

Article

Sustainable Implementation of Robotic Process Automation Based on a Multi-Objective Mathematical Model

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Abstract: (1) Background: In this study on Robotic Process Automation (RPA), the feasibility of sustainable RPA implementation was investigated, considering user requirements in the context of this technology's stakeholders, with a strong emphasis on sustainability. (2) Methods: A multi-objective mathematical model was developed and the Weighted Sum and Tchebycheff methods were used to evaluate the efficiency of the implementation. An enterprise case study was utilized for data collection, employing investigation hypotheses, questionnaires, and brainstorming sessions with company stakeholders. (3) Results: The results underscore the significance of user requirements within the RPA landscape and demonstrate that integrating these requirements into the multi-objective model enhances the implementation assessment. Practical guidelines for RPA planning and management with a sustainability focus are provided. The analysis reveals a solution that reduces initial costs by 21.10% and allows for an efficient and equitable allocation of available resources. (4) Conclusion: This study advances our understanding of the interplay between user requirements and RPA feasibility, offering viable guidelines for the sustainable implementation of this technology.

Keywords: sustainability; robotic process automation; multi-objective optimization; mathematical model



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1. Introduction

The concept of sustainability has garnered growing international focus across various spheres, including the general public, academia, and the corporate realm. The World Commission on Environmental Development (WCED) defined sustainable development as the advancement that fulfills the present requirements while safeguarding the capacity of forthcoming generations to fulfill their own necessities [1]. The significance of societal concerns and the natural ecosystem for communities and enterprises has undergone a profound transformation over the last five decades. Corporate executives are increasingly recognizing the imperative to broaden their objectives beyond conventional financial anticipations. Sustainability endeavors to harmonize economic, societal, and environmental advancement, ensuring the well-being of both current and future generations [2].

Sustainability is a core concept that permeates all stages of this study, aiming to balance the benefits of automation with social, environmental, and economic considerations [3]. Robotic Process Automation (RPA) is a technology that involves the use of software to automate repetitive, low-value, rule-based tasks within a business process [4]. These tasks are typically routine and highly structured and require interaction with existing software systems [5]. However, in an increasingly sustainability-conscious business landscape, the implementation of RPA should be carefully evaluated to ensure that it is not only effective but also sustainable in the long run [5]. RPA can drive sustainability by optimizing tasks, reducing waste, and promoting greater energy efficiency in business activities [6]. RPA has emerged as an innovative technological solution that aims to optimize operational

efficiency, reduce costs, and enhance work quality through task automation [6]. In this context, the aim of this work is to propose a sustainable approach to RPA implementation using a multi-objective mathematical model.

In this work, a thorough review of the current state of research in sustainable RPA implementation was conducted, exploring key publications and proposed approaches. While several publications have addressed the topic of RPA, it is evident that there is a scarcity of publications linking the concepts of sustainability and RPA. There is a need for a more balanced scientific approach that takes into account not only efficiency and cost reduction but also employee impact, environmental preservation, and alignment with strategic company goals.

In the era of digital transformation, numerous companies are actively seeking innovative solutions to optimize their processes and enhance overall efficiency. One such solution is the implementation of Robotic Process Automation (RPA), a technology designed to automate repetitive and standardized tasks that were previously carried out by human beings. However, embracing RPA is far from a straightforward endeavor and presents substantial challenges. Within this context, a company resolved to introduce RPA within its administrative department, automating manual tasks and reallocating resources toward more strategic activities. Despite the initial anticipations of potential RPA benefits, such as heightened productivity, error reduction, and time savings, as the implementation progressed, a spectrum of challenges emerged. These included the substantial implementation costs and the intricacies associated with efficiently scheduling and executing various RPA activities. The company acknowledged the pivotal importance of encompassing the needs and priorities of stakeholders involved in the process, spanning from corporate managers to the administrative department's responsible team, and even extending to the employees who would interact with the automated robots. It was within this framework that the necessity arose to meticulously analyze the issue at hand and devise a solution tailored to the company's needs.

Given the issues, the central research question and research hypotheses that guided this study were formulated.

Central Research Question (CRQ):

CRQ: How do user requirements in the context of stakeholders affect decision making regarding the feasibility of RPA, and how can this relationship be integrated into a multi-objective model to evaluate the efficiency of sustainable RPA implementation?

Hypotheses (H):

H1. *What are the user requirements in the context of stakeholders that affect decision making regarding RPA feasibility?*

H2. *Integrating user requirements in the context of stakeholders into a multi-objective model allows for an efficient evaluation of the efficiency of sustainable RPA implementation.*

H3. *The proposed guidelines for effective and sustainable RPA implementation, based on the case study results, will be useful for organizations seeking to adopt RPA in a sustainable manner.*

The primary aim of this study is to develop a multi-objective mathematical model that allows for optimizing the implementation of RPA, taking into consideration the sustainability perspective of RPA users within the context of stakeholders in this technology. Through this model, the intention was to provide companies with a powerful tool to strategically evaluate and plan the implementation of RPA in their decision-making processes, in a sustainable way. The developed model was applied to a case study of a company that implemented RPA in an administrative department.

The main conclusions of this study can offer valuable insights into the benefits and challenges of sustainable RPA implementation. It is expected that these conclusions can guide companies in making informed decisions, aligning their strategic objectives with sustainability principles, and maximizing the benefits of RPA.

This study is organized as follows: in Section 2, a literature review on the topic under study is presented; in Section 3, the case study and data collection are presented; in Section 4, the proposed multi-objective model is presented; in Section 5, the implementation and results of a case study in an administrative department are presented; in Section 6, the discussion is presented; and finally, in Section 7, the conclusion is presented. This study ends with bibliographical references.

2. Literature Review

2.1. Sustainability and Robotic Process Automation

Sustainability refers to the ability to meet present needs without compromising the ability of future generations to meet their own needs. In other words, it is a principle that aims to balance economic, social, and environmental development in order to ensure that natural resources and social conditions are preserved and maintained over time [7]. Organizations have embraced sustainability to address their social responsibilities and comply with environmental legislation. It means a new paradigm for organizations, emphasizing the significance of businesses that prioritize their social, environmental, and economic responsibilities. These responsibilities have gained value in society and in the regulations that govern companies following this trend. Sustainability presents a challenge for many organizations, but overcoming this challenge relies on establishing good relationships with stakeholders, including customers, suppliers, employees, and society as a whole. Since the introduction of the term sustainability in business, more companies have emerged that incorporate sustainability into their activities, thereby enhancing their economic, environmental, and social objectives [8–11]. Organizations striving for sustainability should focus on three fundamental pillars: economic, social, and ecological [12–14]. A Special Issue on governance and sustainability [15] reinforces the value of the theme and emphasizes the importance of the word ‘sustainability’. It explains why sustainability has become the primary driver of innovation based on a study of sustainability initiatives involving 30 large corporations [16,17].

Technological advancements have revolutionized various sectors, and Robotic Process Automation (RPA) emerges as a promising solution for optimizing and streamlining business processes. In this chapter, the benefits of RPA and its impact on different sectors are explored. By providing a concise definition of RPA and a more engaging presentation, the aim was to capture the reader’s interest in the topic and its advantages [18].

Robotic Process Automation is a technology that enables the automation of rule-based, repetitive tasks through software robots [19]. These robots can mimic human actions in digital systems, performing activities such as form filling, data processing, and interaction with graphical interfaces [20].

