	21	1	0	0	0		1		
	22	0	0	1	0		1		
	23	0	0	1	0		1		
	24	1	0	0	0		1		
	25	0	1	0	0		1		
	26	0	0	0	1		1		
	27	1	0	0	0		1		
	28	0	0	1	0		1		
	29	0	1	0	0		1		
	30	0	1	0	0		1		
	31	0	0	0	1		1		
	32	0	1	0	0		1		
	33	0	1	0	0		1		
	34	0	0	1	0		1		
	35	1	0	0	0		1		
	36	0	0	1	0		1		
	37	1	0	0	0		1		
	38	0	1	0	0		1		
	39	0	0	1	0		1		
	40	0	0	0	1		1		
	41	0	1	0	0		1		
	42	0	1	0	0		1		
	43	1	0	0	0		1		
	44	1	0	0	0		1		
	Work load	10	14	9	11				
		Machine 1	Machine 2	Machine 3	Machine 4				
		1	1	1	1		4		

Figure 43 - Scenario 2 Demonstrator Configuration.

	Makespan	777			
Slack variable	2				
		1	5	-6,68354E-14	2
Parameters	Time it takes to execute each RPA task per machine				
	Tij	Machine 1	Machine 2	Machine 3	Machine 4
	1	28	28	28	28
	2	56	56	56	56
	3	88	88	88	88
	4	48	48	48	48
	5	6	6	6	6
	6	6	6	6	6
	7	6	6	6	6
	8	28	28	28	28
	9	56	56	56	56
	10	88	88	88	88
	11	48	48	48	48
	12	5	5	5	5
	13	28	28	28	28
	14	56	56	56	56
	15	88	88	88	88
	16	48	48	48	48
	17	24	24	24	24
	18	24	24	24	24
	19	24	24	24	24
	20	52	52	52	52
	21	68	68	68	68
	22	28	28	28	28
	23	24	24	24	24
	24	20	20	20	20
	25	3	3	3	3
	26	28	28	28	28
	27	56	56	56	56
	28	88	88	88	88
	29	48	48	48	48
	30	3	3	3	3
	31	3	3	3	3
	32	4	4	4	4
	33	2	2	2	2
	34	28	28	28	28
	35	56	56	56	56
	36	88	88	88	88
	37	48	48	48	48
	38	7	7	7	7
	39	14	14	14	14
	40	6	6	6	6
	41	28	28	28	28
	42	56	56	56	56
	43	88	88	88	88
	44	48	48	48	48
		331,1	740,6	777	775,6
	Number of machines	4			

tempo tarefa

Machine 1	Machine 2	Machine 3	Machine 4
0	0	0	28
0	0	0	56
0	88	0	0
0	0	0	48
0	6	0	0
0	0	0	6
0	0	0	6
28	0	0	0
0	56	0	0
0	88	0	0
0	0	0	48
5	0	0	0
0	0	28	0
56	0	0	0
0	88	0	0
0	0	48	0
0	0	0	24
0	0	24	0
0	0	0	24
0	52	0	0
68	0	0	0
0	0	28	0
0	0	24	0
20	0	0	0
0	3	0	0
0	0	0	28
56	0	0	0
0	0	88	0
0	48	0	0
0	3	0	0
0	0	0	3
0	4	0	0
0	2	0	0
0	0	28	0
56	0	0	0
0	0	88	0
48	0	0	0
0	7	0	0
0	0	14	0
0	0	0	6
0	28	0	0
0	56	0	0
88	0	0	0
48	0	0	0
473	529	370	277

Figure 44 - Data in Scenario 2 Demonstrator.

Cost Machine 1	Cost Machine 2	Cost Machine 3	Cost Machine 4
0,7	1,4	2,1	2,8

Availability Machine 1	Availability Machine 2	Availability Machine 3	Availability Machine 4
480	600	960	1440

Figure 45 - Cost and Availability of Machines in the Scenario 2 Demonstrator.

APPENDIX 6

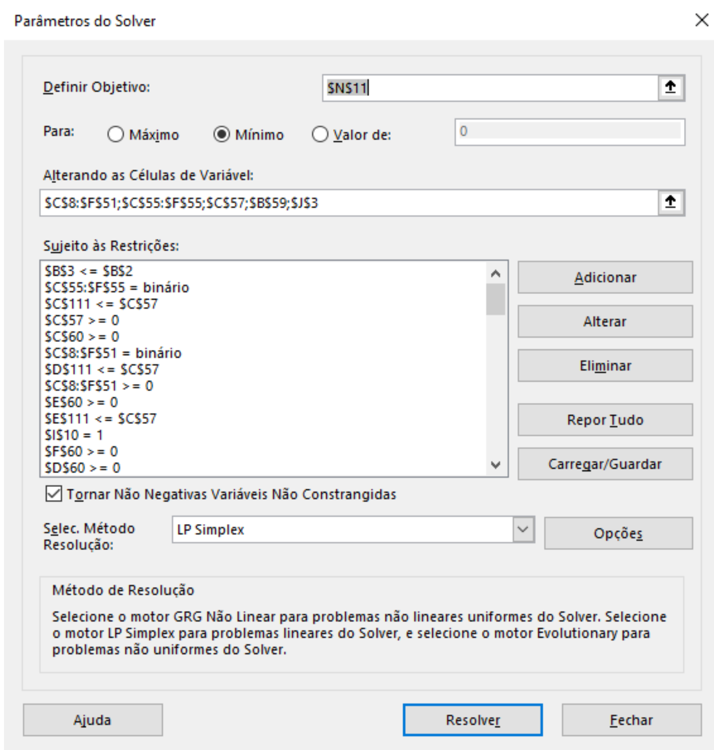


Figure 46 - Scenario 2 Demonstrator Solver Parameters

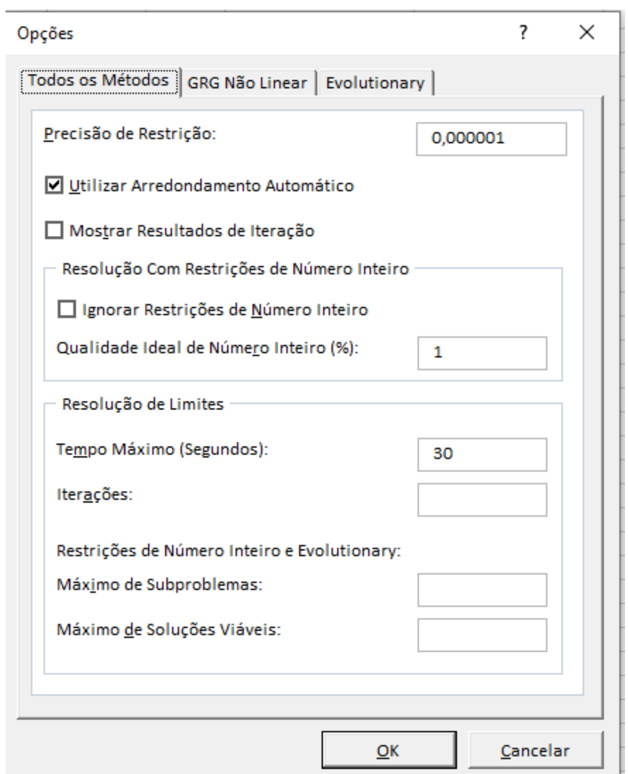


Figure 47 - Scenario 2 Demonstrator Solver Options