INSTITUT D´ADMINISTRATION DES ENTREPRISES

DOCTORATE in BUSINESS ADMINISTRATION

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How to use the TRL scale to select the best approach to managing a project?

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Acknowledgments

First, to God, for the blessings received; to my mother, Arlette, who dedicated his life to my education and development, for all the help and support; To my father, in memory, who always supported my personal growth and dedicated his life to providing me with opportunities that he never had; To my beloved wife, Lucimara, partnership, and safe harbor, for always being by my side, for her love and encouragement, and to my dear daughter, Isabel, who inspired me with her sweetness and passion for learning.

Contents

Abstract

According to the article “The Project Economy,” published in Harvard Business Review magazine in December 2021, there has been a significant shift in focus of the organizations’ economy between the 20th and 21st centuries. During the 20th century, operations (running the business), responsible for ensuring the functioning of organizations, business, as usual, created enormous value. They did it through the constant search for efficiency, quality, and productivity advances. Even with the very expressive growth of internet access and of the so-called exponential technologies, as a result of the increasingly shorter organizational life cycles, during most of the current century, this productivity, especially in western economies, has been practically stable without significant advances.

Projects are increasingly driving short-term performance and long-term value creation through increasingly frequent organizational transformations. It requires faster development of new products and faster adoption of new technologies.

The article mentioned above points out that, in Germany, for example, projects have been steadily increasing as a percentage of GDP since at least 2009, and in 2019, they accounted for up to 41% of the total. While it is difficult to obtain similar, predictable, and reliable data for other countries, it is estimated that similar percentages are likely to apply in most other Western economies. The percentages are likely even higher in China and other essential and growing Asian economies, where project-based work has been an important source of development.

Other relevant information about this market was published by the Project Management Institute in the Edition PMBOK® Sixth (2018), estimating that the value of project-oriented economic activity worldwide would grow from US$12 trillion in 2017 to US$20 trillion in 2027. This process would also represent, from an economic and social point of view, the entry of some 88 million people to work in project management-oriented roles. These estimates were made before nations started spending trillions on projects of recovery from the COVID-19 pandemic.

According to unprecedented research published by Brazil's Green Finance Programme, the potential for raising in Brazil will reach R$ 3.6 trillion for socio-environmental projects in the next 20 years. Green Finance is an alliance between the Brazilian and British governments to leverage sustainable investments and accelerate the

low-carbon economy, which also seeks to stimulate sustainable investments in infrastructure to support Brazil's economic development,

Despite all this importance, project management suffers from a managerial gap. Many methodologies and approaches are on the market, ranging from small guides to comprehensive manuals with methods and bodies of knowledge. However, there is no structured way to know which, among the existing approaches, is the most suitable for project management.

In the research undertaken to verify “How effective are project management methodologies? An Explorative Assessment of Its Benefits in Practice”, Hany Wells concludes that “there is a misalignment between the perceived value of project management methodologies across different groups and between the project and strategic/organizational levels” (Wells, 2012). Most project managers realized that the primary purpose of project management methodologies was management, control, and compliance rather than support and guidance. Research on this aspect reveals that 47.9% of project managers considered project management methodologies not beneficial for their projects and stated that using project management methodologies makes project delivery difficult.

After so many project management studies and publications, growing since the mid-twentieth century, how can methodologies be perceived as harmful to success? Would it be a methodological problem or the absence of a process that helps project managers in choosing the best methodology?

Project management has become increasingly critical in contemporary organizations, where efficiency in achieving goals can represent the difference between success and failure. In this context, the choice between an agile or predictive approach to project management is a constant challenge (Biedenbach & Müller, 2012).

Predictive approaches, also known as "waterfall", usually involve detailed planning at the beginning of the project and are based on the premise that changes will be minimal throughout the process (Leach, 1999). In contrast, agile approaches promote a more flexible and iterative structure, adapting to changes in requirements throughout the project's life cycle (Conforto, Salum, Amaral, Da Silva, & De Almeida, 2014).

The decision on which project management approach to adopt is complex as it involves a series of variables. Issues such as the nature of the project, organizational culture, project manager's experience, among others, influence the choice (Biedenbach & Müller, 2012; Shenhar, Holzmann, Melamed, & Zhao, 2016).

The greatest challenge in selecting the best approach for project management lies in the trade-off between predictability and agility. Predictive approaches offer more certainty and control, but may not be flexible enough to accommodate changes in project requirements (Shenhar & Dvir, 2007).

To choose the best approach for project management, organizations need to consider the project's objectives, constraints, risks, and stakeholders, as well as the culture, resources, and capabilities of the organization (Turner, Ledwith, & Kelly, 2010).

The choice of a project management approach depends on a variety of factors, including the project's size, complexity, and risks, as well as the organizational culture and decision-making processes (Kerzner, 2017).

The choice between agile and predictive project management approaches is a critical decision that can have a significant impact on the project's success. Project managers need to carefully consider the advantages and disadvantages of each approach and make a decision based on the specific needs of the project (Williams, 2005).

Keyword: Projects; Project Management; TRL; Brazil

# Summary

Purpose: This study proposes an adaptation of the TRL scale so that it is possible, from there, to select the most appropriate approach to managing a project.

Originality/value: This research contributes to filling gaps in the literature on how to objectively define the best approach to managing a project and, once defined, how this approach will impact the organization, both from the point of view of project performance metrics and leadership style, team motivation and planning, execution and monitoring methods. Although over the last decades, several methods and frameworks for project management have been presented by the market, no process helps project managers in deciding on which approach best fits the nature of the project.

Research limitations: A possible limitation of the research is related to the reach of the author's network for data collection. Since the author's professional background is mainly in public organizations, most respondents may have project experience related to public companies, not covering all sectors (or most of them). Another possible limitation is that the author's network has a strong connection with agile methods (agilists). On the other hand, this scenario may be reduced because the author is the president of the PMI Project Management Institute, a chapter of the Federal District. This institute has a more robust tradition in predictive approaches.