The implementation of RPA is facilitated by specialized tools that allow the creation and management of robots [21]. These tools enable the capture of steps in a manual process, the creation of automated workflows, and the integration with existing systems. As a result, RPA can be deployed in an agile and flexible manner, delivering significant efficiency gains [22].

The benefits of RPA are extensive and directly impact organizations. By dividing these benefits into individual points, it is possible to emphasize each of them more clearly and emphatically. Recent studies have shown that RPA brings advantages such as increased operational efficiency, cost reduction, improved quality and accuracy, resource allocation for higher-value tasks, agility, and scalability [23].

2.2. Concepts about Production Planning and Scheduling Problems

Planning involves defining objectives, determining actions, and allocating resources to achieve desired outcomes. On the other hand, scheduling deals with sequencing activities or tasks within specific constraints. Integrating planning and scheduling enables efficient resource allocation, the minimization of costs, and the meeting of project deadlines [24].

Heuristic algorithms have been widely used to solve planning and scheduling problems. These methods employ intuitive rules and strategies to find near-optimal solutions within a reasonable time frame. Metaheuristic algorithms such as simulated annealing have been successfully applied to various planning and scheduling problems [25]. The authors of [26] proposed a hybrid metaheuristic algorithm that combines genetic algorithms and particle swarm optimization to solve a complex project scheduling problem.

Many planning and scheduling problems can be formulated as constraint satisfaction problems (CSPs), where the goal is to find a feasible assignment of values to variables that satisfy a set of constraints. Backtracking, constraint propagation, and local search techniques have been widely employed to solve CSPs [27]. Researchers have applied CSPs to vehicle routing problems, resource allocation, and job shop scheduling [28].

Another way to solve planning and scheduling problems is through multi-objective approaches. In recent years, multi-objective optimization has gained significant attention due to its ability to address complex decision-making problems involving conflicting objectives. Simultaneously, planning and scheduling have emerged as crucial components in various domains, including manufacturing, transportation, and project management. This chapter provides a comprehensive review of the literature on multi-objective problems and explores the concepts of planning and scheduling in these contexts.

Multi-objective optimization deals with problems that have multiple conflicting objectives. Its aim is to find a set of solutions, known as the Pareto front, that represents the trade-offs between these objectives. The application of multi-objective optimization techniques has yielded valuable insights in diverse fields. For example, [29] investigated multi-objective optimization in sustainable supply chain management and demonstrated its effectiveness in cost reduction and environmental impact reduction.

Evolutionary algorithms, such as genetic algorithms and particle swarm optimization, have been extensively used to solve multi-objective problems. These algorithms employ a population-based approach, simulating natural evolution to search for optimal solutions. In [30], the authors proposed the widely known NSGA-II algorithm, which combines non-dominated sorting and crowding distance to enhance the diversity and convergence of solutions.

Selecting a solution from the Pareto front requires decision-making methods that consider the decision-maker's preferences. Aggregation methods, such as the Weighted Sum and ϵ -constraint, and interactive methods, like reference-point-based methods and visual analytics, have been explored [31]. In [32], the hyper-volume indicator was introduced, providing a quantitative measure of the quality of a set of solutions, enabling informed decision making.

This chapter provided an overview of the literature on explored planning and scheduling concepts and the application of multi-objective optimization techniques, such as evolutionary algorithms. Additionally, heuristic approaches and constraint satisfaction problems have been effective in solving planning and scheduling problems. The integration of these concepts and techniques contributes to enhanced decision-making processes and resource allocation in various domains.

2.3. Identification and Analysis of Relevant Articles

In order to understand the current state of scientific work developed in the subject under study and evaluate the suitability of the research proposal, it has become essential to conduct a literature review. This approach allows us to explore existing models and frameworks, as well as identify gaps and direct contributions more effectively. The literature review is a meticulous process that involves searching and analyzing a variety of academic sources, such as scientific articles, theses, dissertations, and other relevant works. This extensive research enables us to understand the different approaches taken by renowned researchers and the key findings achieved thus far.

The review on the subject of this chapter was based on the analysis of a carefully selected set of data sources considered relevant to the research question. The pertinent

information presented in this article was obtained from a collection of contributions by renowned authors who have addressed the topic or some aspect of it. The collection of analyzed articles was sourced from the online database “B-on,” which was chosen for its ability to provide access to the complete content of a wide range of scientific publications in indexed journals, as well as publications in internationally indexed scientific conferences in the ISI WOS and/or Scopus systems. “B-on” is among the most comprehensive databases, encompassing thousands of peer-reviewed journals from various scientific fields. Researchers can access most of the well-known international scientific databases through the online scientific library “B-on” of the Portuguese Foundation for Science and Technology, which was used to carry out the underlying search process for this work based on the three groups (Group 1, Group 2, and Group 3) shown in Table 1.

Table 1. Groups 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” Or “Structure” Or “Multi-objective” or “Planning and scheduling”	“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 Keywords (KW) or the Abstract (AB) of the intended sets. Table 2 expresses the number of articles found in each research test.

Table 2. Research tests performed through the “B-on.”

	Title	OR	Keywords (KW)	OR	Abstract (AB)	
Set 1	(Group 1 AND Group 2 and Group 3) $n = 0$	OR	(Group 1 AND Group 2 AND Group 3) $n = 1$	OR	(Group 1 AND Group 2 AND Group 3) $n = 170$	$n = 171$
Set 2	(Group 1 AND Group 2) $n = 380$	OR	(Group 1 AND Group 2) $n = 114$	OR	(Group 1 AND Group 2) $n = 7626$	$n = 8120$
Set 3	(Group 1 AND Group 3) $n = 11$	OR	(Group 1 AND Group 3) $n = 17$	OR	(Group 1 AND Group 3) $n = 635$	$n = 663$

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 3.

Table 3. Publications obtained through the B-on, after the application of some filters.

	Set 1	Set 2	Set 3
Initial result:	$n = (0; 1; 170)$	$n = (380; 114; 7626)$	$n = (11; 17; 635)$
1—Restrict to Peer-Reviewed	$n = (0; 1; 125)$	$n = (237; 77; 5533)$	$n = (9; 12; 347)$
2—Type of fonts: Academic Journals; Conference Materials; Books	$n = (0; 1; 125)$	$n = (237; 77; 5533)$	$n = (9; 12; 346)$
3—From 2000 to 2023	$n = (0; 1; 123)$	$n = (197; 69; 4799)$	$n = (9; 12; 337)$
4—Language: English	$n = (0; 1; 120)$	$n = (191; 69; 4704)$	$n = (9; 12; 324)$
5—Restrict to Full Text	$n = (0; 0; 107)$	$n = (164; 58; 3797)$	$n = (9; 11; 286)$

After applying the filters, a reading of the title, key terms, and abstract of each article was conducted to determine which articles were directly relevant to the research. After the initial search, a total of 8432 papers were obtained. Upon applying the filters, a total of 4432 articles remained, out of which only 19 were aligned with the research theme. One of the reasons for the low number of relevant papers is that most of them focused on evaluating the formation of a collaborative network, which is beyond the scope of this study. It is important to note that assessing the formation of a network is different from evaluating an organization's participation or integration within a network. Figure 1 illustrates a flow diagram depicting the literature search process and the screening methodology employed in this research work.

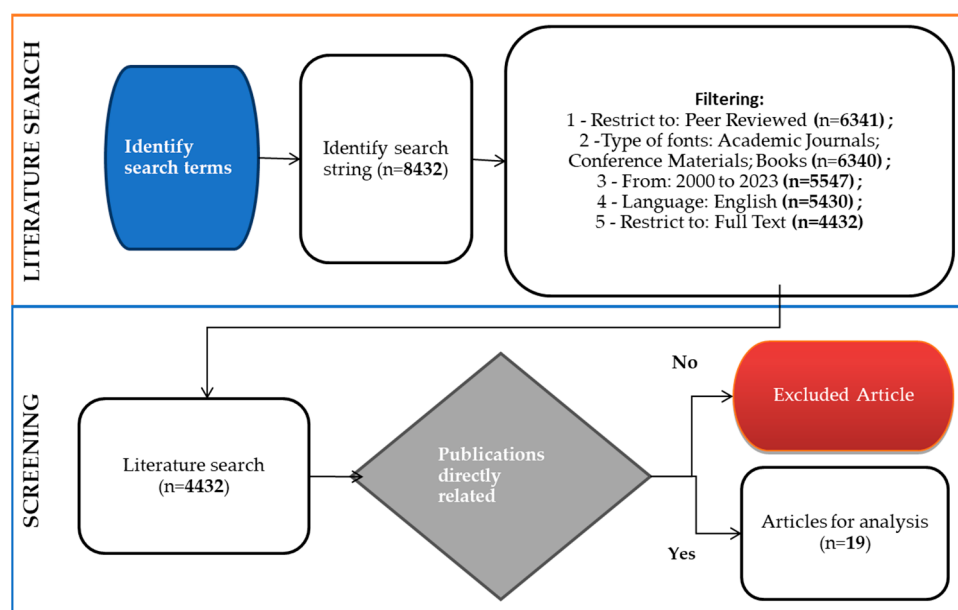


Figure 1. Flow diagram of literature search and respective screening, adapted from [33].

Summary of Review Findings

In this section, the synthesis and analysis of the articles are presented. Data about the articles are presented, which were considered the most relevant on the topic focused on in this work. Table 4 presents the 19 articles found and the themes of the identified models.

Table 4. Identified articles and the respective themes of the models found.

	Decision Support Model for Implementing RPA	Decision Support Template for Selecting RPA Tool	RPA Financing Return Assessment Model	RPA Monitoring Assessment Model
[34]		X		
[35]	X			
[36]			X	
[37]			X	
[38]	X			
[39]	X			
[40]				X
[41]	X			

Table 4. Cont.

	Decision Support Model for Implementing RPA	Decision Support Template for Selecting RPA Tool	RPA Financing Return Assessment Model	RPA Monitoring Assessment Model
[42]	X			
[43]	X			
[44]	X			
[45]	X			
[46]	X			
[47]			X	
[48]		X		
[49]	X			
[50]				X
[51]	X			
[52]	X			
[This work]	X	X	X	X

A literature review was carried out with the aim of identifying relevant studies belonging to the research topic. As a result of this review, Table 4 was compiled, which presents the various themes covered by the models developed and their corresponding associated works. Each of the objectives of the mentioned works is demonstrated through a brief explanation.

The following text presents the main objectives of each of the works. Article [34] has the primary objective of proposing a strategy for the use of RPA in the accounting and finance services of a company, identifying opportunities, benefits, and challenges of RPA implementation. Dissertation [35] aims to identify and explore the benefits of implementing RPA in the banking sector processes. Work [36] aims to develop a definition of Robotic Process Automation, identify management aspects in Polish companies, and create a Robotic Process Automation management model. Article [37] highlights the potential of process automation with RPA, proposing a system of automatable indicators and providing decision support to maximize the return on investment. Project [38] aims to design a customized robot for the processes of the Heliotec company and determine the feasibility of RPA implementation based on technical, economic, and organizational analyses. The objective of work [39] is to perform Robotic Process Automation through an advanced process analysis model. The objective of work [40] is to develop an evaluation framework based on thirteen criteria for process analysis, applying it to real data. Article [41] provides perspectives on the improvements and deteriorations achieved in RPA projects in the automotive industry, highlighting that the promised benefits are not always achieved in practice. In [42], a theoretical model is proposed for implementing RPA in higher-education institutions. The dissertation [43] proposes a framework for evaluating the fundamental factors for successful RPA implementation, based on a literature review on information technology implementation. Research [44] conducts a Delphi study for RPA professionals to evaluate and adjust specific criteria in the choice of processes to be automated. Using design science as a research model, [45] proposes a system that assists in the identification of process automation. The study [46] develops a framework for RPA project implementation, with variable stages and flexible guidelines applicable in different corporate environments. The research [47] investigates the financial risks and barriers in adopting RPA in the beef industry, aiming to achieve sustainability. Article [48] identifies three important decisions for RPA Managers: selection of internal versus external resources, on-premises versus

cloud deployment, and proprietary tools versus open source solutions. The objective is to analyze the applicability of these decisions in service companies. The study [49] proposes the application of RPA in the auditing field, aiming to free auditors from repetitive tasks and allow them to focus on activities that require professional judgment. The study [50] aims to develop an analytical evaluation framework for selecting RPA solutions, providing useful criteria and a checklist for successful RPA implementation. The research [51] aims to develop a process evaluation model to identify suitable business processes for RPA implementation. The work [52] conducts a literature review to identify and analyze RPA implementation models.

The most frequently addressed theme among these works is the decision support model for implementing RPA.

However, when comparing the contributions of the work with existing ones, significant factors and innovations were identified. In general, the research stands out for offering, within a single model, the other themes identified in Table 4, including a new theme for which there is no model or work in the literature that addresses this topic: the project allocation model RPA. This comprehensive approach sets this work apart from others, as they often only focus on one specific aspect of RPA use.

The motivation behind developing a new model arises from the perception of a gap in the existing literature. Although some relevant works on RPA were found, it was found that many of them do not address fundamental aspects for a successful and sustainable implementation. Based on this literature review, it was observed that this work is justified by its scope and integration of multiple fundamental aspects for the sustainable implementation of RPA. This perspective will enable organizations to have a more complete understanding of the challenges and opportunities involved in this process, as well as clear guidance for making strategic decisions.

The validity of this work lies in proposing a comprehensive and structured decision support model that is capable of providing clear and well-grounded guidance for the sustainable implementation of RPA in different organizational contexts. In light of the above, this work makes a significant contribution to the field by offering a comprehensive, structured, and applicable model aimed at supporting organizations in successfully implementing RPA sustainably, considering the existing challenges and opportunities.

This model addresses RPA implementation, assists in the selection of RPA tools, aids in assessing RPA financing, and supports the evaluation of RPA monitoring. The great strength and innovation of this model lie in encompassing all these topics within a single framework, while also addressing a new theme for RPA technology, which is RPA project allocation. More specifically, it can be observed that the model, in its response to the implementation of RPA, addresses issues such as energy efficiency analysis, paperless RPA automation, workforce impact, ethical considerations (such as data privacy and security), the engagement of all stakeholders, cost–benefit analysis, scalability, and flexibility (choosing a scalable and adaptable RPA solution to meet evolving business needs).

By considering these environmental, social, and economic aspects, organizations can ensure that the implementation of RPA aligns with sustainable practices and positively contributes to the overall well-being of businesses and their stakeholders. Based on the requirements that were considered for the model, which is presented later in this article, it was realized that the model provides solutions for a sustainable implementation of RPA that meet the needs of organizations. The other analyzed and presented works are solely based on one of the studied themes, highlighting the innovation, efficiency, and effectiveness of the model in relation to the sustainable implementation of RPA.