1. Introduction

The author has over 25 years of experience in project, program, and portfolio management, strategic planning, and business agility. He has already headed the CAIXA Econômica Federal project office. CAIXA has more than 250 billion dollars in assets, is a 100% public bank, and is one of the largest in Brazil. He was also responsible for structuring the projects, programs, and portfolios office of the Ministry of Science, Technology, Innovation, and Communications of Brazil, where he helped develop the project management framework for the Ministry. He is a Project Management professor at the country's most prominent universities and some of the largest business schools in Latin America. He has the world's leading certifications in Project Management and is considered an essential reference in the community. Therefore, he actively participates in the development of the profession.

1.1. Background and Motivation

The author's background is mainly associated with project, program, and portfolio management in public organizations. For 20 years, he was an employee of CAIXA Econômica Federal, a public bank with more than 160 years of existence, more than 87 million customers, and 60 thousand service points distributed throughout Brazil. At CAIXA, he worked managing large programs, mainly focused on innovation. For three years, he was head of the corporate project management office (PMO), actively participating in strategic planning processes and defining methodologies for the organization. Between 2018 and 2019, he was mainly dedicated to the corporate process of organizational change management, working on CAIXA's digital transformation program. In 2019, he was invited to assume the General Coordination of the Ministry of Science, Technology, Innovation, and Communications - MCTIC, responsible for helping to create the Ministry's corporate project management office (PMO).

The experience in the MCTIC was decisive for the motivation of this research since the author was tasked with building a project management methodology that contemplated the entire portfolio of the Ministry. The initial portfolio was composed of projects of the most different technologies, from research on vaccines (dengue, for example), rocket launchers, and particle accelerators.

When faced with the dilemma of "how to indicate the best project management method or approach to portfolio projects," the author immersed himself in a series of research that made him realize the significant gap that exists between the perception of the problem's nature and the selection of the best approach to be used. The lack of a robust approach, with scientific references and practical application for choosing the best approach to manage the delivery of a project and the need to consider the context and nature of the problem in this definition was the primary motivation for this research.

1.2. The need for projects in organizations

According to Kerzner: "Project management is essential to the success of organizations, as projects are the way in which organizations implement their strategies. Organizations can face several challenges when executing projects, including tight schedules, limited resources and reduced budgets. Management project management can help mitigate these challenges by providing a framework to effectively plan, execute, and monitor projects. Additionally, project management can help organizations improve efficiency, increase quality, and reduce costs for their projects, providing greater value to its customers and shareholders." (Kerzner, 2018).

Programs and projects are managed under different organizational approaches. Over time and, mainly because of the increasingly accelerated cycle of changes, new methodologies and approaches have emerged more consistently. They are increasingly being widely used by public and private organizations worldwide. Some practices seem to receive greater prominence, reaching the level of “best practices for project management,” while others are content with the status of “best practices” or “guide.” International institutes and organizations maintain these good practices and are constantly evolving.

At the end of the 20th century, a new paradigm for product development and project management emerged: Agile Project Management. With the promise of agility and adaptability, as the world is increasingly complex and volatile, Agile has been sought by several organizations with the panacea or the "Holy Grail," as well as, at other times, traditional approaches.

The search for modernization of management practices is legitimate since it is a fact that efficiency and effectiveness are of corporate interest. An organization's strategy is simultaneously carried out by operational processes (routines) and, in particular, by programs and projects, responsible for the change, thus materializing the scope of the strategy, the vision of the future, enabling new organizational capabilities and, therefore, enabling the realization of the expected benefits. Coordinated management of an organization's efforts in alignment with its strategy is essential for its success and for achieving the benefits that society and customers expect. As a result, the management of portfolios, programs, and projects gained prominence, becoming one of those responsible for the success of organizations.

An organization exists to fulfill its mission, and for this, it will need organizational processes that ensure that this organization maintains predictability, quality, and standard in its deliveries and routines. Organizational process management is responsible for ensuring that this occurs. However, it is essential to remember that this organization will be inserted in a context, often the market or the government itself. We know that the waves of change (Veetil, 2021) are getting shorter and shorter, which means that organizations need to adapt more and more quickly to changes in context and, for that, they will need projects (see definition of projects, associating them with the changes).

1.2.1. Overview of Project Management Approaches

The Project Management Institute defines a project as a temporary endeavor undertaken to create a unique product, service, or result (PMBOK® Sixth Edition, 2018).

The discussion about the best approach to developing products, services, and results (through projects) is old. In 1986, Takeuchi and Nonaka published an article in the Harvard Business Review entitled: The New New Product Development Game (Takeuchi & Nonaka, 1986). This article marks a critical moment in the history of product development and, therefore, for project management because, in it, the authors compare

the so-called “old approach,” which did not respond satisfactorily when the context was associated with the development of new products, and what they present as the “rugby approach”, that is called Scrum. The “rugby approach.
The Scrum, utilized in rugby where team members unite to regain control of the ball, shares striking similarities with the Agile Scrum framework employed in project management. Both Scrum methodologies exemplify dynamic and iterative processes where teams cooperatively strive towards their objectives.

Similarities between the two Scrums can be found in their iterative and incremental nature. In rugby, the Scrum is a repeated play within the game, akin to the Agile Scrum framework where teams operate in 'sprints' typically lasting between two and four weeks. The core aim of both approaches is to reach a desirable result through a series of recurring iterations.

Collaboration is another shared characteristic between the two Scrums. In the context of rugby, the team joins forces to recapture the ball, while in the Agile Scrum framework, cross-functional teams work collectively to produce a product or fulfill a project objective. The essence of communication and cooperation is integral to both scenarios to ensure unified team effort towards a shared goal.