Next, to support the model, a practical case study of a company is presented. It details the case study and the foundations on which it was developed and implemented, as well as the advantages resulting from this work.

3. Case Study and Data Collection

3.1. Case Study

In the era of digital transformation, many companies are seeking innovative solutions to optimize their processes and increase efficiency. One of these solutions is the implementation of Robotic Process Automation (RPA), a technology designed to automate repetitive and standardized tasks previously performed by humans. However, adopting RPA is not a simple task and poses significant challenges.

A company has decided to implement RPA in its administrative department. As a leader in its industry, the company faced significant challenges due to the large volume of repetitive and standardized tasks manually performed by its employees. The introduction of RPA helped automate these tasks and free up resources for more strategic activities. Initially, the company was excited about the potential benefits of RPA, such as increased productivity, fewer errors, and time savings. However, as the implementation progressed, some challenges emerged.

One of the main challenges this company faced was the high cost of RPA implementation. They invested a significant amount of money to acquire the technology and train their team to work with it. However, they realized that even with the automation of various tasks, they still struggled to optimize and manage the resources associated with RPA in the best possible way.

The company had a diverse set of RPA activities that needed to be scheduled and executed. These activities encompassed a variety of administrative tasks such as data processing, report generation, document management, and internal communication. Each activity had its own execution time, and in addition to that, there were independent setup times for the machines and task sequencing. Efficiently organizing all these activities, minimizing wait times, meeting deadlines, and balancing the workload of the machines were real challenges.

During the RPA implementation, the company recognized the importance of considering the needs and priorities of stakeholders involved in the process. The key stakeholders included company managers, the team responsible for the administrative department, and even the employees who would collaborate with the robots.

It was in this context that the need arose to analyze the problem and find a solution for the company.

3.2. Data Collection

Data collection is a fundamental step in any research or case study. In this text, this section explains how the data collection process was conducted to address a specific problem within the company, using questionnaires as the primary instrument. The objective was to gather data for the case study in order to gain a better understanding of the problem and build a model capable of finding solutions for that specific case.

A company decided to implement Robotic Process Automation (RPA) in its administrative department. One of the main challenges faced by this company was the high cost of RPA implementation. However, it was realized that even with the automation of various processes, it was necessary to optimize and manage the resources associated with RPA in the best possible way. To achieve this, a questionnaire was chosen as the method of data collection due to its efficiency in obtaining information quickly and comprehensively.

Before initiating the data collection, it was necessary to develop a detailed questionnaire that covered various aspects related to the problem at hand. The questionnaire was designed to address issues such as identifying user requirements in the context of stakeholders, which affect decision making regarding the feasibility of RPA, as well as how they influence the efficiency of sustainable RPA implementation. Additionally, a section of the questionnaire was exclusively dedicated to the RPA Manager, containing questions about the total number of activities automated by RPA, average execution time, daily cost of resources, and details of each machine acquired by the company. These questions are directed toward the RPA Manager.

The next step involved defining the target audience for data collection. In this case, all users within the context of stakeholders who affect decision making regarding the feasibility of RPA in the company were considered as 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 the questionnaire was developed, its distribution took place. A paper format was chosen for this purpose. Employees received the paper questionnaire delivered 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 emphasized that the purpose of the questionnaire was to obtain honest and constructive feedback without any negative impact on their careers.

A specific deadline of one week was set for the employees to respond to the questionnaire to ensure efficient data collection. Additionally, if any doubts arose during the questionnaire completion, employees could ask the person responsible for distributing the questionnaires for clarification on any 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. Quantitative data analysis was performed.

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

The report was shared with the company's senior management and the RPA team for the purpose of discussing it in meetings. The requirements to be implemented were identified, and an action plan was developed to analyze the before and after of the implementation of those requirements at the end of the project.

Data collection through questionnaires proved to be an effective approach to gather valuable insights into the studied problem within 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 sustainable RPA implementation.

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

By involving a diverse range of participants, including stakeholders and the RPA team, the questionnaire captured different perspectives and experiences related to the problem at hand. This comprehensive approach ensured that the collected data reflected the overall organizational context and provided valuable insights into the various aspects of RPA implementation.

The assurance of confidentiality and anonymity in the questionnaire responses proved crucial in fostering honest and unbiased feedback from the participants. By emphasizing the protection of identities and the absence of any negative impact on careers, employees felt more comfortable providing candid responses, resulting in 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. A specific deadline was set for responses, and participants had the opportunity to seek clarifications, ensuring a comprehensive set of responses.

The compilation and organization of 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 foundation for the development of a detailed report that summarized the findings and presented actionable recommendations.

The report, shared with the company's senior management and the RPA team, served as a 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 the before and after of the implementation of the 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 gathering valuable information about the studied problem within the company. The comprehensive insights obtained from the questionnaire responses facilitated a deeper understanding of the problem, informed decision making, and supported the sustainable implementation of RPA.

The following are the questions and their respective answers from the questionnaire:

Questions 1 to 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 have been implemented currently?

A: 44 RPA activities

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

A: The answer to this question is presented through a graph analyzing the times, in minutes, of the company's 44 RPA activities, in Figure 2.

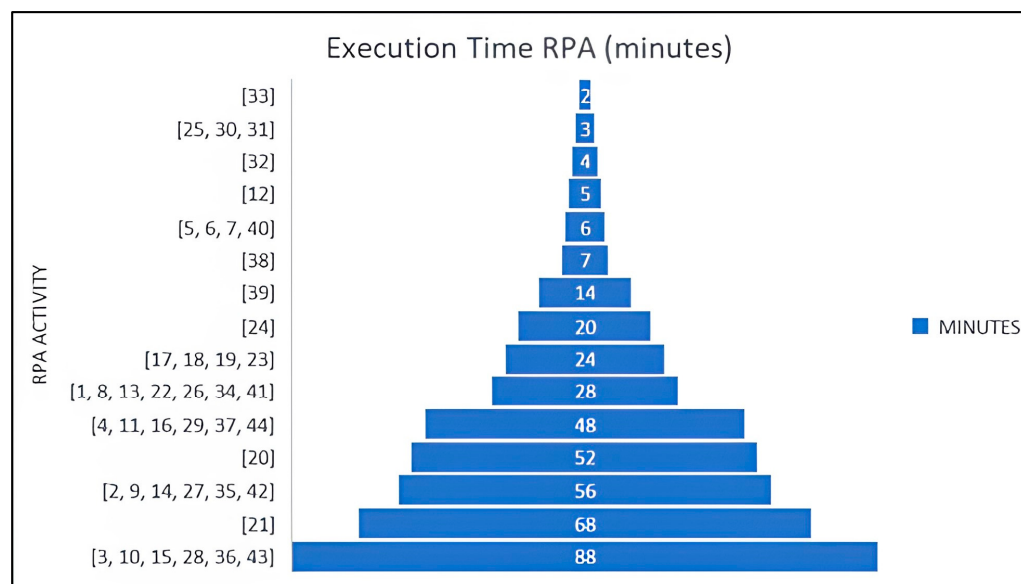


Figure 2. Execution times of RPA activities.

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

A: 3000 monetary units (m. u.)