Furthermore, both Scrums necessitate teams to be self-organizing and possess diverse functional capabilities. In rugby, the team requires an array of skills to operate effectively. Similarly, within the Agile Scrum framework, the team should have the capacity to work across multiple domains, such as development, testing, and design. In both instances, the team's ability to adapt and swiftly respond to emerging changes and challenges is crucial.

Consequently, the rugby Scrum and Agile Scrum framework share commonalities in their iterative and incremental methodologies, their emphasis on collaboration, and their requirement for a self-organizing team. These resemblances can be attributed to the Agile Scrum framework's inspiration from the rugby Scrum. Both Scrums are recognized as efficient mechanisms for goal achievement within a team and find application in diverse contexts.

In the article mentioned above, the “Old approach” is specified as follows: Under the old approach, a product development process moved like a relay race, with one group of functional specialists passing the stick to the next group. The project went sequentially from phase to phase: concept development, feasibility testing, product design, development process, pilot production, and final production. This approach, often referred to as waterfall or predictive, was, until now, the known way of managing projects.

Since projects are not an end in themselves but a means to achieve a result, it is possible to say that a project exists to solve a problem. Therefore, when they say that “companies are fully aware that the old, sequential approach to developing new products simply will not get the job done,” the authors divide the problems into two types: new products (unknown) and old products (known). The sequential approach, or waterfall, has shown itself, over the years, to be effective for the second type of problem: the known ones.

Known problems are those that have occurred in the past. The solution has already been discovered, validated, and can be replicated. When it comes to new, unknown problems, we have a different subdivision: unknown-knowable and unknown-unknowable. The first subdivision is related to problems that did not exist in the past; in other words, they are new; they only exist in the present and do not have a known solution. This subdivision (unknowns-knows) can also be associated with past problems whose existing solution no longer meets the expectations of customers and users. A famous quote wrongly assigned to Henry Ford: “If I had asked people what they wanted, they would have said faster horses.” It is a good metaphor for this situation, although there is no evidence that this phrase was proclaimed by Ford (Vlaskovits, 2021).

The second subdivision (unknowns-unknowables) refers to problems of the future that, at present, only populate the imagination of organizations and cannot be accessed, tested, or even explored. It is up to the methods of anticipatory intelligence, foresight, or weak signals to monitor them. A valuable reference to this kind of problem is presented by the author, essayist, mathematical statistician, and risk analyst, Nassim Nicholas Taleb, in his book: The Black Swan, one of the 12 most influential books since World War II, according to The Sunday Times.

Returning to the article by Takeuchi and Nonaka, the central point is related to New Products from the present and not from the past, which required a new response, which sequential methods were unable to provide. From this finding, the research indicates a new approach to project management, a holistic method, compared to a rugby team, in which the product (compared to the rugby ball) "gets passed" within the team as it moves as a unit up the field. The comparison with Scrum, a rugby game, is born out of this characteristic and from this name. The approach created by Ken Schwaber and published in 1995 as "The Scrum Methodology" is born. "The primary difference between the defined (waterfall, spiral and iterative) and empirical (SCRUM) approach is that The SCRUM approach assumes that the analysis, design, and development processes in the Sprint phase are unpredictable. A control mechanism is used to manage the unpredictability and control the risk. Flexibility, responsiveness, and reliability are the results (Schwaber, 1997).

There are, therefore, two main approaches (one at each extreme) to project management: predictive (also called traditional or waterfall) and adaptive (also called Agile):

Empiricism is a philosophical tradition that originated in England in the 17th century and emphasizes the importance of experience as a source of knowledge. According to empiricism, all knowledge is derived from sensory experience and observation of facts. This philosophical approach emphasizes the role of observation and experimentation in the acquisition of knowledge.

The Scrum framework, an Agile framework, is based on an empirical process of continuous inspection and adaptation, which is in line with the principles of empiricism. The Agile approach recognizes that the environment in which software projects are executed is complex and uncertain, and therefore emphasizes adaptability and flexibility over predictability and control. The principles of transparency, inspection, and adaptation that underlie the Scrum process align with the empirical approach of learning from experience.

Rationalism and Cartesian thinking are philosophical traditions that emphasize the importance of reason and logic in the acquisition of knowledge. These traditions are more aligned with predictive methods that emphasize predictability and rational order. In contrast, the Scrum approach recognizes the limitations of attempting to control and predict all aspects of a project and emphasizes the importance of identifying customer needs and delivering value in an agile and iterative way.

The Scrum framework, and Agile frameworks in general, can be viewed as a practical application of the principles of empiricism in project management. The Agile approach emphasizes the importance of learning from experience, experimentation, and continuous adaptation to deal with the complexity and uncertainty of software projects. The empirical process of continuous inspection and adaptation that underlies the Scrum methodology aligns with the principles of empiricism, which emphasizes the role of observation and experimentation in the acquisition of knowledge.

There are various approaches to software development, each with its own unique characteristics and benefits. The Adaptive/Agile approach is a flexible development methodology that is particularly suited for projects with changing requirements. In this approach, requirements are subject to a high level of uncertainty and volatility, and may change throughout the project. The team works in short iterations, delivering working software quickly and adapting to new requirements as they arise.

On the other hand, the Hybrid approach is a combination of two or more agile and non-agile elements, resulting in a final outcome that is not purely agile. This approach is useful when some aspects of the project require a more structured, non-agile approach, while others can benefit from the flexibility and speed of agile development.

Finally, the Predictive approach is a development methodology in which the scope, time, and cost are determined in advance and closely monitored throughout the project. This approach is useful for projects where the requirements are well-defined and the goal is to deliver a specific outcome within a fixed timeframe and budget.

Each of these approaches has its own strengths and weaknesses, and the choice of methodology will depend on the project requirements, resources, and constraints. By understanding the differences between these approaches, project managers can choose the most appropriate methodology for their project and improve the chances of project success.

Figure 1 depicted below, illustrates the difference between predictive and adaptive approaches from the project management perspective: the higher the uncertainty, the more cycles (iterations) are necessary to validate the solution in light of the problem.

According to the PMBOK® Seventh Edition (2021), the three project management approaches, Predictive (or Waterfall), Adaptive (or Agile), and Hybrid can be defined as follows:

"Hybrid approach. A hybrid development approach is a combination of adaptive and predictive approaches. This means that some elements from a predictive approach are used and some from an adaptive approach are used." (PMBOK® Seventh Edition, 2021)

"A predictive approach is useful when the project and product requirements can be defined, collected, and analyzed at the start of the project. This may also be referred to as a waterfall approach." (PMBOK® Seventh Edition, 2021)

"Adaptive approach. Adaptive approaches are useful when requirements are subject to a high level of uncertainty and volatility and are likely to change throughout the project. A clear vision is established at the start of the project, and the initial known requirements are refined, detailed, changed, or replaced in accordance." (PMBOK® Seventh Edition, 2021)

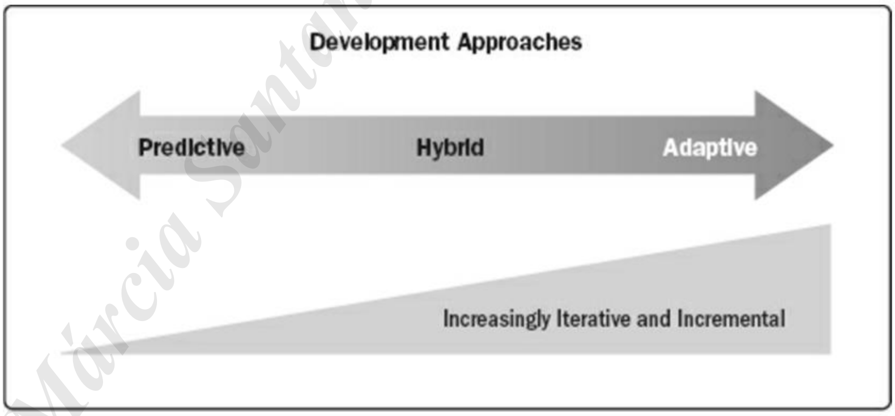

Figure 1: Development Approaches
Source: PMBOK® Seventh Edition (2021)

Figure 2 depicts the fundamental differences between iterative and incremental approaches. In the iterative approach, the project is divided into cycles, each being a repetition of the full development cycle. In this approach, the entire system is considered in each iteration, allowing for refinement and improvement of the project over time based on feedback and learning. This provides greater flexibility and adaptability to changes. Conversely, the incremental approach focuses on the continuous delivery of small complete parts of the system. Each increment adds a feature or component to the system, progressively advancing towards the final solution. This allows for faster and continuous delivery of value, even if the complete system is not yet finalized.

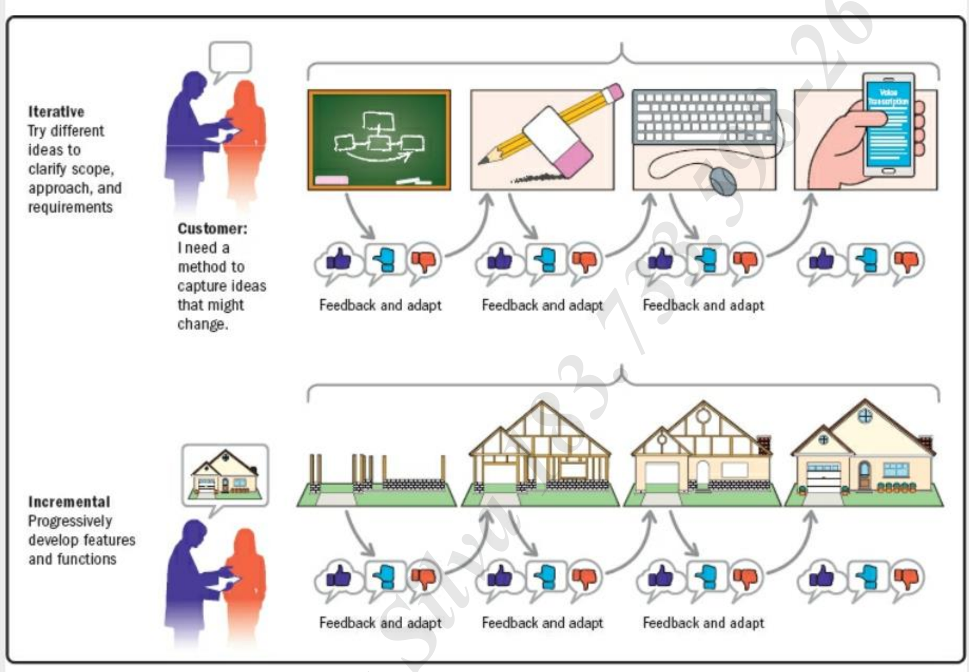

Figure 2: Differences between iterative and incremental approaches
Source: PMBOK® Seventh Edition (2021)

Table 1 summarizes the differences between predictive, iterative, incremental, and agile approaches, highlighting their features concerning requirements, activities, deliverables, and goals. In predictive approaches, requirements are predefined, activities are sequential, deliverables are single, and goals are fixed. Iterative approaches allow requirements refinement, repetitive activities, multiple deliverables, and adaptable goals. Incremental approaches focus on delivering partial requirements, parallel activities, progressive deliverables, and scalable goals. Lastly, agile approaches are characterized by flexible requirements, interactive activities, constant deliverables, and dynamic goals.