4. How many RPA machines have been acquired in the company?

A: 4 RPA machines

5. What is the daily available time of each RPA machine and what is the daily cost?

A: The answer to this question is presented through a Table 5 with the cost and availability of each RPA machine.

Table 5. Daily cost and daily availability of RPA machines.

	RPA Machines Cost per Day (Monetary Units)	Availability RPA Machines per Day (Min)
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 answered the questions. In other words, the questionnaire distributed to the individuals started from question 6.

6. Are you part of the company's RPA team?
 - (a) Yes (10)
 - (b) No (20)
7. Regarding costs, how important is this factor in the implementation of RPA?
 - (a) Extremely important. (20)
 - (b) Important. (5)
 - (c) Neutral. (5)
 - (d) Less important.
 - (e) It is 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 are energy efficient similar to manual/traditional processes.
 - (d) I don't know enough to answer. (8)
9. What would be the possible impacts on employees with the implementation of RPA in the current company?
 - (a) Reduction in the number of employees. (2)
 - (b) Redirecting employees to more strategic tasks. (10)
 - (c) Improvement of working conditions. (8)
 - (d) I don't know enough to answer. (10)
10. In what ways do you think RPA automation can help reduce paper consumption in the enterprise?
 - (a) Eliminating the need for printed documents. (5)
 - (b) Automating processes to reduce waste.
 - (c) Minimizing errors that lead to rework and unnecessary use of resources. (5)
 - (d) All of the above options. (20)
11. Do you believe that the sustainable implementation of RPA 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 for allocating RPA projects to machines in terms of effectiveness?
 - (a) Highly effective.
 - (b) Moderately effective. (2)

- (c) Ineffective. (13)
 - (d) Not sure. (15)
13. How do you rate 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 the project completion time does not significantly affect the results. (2)
 - (d) Not sure about the importance of completion time. (3)
14. What is the main objective of implementing RPA in an organization?
- (a) Completely replace employees with robots to reduce costs. (3)
 - (b) Improve operational efficiency by automating repetitive tasks. (23)
 - (c) Increase the complexity of business processes to achieve more advanced results.
 - (d) Expand the current workforce by hiring robots. (4)

The questions and hypotheses were devised and selected through a meeting with the Business Line Directors and the RPA Manager. After answering the questions in the questionnaire, a brainstorming session was held with the Line of Business Directors and the RPA Manager, the same people who asked the questions, in order to analyze the responses and identify the necessary requirements to be taken into account in the blueprint for sustainable implementation of RPA. The use of brainstorming as a technique to select stakeholder requirements based on responses to a questionnaire can be effective since brainstorming is known to stimulate the generation of creative ideas. By bringing a group of people together to discuss the survey results, it is possible to obtain a wide range of perspectives and insights that can lead to the identification of relevant and innovative requirements [53]. Brainstorming involves the active collaboration and involvement of stakeholders, allowing them to express their opinions and contribute to the discussion. This creates a sense of belonging and engagement, which can increase the likelihood that the identified requirements are relevant and meet the real needs of stakeholders [54]. Brainstorming is an agile technique that allows the rapid generation and evaluation of ideas, and this was verified in the process. By bringing a group of people together to discuss survey results, you can perform real-time analysis of the responses and identify patterns or gaps in the requirements. This facilitates decision making and the selection of the most relevant requirements [55]. The use of collective intelligence is also seen. Brainstorming capitalizes on the collective intelligence of the group, allowing different perspectives, knowledge, and experiences to be shared. By discussing survey results in a collaborative environment, it is possible to gain valuable insights that may not have been considered initially. This enriches the quality of the identified requirements [56]. Another important point is the facilitation of communication and mutual understanding: Brainstorming promotes open communication and the exchange of ideas between participants. By discussing the results of the survey together, it is possible to clarify doubts, deepen understanding, and resolve any conflicts or discrepancies. This contributes to building consensus and a mutual understanding of stakeholder requirements [57]. Overall, the use of brainstorming as a technique to select stakeholder requirements based on survey responses is justified by its ability to generate creative ideas, promote stakeholder collaboration, facilitate the rapid generation and evaluation of ideas, harness collective intelligence, and facilitate communication and mutual understanding. This approach can help ensure that the selected requirements are comprehensive and relevant and meet the needs of the stakeholders involved. From the previously presented questions, there were some questions for which the following analyses were presented, in order to present and list the requirements selected by the stakeholders and their justification. In addition, for the model, the data referring to the first six questions were used, including the data in Figure 2, which represent the times of the RPA activities; the data in Table 5, which represent the availability of the RPA machines; and, finally, the data in Table 5, which represent the costs associated with each of the RPA machines.

Question 7 (*“Regarding costs, how important is this factor in the implementation of RPA?”*) reveals the importance attributed to costs in the implementation of RPA. The answers can be used to highlight the relevance of this objective, demonstrating the concern with the reduction in costs associated with the implementation of RPA.

Question 11 (*“Do you believe that the sustainable implementation of RPA can improve team productivity?”*) can be used to justify the objective of minimizing the average workload. The responses will provide insights into the participants’ perception of RPA’s ability to improve team productivity, which is directly related to reducing the average workload.

Question 12 (*“How would you rate the current process for allocating RPA projects to machines in terms of effectiveness?”*) provides insights into the current effectiveness of allocating RPA projects to machines. Based on the responses, you can justify the importance of this objective, highlighting the need to improve allocation to increase operational efficiency.

The importance of the objective of minimizing the makespan of RPA projects can be inferred based on the answers to **question 13** (*“How do you rate the importance of minimizing the time required to complete automation projects?”*). The answers will indicate the participants’ perception of the importance of reducing the time needed to complete automation projects, which is related to the makespan concept.

In this way, the four objectives that were selected by stakeholders as the main ones to be considered in the model can be presented: allocation of RPA projects to machines; cost minimization; makespan minimization; minimization of the average workload; these objectives pertain to RPA features and projects.

These requirements were selected based on the answers to the other questions and also taking into account the operational result of the technology, referring to the pillars of sustainability.

For the requirement of allocating RPA projects for machines, two pillars of sustainability (economic and environmental) were considered.

- **Economic pillar:** By allocating RPA projects more efficiently, minimizing machine downtime, it is possible to increase productivity and operational efficiency, resulting in a better allocation of the organization’s financial resources.
- **Environmental pillar:** The efficient allocation of RPA projects to machines can reduce the unnecessary consumption of energy and resources, contributing to the reduction in carbon emissions and the more sustainable use of natural resources.

For the requirement of minimizing costs, two pillars of sustainability (economic and social) were considered.

- **Economic Pillar:** Minimizing costs in implementing RPA can lead to a more efficient allocation of the organization’s financial resources, freeing up funds for investments in sustainable practices and initiatives in other areas.
- **Social pillar:** Cost reduction can allow the organization to adopt a more socially responsible approach, such as protecting existing jobs, improving working conditions, and redirecting employees to more strategic tasks.

For the requirement of minimizing the makespan, two pillars of sustainability (economic and social) were considered.

- **Economic pillar:** By minimizing the time required to complete automation projects, the organization can improve operational efficiency, reduce costs, and increase productivity, resulting in better financial performance.
- **Environmental pillar:** By reducing makespan, less resources are used, such as energy and paper, in addition to a decrease in carbon emissions associated with the automation process.

For the requirement of minimizing the average workload, two pillars of sustainability (economic and social) were considered.