Characteristics				
Approach	**Requirements**	**Activities**	**Delivery**	**Goal**
Predictive	Fixed	Performed once for the entire project	Single delivery	Manage cost
Iterative	Dynamic	Repeated until correct	Single delivery	Correctness of solution
Incremental	Dynamic	Performed once for a given increment	Frequent smaller deliveries	Speed
Agile	Dynamic	Repeated until correct	Frequent small deliveries	Customer value via frequent deliveries and feedback

Table 1:Differences between predictive, iterative, incremental, and agile approaches
Source: PMBOK® Seventh Edition (2021)

Table 2 highlights the differences between the traditional and agile approaches across various aspects. In requirements, the traditional approach prioritizes precise initial requirements and a low change rate, while the agile approach encourages creativity and innovation, even with unclear requirements. Regarding users, in the traditional approach, they're usually not involved, unlike the agile approach which fosters close and frequent collaboration. Documentation is formal in the traditional approach, while the agile relies more on tacit knowledge. Larger projects tend to favor the traditional approach, while smaller projects fit better the agile one. Organizational support in the traditional approach tends to utilize existing processes, suitable for larger organizations, while the agile approach requires a willingness to embrace such methods. In terms of team, the traditional approach handles better distributed teams and possible fluctuation, while the agile approach favors smaller, co-located teams. Critical systems are more suited to the traditional approach, while less critical systems are better managed agilely. Finally, the project plan in the traditional approach is linear, while in the agile approach it's complex and iterative.

Characteristic	Traditional approach	Agile approach
Requirements	precise initial requirements; low change rate	creative, innovative; requirements unclear
Users	not involved	close and frequent collaboration
Documentation	formal documentation required	tacit knowledge

Project size	bigger projects	smaller projects
Organizational support	use existing processes; bigger organizations	prepared to embrace the agile approach
Team members	not accentuated; fluctuation expected; distributed team	collocated team; smaller team
System criticality	system failure consequences seriously	less critical systems
Project plan	Linear	complex; iterative

Table 2: Difference between the traditional and agile approach
Source: Špundak (2014)

1.2.2. The main challenges for Project Management in Organizations

The ability to make good decisions about the best way to manage a project or program in an organization is essential for the success of many, which makes it necessary to know the characteristics and context in which projects materialize in order to choose the best approach, methodology or set of rules to apply. The need to verify that the method or approach chosen is appropriate for the problem to be solved becomes fundamental to ensure that a given approach is reflected in better results.

In their article published in 2015 “A contigency fit model of critical success factors for software development projects: a comparasion of agile and traditional plan-based methodologies”, the authors conclude that empirical studies comparing traditional and agile project management approaches have been recommended by several authors so far (Ahimbisibwe et al., 2015).

This same need is perceived in the project management community in the form of heated discussions about “what is the best approach,” but without a structured method for this decision-making.

Likely, no program, project management methodology, or approach fits all cases. This choice depends a lot on the context, the nature of the programs and projects, the preference of managers, partners and entities involved, and other aspects, but, again, there is no way to prove this dependence without a more profound analysis being carried out.

Searching the term Project Management, as can be seen in the following table, which compiles the number of publications from the Web of Science database, attracts many thousands of publications, which shows the relevance of the topic, especially since 2008, when the number of publications exceeded 1000 per year, reaching more than 2800 in 2017.

Searching about “Methodologies” or “Approaches” to Project Management, however, in the same database, it is possible to perceive that the number of papers is significantly lower, and the few articles found are related to the software and information technology industry.

Period	Publications	Cumulative Publications
2021	13	200
2020	15	187
2019	23	172
2018	17	149
2017	22	132
2016	16	110
2015	8	94
2014	9	86
2013	10	77
2012	9	67
2011	7	58
2010	5	51
2009	6	46
2008	9	40
2007	3	31
2006	8	28
ATÉ 2005	20	20
Project Management Methodology		

Period	Publications	Cumulative Publications
2022	205	33913
2021	2539	33708
2020	2740	31169
2019	2723	28429
2018	2825	25706
2017	2801	22881
2016	2129	20080
2015	2160	17951
2014	1836	15791
2013	1455	13955
2012	1337	12500
2011	1475	11163
2010	1400	9688
2009	1193	8288
2008	1082	7095
2007	729	6013
2006	843	5284
ATÉ 2005	4441	4441
Project Management		

Table 3:Comparison between occurrences in the Web of Science database of the expressions "Project Management" and "Project Management + Methodology"

Source: Author

The methodology used for this research, systematic literature review, follows a comprehensive and systematic approach to synthesizing the existing knowledge on a specific topic or research question. A brief explanation of the process used follows.

Defining the research question: The first step is to clearly define the research question or topic that will be investigated. This will help determine the inclusion and exclusion criteria for selecting relevant studies. From the questions formulated for the present work, the first step of the research consisted in identifying the relevance of the theme “project management” and “agile” over time. The perception of the growth of interest in these topics, especially in agile, reinforced the main question about how organizations are making decisions about the best approach to use.

Data retrieval: The next step is data retrieval, which involves searching various sources such as bibliographic databases and scientific journals, (Scopus Elsevier, Web of Science and Google Scholar) to identify relevant studies. Through the selected databases to search for references and studies that could shed light on this issue and then, realizing the scarcity of publications on the subject, the questions used to collect data were formulated. data, with the intention of identifying the current decision-making process of the project management method/approach.

Study selection and Data extraction: The retrieved studies are then screened to determine their eligibility based on the inclusion and exclusion criteria established in the first step. Only studies that meet the criteria are selected for further analysis. Once the studies have been selected, the next step is to extract relevant data from each study, including information such as study design, sample size, study results, and others.

Quality assessment and Data synthesis: The quality of each study is then assessed to determine its validity and reliability. This research prioritized studies classified as A1, A2 and B, a crucial decision for ensuring that the results of the review are based on high-quality studies. The extracted data from each study is then synthesized to form a comprehensive overview of the current state of knowledge on the research question.

Conclusion and implications: The final step is to draw conclusions and discuss the implications of the review. This includes summarizing the findings, identifying gaps in the current knowledge, and making recommendations for future research.

Google Ngram Viewer or Google Books Ngram Viewer is an online search engine that maps the frequencies of any comma-delimited set of search strings using an annual count of n-grams found in print sources between 1500 and 2008. The Y axis shows the frequency of occurrence of words in Google's book database, while the X axis represents time. The following image shows the evolution of the number of occurrences of Agile (red line) and Project Management (blue line) from 1950 to 2019.

Significant growth in the interest of Agile can be noticed from the beginning of the '90s. "Project Management" grows at the beginning of the '60s similarly. In 2008, interest in Project Management showed a decrease in interest and a sharp drop until 2015, when it stabilized again. 2014 marks a critical moment in the history of these two expressions when interest in Agile surpasses interest in Project Management on the database of Google Books.

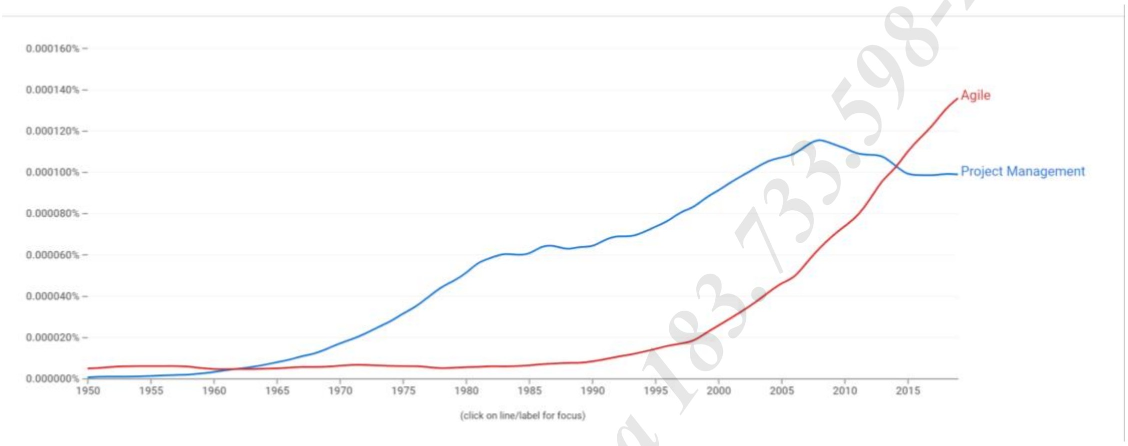

Figure 3: Occurrences of words Project Management and Agile in the Ngram database between 1950 - 2019
Source: Author

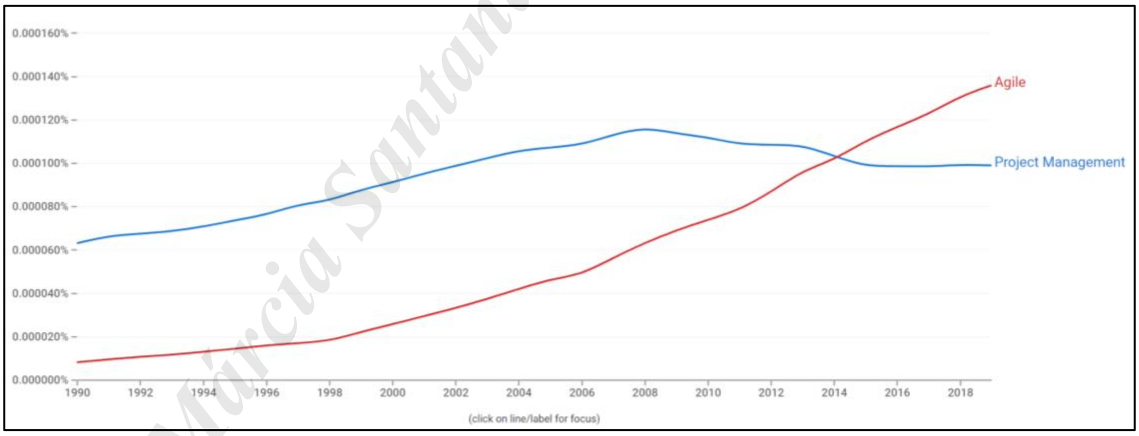

Figure 4: Occurrences of words Project Management and Agile in the Ngram database between 1990 - 2019
Source: Author

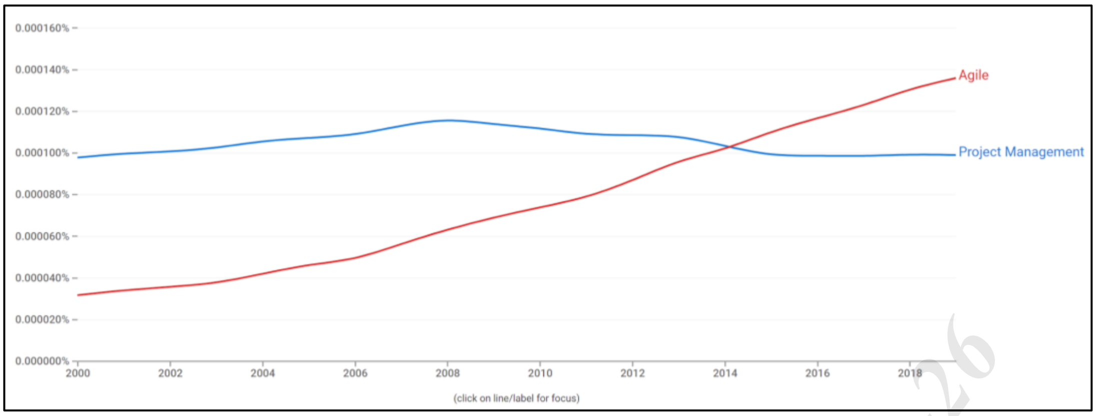

Figure 5: Occurrences of words Project Management and Agile in the Ngram database between 2000 - 2019
Source: Author

The interest in “Agile” from the beginning of the ‘90s also appears in the Web of Science database. This tendency is indicated in Table 4.