- **Social Pillar:** By reducing the average workload of employees, the sustainable implementation of RPA can improve work–life balance, promote employee well-being, and contribute to a healthy work environment.
- **Economic pillar:** Reducing the average workload can increase the productivity and efficiency of the team, resulting in a better allocation of the organization’s financial resources and an increase in profitability.

4. Proposed Multi-Objective Optimization Model

The proposal for a multi-objective mathematical optimization model was presented here, which aims to address the problem of production planning and scheduling in the context of the 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 department. The three objectives that were presented include minimizing the machine cost, minimizing makespan (total execution time), and minimizing the machine workload balance. To verify the results of this model, Excel Solver was used based on the mathematical model presented below.

4.1. Mathematical Formulation

This section presents some mathematical formulations for building the proposed model.

4.1.1. 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).

4.1.2. Model (Constraints and Objective Functions)

Constraints:

1. Each task must be scheduled on exactly one machine:

$$\sum_{j=1}^m x_{ij} = 1, \forall i \in \{1, 2, \dots, n\} \quad (1)$$

2. Each machine can execute only one task at a time:

$$\sum_{i=1}^n x_{ij} \leq 1, \forall j \in \{1, 2, \dots, m\} \quad (2)$$

Objective functions:

3. The variable makespan is defined as the total completion time of tasks:

$$\text{Minimize makespan : } \sum_{i=1}^n \sum_{j=1}^m x_{ij} \times T_{ij} \quad (3)$$

4. The cost variable is defined as the sum of costs of all scheduled tasks:

$$\text{Minimize cost : } \sum_{i=1}^n \sum_{j=1}^m x_{ij} \times C_{ij} \quad (4)$$

5. The average workload is defined as

$$\text{Minimize average workload : } \sum_{j=1}^m \left(\sum_{i=1}^n x_{ij} \times T_{ij} \right) + (\text{total_machine_time} - \text{defined_value}) \quad (5)$$

4.2. Scheduling Methods

The model presented here used scalarizing methods. Initially, the sum of weights method is applied, and then the model is evolved by applying 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 [58,59]. 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 [60,61]. Mathematically, the formula can be expressed as Equation (6):

$$\sum (\text{Criterion}_i \times \text{Weight}_i) \quad (6)$$

In Equation (6), “*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 enabling a more informed and justified decision-making process based on the preferences of the decision-makers.

In this work, the Tchebycheff [62] method is applied to solve the multi-objective optimization model. The Tchebycheff method, also known as the 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 is formulated and presented in Equation (7):

$$\min \max [w_i | f_i(x) - z_i^* |] \quad (7)$$

It has been verified that the weighting coefficients for objective *i* (*w_i*) and the components of a reference point (*z_i*) assume a small positive value [62]. Then, Equation (8) associated with the method is also presented:

$$\begin{aligned} &\min \lambda \\ &\text{s.t. } w_i (f_i(x) - z_i^*) - \lambda \leq 0 \end{aligned} \quad (8)$$

In this study, an optimization problem was used to solve a multi-objective optimization problem as described.

Next, the notation used in the model was checked.

4.3. Weight Assignment to Objectives and Tested Combinations

In this subchapter, detailed information is provided on how the weights were assigned to the objectives of the multi-objective model, and the combinations that were tested

are presented. The weights were determined based on the relative importance of each objective and the objective to minimize cost, makespan, and average workload. By testing different combinations, it is possible to evaluate the model's performance under various objective weights.

The weights were assigned incrementally, ranging from 0 to 1 with increments of 0.10. This approach allowed us to explore a total of 66 possible weight combinations for the three objectives. Each of the rows in the table represents one of the examples of weight combinations. The total sum must add up to 1. For example, weight 1 was assigned to one of the objectives and 0 to the other two objectives. Subsequently, the total value of 1 was distributed among the weights of each of the objectives. The table below (Table 6) illustrates the tested combinations, where "weight objective 1", "weight objective 2", and "weight objective 3" represent the assigned weights for the cost, makespan, and average workload objectives, respectively:

Table 6. 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 weight combinations facilitate a thorough analysis of the results, enabling us to identify the most efficient solutions for each individual objective as well as the overall set of objectives.

In the next subchapter, the results obtained by applying the multi-objective model using the mentioned weight combinations are presented. Emphasis is placed on the non-dominated solutions found, and performance evaluation graphs are presented to better illustrate the results.

5. Implementation and Results to Case Study in an Administrative Department

5.1. Implementation Details

The developed mathematical model was executed using Microsoft Excel from Office LTSC, utilizing the same configuration as an Intel CORE i7 vPro 2.2 GHz computer with 8 GB of memory. The model was implemented 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 necessary data for the problem were inputted into a data spreadsheet, organized according to the problem specifications and identified constraints. The model implementation took place within the Excel spreadsheet, where variables and constraints were defined

based on the problem requirements. Mathematical formulas were developed accordingly, taking into account the problem specifications and identified constraints.

To ensure the quality and efficiency of the solution, specific configurations were adopted in the Excel Solver. The Solver was set with a maximum time limit of 30 s for the calculation execution. A constraint precision of 0.000001 was required, meaning that the constraints had to be satisfied with a very small margin of error. Additionally, an ideal quality integer value of 1 was set, indicating that the optimal solutions had to 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 close enough 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 require limits on variables and establish a mutation rate of 0.075. The LP Simplex resolution method was used for selection. Unconstrained variables were set as non-negative.

These configurations were applied during the execution of the mathematical model using the Excel Solver. Multiple tests were conducted to ensure the robustness and efficiency of the model, and the results were analyzed and validated to meet the expectations and requirements of the problem under study.

The utilization 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 for the given problem.

To visualize and communicate the results obtained from the execution of the mathematical model, charts were developed using the powerful charting capabilities available in Microsoft Excel. The Excel charting tool offered a wide range of visualization options, allowing for a clear and precise representation of the results. Advanced formatting and customization features were utilized to create visually appealing and highly informative visualizations.

These charts played a vital role in communicating the results and supporting decision making based on insights derived from the implemented mathematical model.

5.2. Results

Now, this section explains the results obtained from the application of the multi-objective model using the aforementioned weight combinations. In this section, the advantages of the evaluation methods used are discussed, namely the Weighted Sum method and the Tchebycheff method, and the suitability of each of these methods for the problem in question is addressed.

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 assigned 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, valuable insights were gained into the performance of the multi-objective model, and high-quality solutions were identified, considering the defined objectives.

In the following figures (Figures 3 and 4), the results achieved with each method were compared, their characteristics were compared, and their suitability for the problem in question was evaluated. 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. The blue bubbles on a three-dimensional Pareto curve chart represent the tasks or activities that make up a process or system. The size of the blue bubbles is proportional to the work load of each task. In the graphs that show these blue bubbles, the X axis represents the cost, the Y axis represents the makespan and the size of the bubbles represents the work volume. Thus, the larger blue bubbles represent tasks that have a greater volume of work and, therefore, a greater impact on the cost and makespan of the process or system. The Pareto curve is a useful tool for identifying the tasks or activities that have the greatest impact on a process or system. From the analysis of the Pareto curve, it is possible to take measures to optimize the process or system, focusing on the tasks or activities that have the greatest impact.