Period	Publications	Cumulative Publications	Period	Publications	Cumulative Publications
2006	592	3740	2022	666	24281
2005	529	3148	2021	2133	23615
2004	504	2619	2020	1986	21482
2003	376	2115	2019	2123	19496
2002	264	1739	2018	2079	17373
2001	206	1475	2017	1847	15294
2000	182	1269	2016	1512	13447
1999	154	1087	2015	1364	11935
1998	173	933	2014	1074	10571
1997	235	760	2013	942	9497
1996	99	525	2012	747	8555
1995	44	426	2011	766	7808
1994	225	382	2010	761	7042
1993	29	157	2009	938	6281
1992	36	128	2008	853	5343
1991	22	92	2007	750	4490
ATÉ 1990	70		ATÉ 2006	3740	
Agile			**Agile**		

Table 4: Occurrences in the Web of Science database of the word Agile
Source: Author

1.3. Research Overview

The script of this paper is presented in this chapter. Thus, the research question, the study's rationale, the intended objectives, and the contributions are described below.

1.3.1. Research Question and Objectives

Below, the objectives of this study are presented.

Primary:

- Can the TRL scale help choose the best approach to managing a project?

Secondaries:

Considering that the answer to the primary question may not be binary, only yes or no, secondary objectives were formulated in order to investigate whether any of the factors such as the level of understanding of the problem or the level of knowledge about project management, could interfere in the perception and value regarding the participant's choice, since eventually a choice may appear better or worse for a project manager with less knowledge about the problem the project aims to solve (making the respondent assume, for example, assumptions that there is no existing knowledge about the problem and therefore choose an empirical approach). Therefore, the secondary objectives to be investigated are:

- Does the level of understanding about the problem the project intends to solve influence satisfaction with the method or approach chosen to manage the project?
- Does the knowledge level about project management influence satisfaction with the method or approach selected for managing the project?

Thus, this paper aims to develop a model that allows to evaluate of the level of complexity of a project and, therefore, to determine the degree of severity of the constraints (scope, time, costs, benefits, and risk) to be applied to the project and the most appropriate project management approach.

1.3.2. Contribution of the Thesis

The present study brings theoretical contributions to the academy and practices to the industry.

From a theoretical point of view, this study highlights the growing discussion about the use of agile methods versus the use of predictive methods. It would help to understand how the context of a problem will influence the choice of the best approach and bring a robust theoretical basis for this discussion using a reference model recognized by the academy.

Research on Agile, in the context of Projects, has grown significantly, year after year, suggesting the topic's growing importance for organizations. The absence of a consistent theoretical basis to assist organizations in selecting the best approach can cause the results of change initiatives to deviate even further from what was expected.

Period	Publications	Cumulative Publications
2022	62	6697
2021	667	6635
2020	645	5968
2019	755	5323
2018	772	4568
2017	672	3796
2016	454	3124
2015	360	2670
2014	318	2310
2013	248	1992
2012	173	1744
2011	222	1571
2010	181	1349
2009	241	1168
2008	216	927
2007	146	711
2006	167	565
ATÉ 2005	398	398
Agile + Project		

Table 5: Occurrences in the Web of Science database of the words Agile + Project
Source: Author

An essential contribution to the academy stems from the data collected to carry out this research. The data will be of great value and utility to better understand which factors are considered when selecting an approach to project management and, with that, opening doors to advance future research, refine existing models, and improve the existing conceptual foundation of project management.

From a practical point of view, the research offers a tested model that organizations can immediately apply. Considering that organizations from all sectors carry out projects, the usefulness of a model that helps them in the selection of the best approach in an objective and safe way, the benefit of such an instrument will be available to organizations of a broad scope.

1.3.3. Thesis Roadmap

From the introduction of this document, the structure of the work is divided into four sections.

In addition to this introduction, the work is divided into four sections. The theoretical basis and all the references on problem-solving, technology readiness levels, and their derivations are presented below, which will support the model's proposition for measuring the readiness level of project management for selecting the best approach or method.

The data collection process, its respective instruments, and the analysis process are presented in the subsequent section.

Furthermore, finally, in the last two sessions, discussions and possible conclusions are evaluated with the data collected and analyzes carried out.

The structure of the thesis is reflected as follows:

Session 2 – Literature Review - This chapter presents the inferences from the literature review, including discussions on the concepts and theoretical frameworks adopted for building the model.

Session 3 – Research Methodology- This chapter is dedicated to explaining the development of the study focusing on the proposed model and the hypotheses to be tested. Data collection and testing, and evaluation processes are introduced and discussed in this session.

Session 4 – Discussions – Discussion of the results of the Session Hypothesis.

Session 5 – Conclusions - conclusions of the study.

2. Literature Review

This chapter presents the entire theoretical basis of the study, divided into four sessions. The first session will address the epistemological process for problem-solving. The TRL model, its origins, applications, and variations are discussed in the second session. The third session will introduce the correlation between project management and technology readiness. Finally, the fourth session presents the TRL model adapted to project management.

2.1. Theory and General Concepts Adopted

The phenomena object of the study is:

- “The factors that influence the selection of an approach to managing a project.”

The unit of analysis of the study is:

- “The Project Manager or equivalent role”

2.2. Problems and Decision Making

Although there are several definitions of a project, the definition presented by PMBOK® Sixth Edition (2018) is a temporary endeavor undertaken to create a unique product, service, or result. It involves a series of activities and tasks that consume resources, and it must be completed within a specification, defined with a start date and designation.