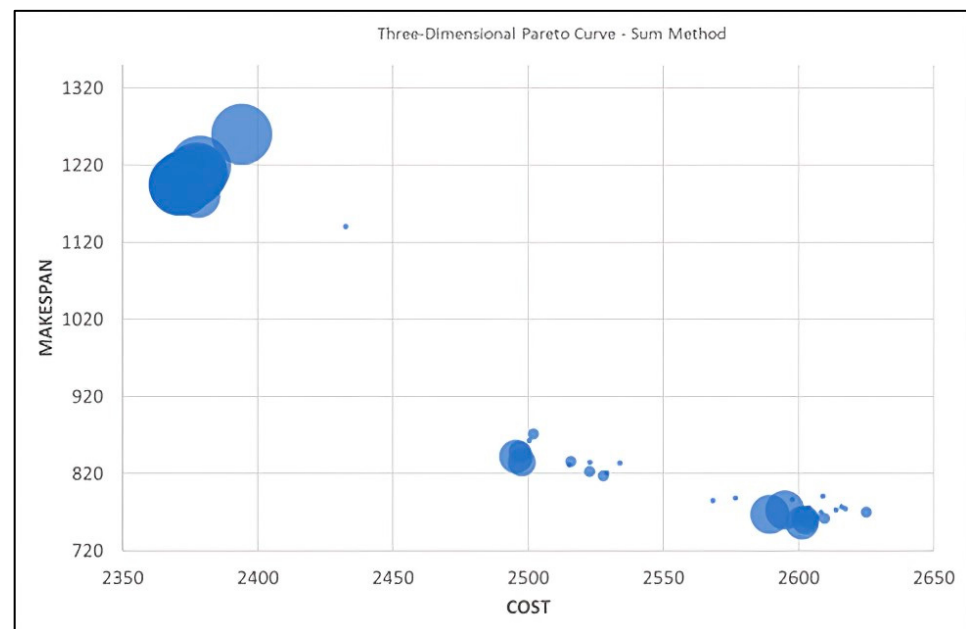


Figure 3. Three-dimensional Pareto curve about Weighted Sum method.

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 analyzing 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 favorable 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:

In Table 7 and Figure 5, it is possible to analyze 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 is the same at 11.

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 lowest makespan.
- The average workload is consistently 11 for all points.

In Table 8 and Figure 6, it is possible to analyze the data referring to the 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.

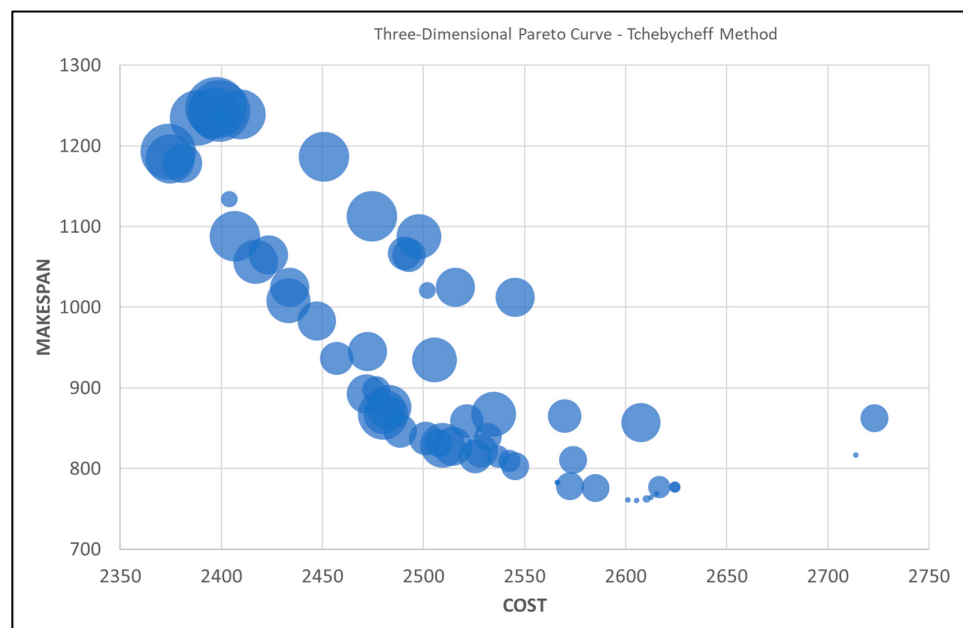


Figure 4. Three-dimensional Pareto curve about Tchebycheff method.

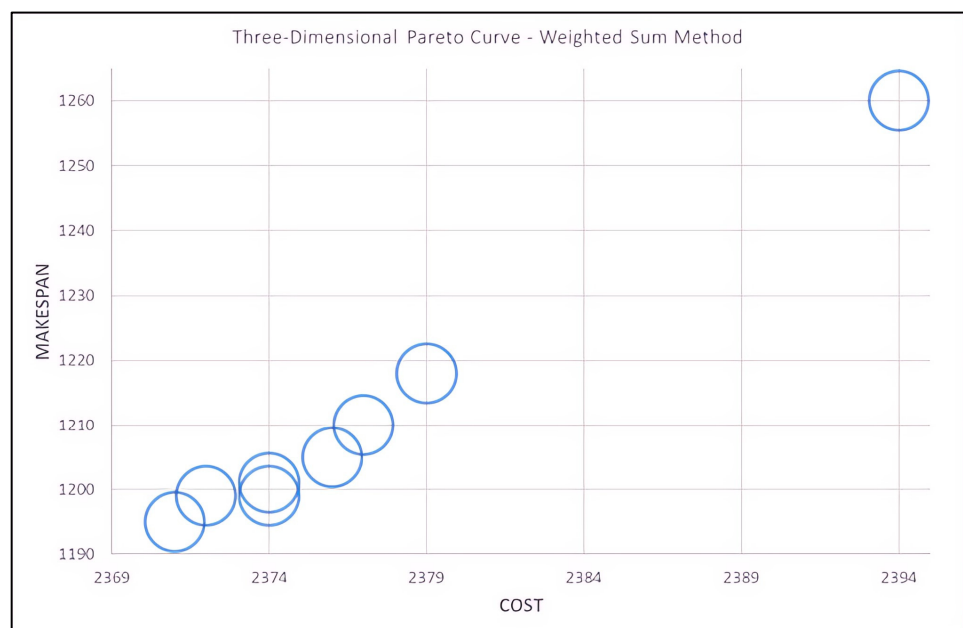


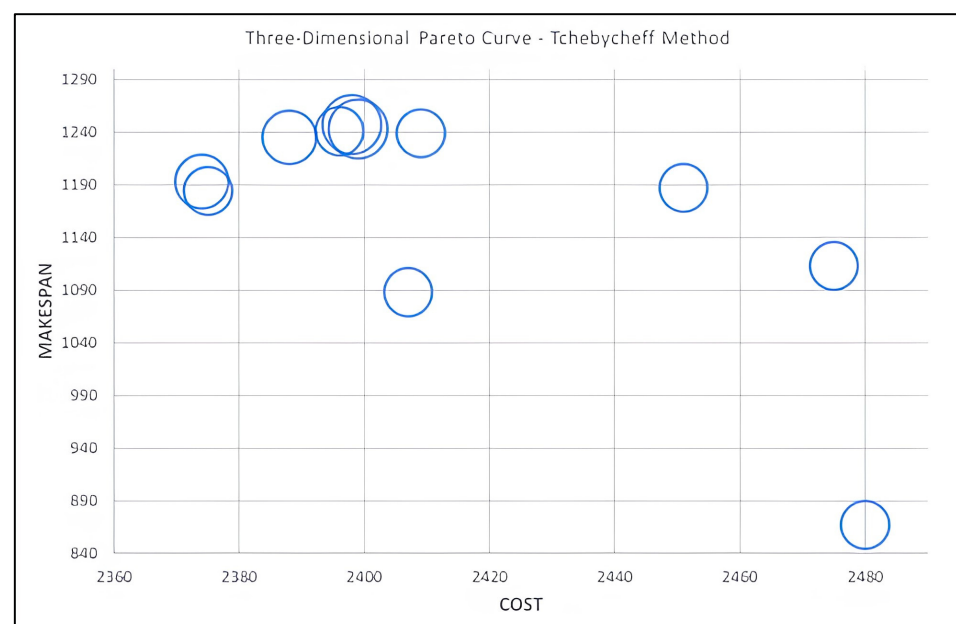
Figure 5. Point values of three-dimensional Pareto curve about Weighted Sum method.

Table 7. Point values of the Weighted Sum method.

	Weighted Sum	
	Cost	Makespan
Point 1	2394	1260
Point 2	2379	1218
Point 3	2377	1210
Point 4	2376	1205
Point 5	2374	1201
Point 6	2374	1199
Point 7	2372	1199
Point 8	2371	1195

Table 8. 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 6.** Point values of three-dimensional Pareto curve about Tchebycheff Method.

6. Discussion

To compare the results obtained by the Weighted Sum, in Table 9, and Tchebycheff, in Table 10, methods, a simple statistical analysis of the data presented was carried out. Measures such as mean, standard deviation, median, maximum, and minimum values were considered for each of the metrics: cost, makespan, and average workload.

Table 9. 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 10. 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

When analyzing the results, differences were observed between the two methods in terms of cost metrics, makespan, and average workload. Each of these metrics was discussed 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 currency units, the percentage reduction in cost can be calculated:

For the Weighted Sum method, $((3000 - 2371)/3000) \times 100 = 21.10\%$

For the Tchebycheff method, $((3000 - 2374)/3000) \times 100 = 20.90\%$

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.

When comparing the averages, it is evident that the Weighted Sum method presented a smaller 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 stakeholders' objectives, it is possible to consider the Weighted Sum method to be more appropriate, as it obtained superior results in terms of cost reduction, lower overhead, and a more uniform distribution of tasks (average workload close to the desired value).

Regarding the sustainable implementation of Robotic Process Automation (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 investments 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 the assignment of 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 allocating tasks to machines, based on the results obtained, it was identified that the optimal point in terms of minimizing cost, 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% decrease compared to the initial value of 3000 monetary units. This cost reduction can bring significant financial benefits to the organization, enabling better utilization of the available resources.

Additionally, the makespan was reduced to 1195 time units, indicating a shorter total 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 machines, 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 Table 11, 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.

Table 11. 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

Three sets of possible solutions were identified for the Weighted Sum method, in Tables 12–14. The weights attributed to each of the objectives are presented in the following solutions:

Table 12. 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 13. 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 14. 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.

7. Conclusions

This study aimed to analyze the relationship between user requirements and the feasibility of sustainable implementation of Robotic Process Automation (RPA), integrating them into a multi-objective model to assess its efficiency. It can be concluded that user requirements have a significant impact on the viability of RPA and integrating them into a multi-objective model allows for a more accurate and efficient assessment. Through the investigation, it was possible to answer the central research question and the research hypotheses:

(CRQ): Throughout the analysis, it was concluded that user requirements have a significant impact on decision making regarding the viability of RPA. The integration of these requirements into a multi-objective model enabled a more accurate and efficient evaluation of the efficiency of sustainable RPA implementation. This integration of user and stakeholder requirements into a multi-objective model can also be applied in other areas beyond RPA, allowing for a comprehensive and efficient evaluation of the efficiency and sustainability of implementations in different organizational contexts.

(H1): The requirements identified within the stakeholder context that affect decision making regarding the feasibility of Robotic Process Automation (RPA) are the allocation of RPA activities to machines considering each machine's characteristics; cost minimization; makespan minimization; and average workload minimization.

(H2): Integrating user requirements within the stakeholder context into a multi-objective model allows for an efficient assessment of the effectiveness of sustainable RPA implementation. By incorporating user requirements into the evaluation model, it is possible to consider multiple objectives. This enables a comprehensive and balanced evaluation of RPA implementation efficiency, taking into account the needs and expectations of stakeholders. The multi-objective approach ensures that different perspectives are considered, resulting in more informed decisions aligned with the organization's objectives.

(H3): The proposed guidelines for effective and sustainable RPA implementation, based on the study's results, will be helpful for organizations seeking to adopt RPA in a sustainable manner. These guidelines provide practical guidance and evidence-based recommendations to assist organizations in planning, implementing, and managing RPA sustainably.

When examining the research questions of this investigation, it became evident that the suggested recommendations for the efficient and long-lasting integration of RPA (Robotic Process Automation) will be beneficial for organizations that intend to adopt this technology in a sustainable way. These guidelines offer practical guidance for the planning, implementation, and management of RPA, considering user needs, stakeholder involvement, the efficient allocation of activities, and economically viable and environmentally responsible solutions.

The model presented stands out for encompassing a variety of fundamental aspects for the sustainable implementation of Robotic Process Automation (RPA) in a single model. The model addresses RPA implementation, for example, through its implementation in an administrative department, allowing for the identification of benefits achieved through sustainable implementation. Additionally, it assists in the selection of RPA tools by analyzing the costs of different available options, enabling evaluation. It also aids in evaluating RPA funding by comparing resources expended before and after model application and supports RPA monitoring by allocating RPA activities to machines, thus enhancing efficiency and effectiveness in project monitoring.

The primary strength and innovation of this model lie in its ability to encompass all these topics within a unified framework while also addressing a novel theme for RPA technology, which is the allocation of RPA projects. Specifically, it can be seen that the model, in response to RPA implementation, addresses issues such as energy efficiency analysis, paperless RPA automation, the impact on the workforce, ethical considerations (such as privacy and data security), the involvement 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 aspects, organizations can ensure that RPA implementation is aligned with sustainable practices and contributes positively to the overall well-being of companies and their stakeholders.

In the case study, significant differences were observed between the evaluation methods, highlighting the superiority of the Weighted Sum method in reducing costs, in minimizing makespan, and in the balanced distribution of the workload.

This sustainable implementation of RPA can bring economic, environmental, and social benefits to the organization.

It is recommended to implement Solution 1, which allows for the efficient and uniform allocation of available resources, facilitating machine maintenance and updates. This solution will bring practical benefits to the company in terms of resource utilization efficiency and a more stable working environment. This solution also resulted in a 21.10% decrease in the initial cost associated with RPA implementation.

This study can be considered relevant because it emphasizes the importance of considering user and stakeholder requirements when implementing RPA. Based on the results, it is suggested that organizations use these guidelines to implement RPA in a sustainable way, obtaining economic, environmental, and social benefits.

However, it is important to mention the limitations of this study. The results are based on a specific case study, and the generalization to other contexts may vary. Additionally, assigning weights to objectives in the multi-objective model can be subjective, requiring careful definition.

As directions for future research, it is suggested to investigate the sustainable implementation of RPA in different organizational contexts and improve decision making models that consider different metrics and stakeholder preferences.

This will allow for a comprehensive evaluation of sustainable RPA implementation and alignment with organizational strategic objectives.

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