The “achievement of a specific objective” refers to emphasizing that the project will never be an end but rather a means for an organization to achieve an end, a result, or a benefit. Benefits can be an advantage or profit gained from something, the measurable improvement resulting from an outcome perceived as an advantage by one or more organizational objective(s), and which contributes towards one or more organizational objective(s). (Programmes, 2011).

In order to achieve these benefits, the organization will need to enable new organizational capabilities, which are obtained by completing a set of project outputs, the tangible or intangible artifact produced, constructed, or created as a result of a planned activity.

Once a new capability, in the form of several related project outputs, has been delivered, the new capability is then adopted (through organizational change management) and put into use. The use of the new capability modifies organizational behavior as a result. As capability is utilized, new behavior becomes natural behavior, and new work practices become the new norm.

Regarding the benefits, these can be defined as the measurable improvements that result from this situation. Different Stakeholders perceive benefits differently, which is the key to understanding the benefits as they should be considered positive advantages from the stakeholder perspective. (Programmes, 2011).

The objective to be achieved with the projects becomes an organizational goal. Achieving the goal requires defining the best approach to manage constraints such as time, costs, risks, benefits, resources, human skills, and quality, among others. Markman defines a decision as: "…those in which the decision maker has some unsatisfied goal and a set of options that might satisfy the goal. The decision maker must then evaluate the options in some way and select one (Markman, 2001).

The field of decision-making is quite broad. Ranging from psychology, in which 1954 and 1961, Ward Edwards published two seminal articles that created behavioral decision research as a new field in psychology, economics (Edwards, 1954 – 1961), represented, for instance, by the Nobel Prize winner Daniel Kahneman in several works, among others (Kahneman & Tversky, 1979).

A common point in the theories is that decision-making, regardless of the field of study or science, will go through a particular situation in which the decision-making agent will need to seek specific knowledge to solve a problem. "Rather than new methods, a better understanding of the problems to which they apply seems to represent an equally fruitful avenue of future research and innovation" Walker et al. (2010)

2.2.1. The G.H Walker's Model

Walker et al. (2010) present a valuable reflection on ergonomics in their research. It is crucial to emphasize that ergonomics is defined as "a discipline in its own right, as the theoretical and fundamental understanding of human behavior and performance in purposeful interacting socio-technical systems, and the application of that understanding to design of interactions in the context of real settings. This definition is justified in the financial, technical, legal, organizational, social, political, and professional contexts in which ergonomists work." (Wilson, J. R., 2000)

The research points to the growth in the word "complexity," considering that, since 1958, more than 80 journal papers from the mainstream ergonomics literature have used either the words 'complex' or 'complexity' in their titles. Of those, more than 90% have been published in only the past 20 years" Walker et al. (2010).

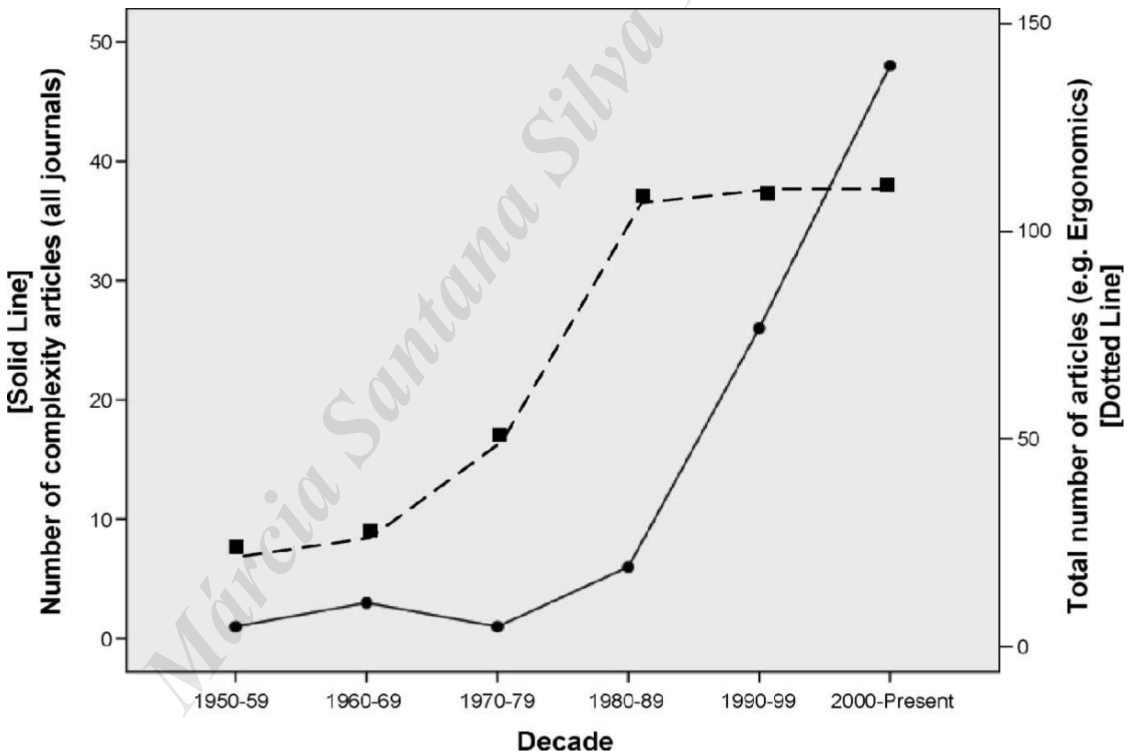

Figure 6: Number of complexity articles x Decade
Source: Walker et al. (2010)

The main point of Walker et al. (2010) is based on "the idea that some ergonomics problems are different from others and that complexity is a potentially powerful contingency factor when selecting appropriate ergonomics methods. Ergonomics methods must match the fundamental nature of the problem they aim to solve". According to the author, complexity is a contingency factor in defining a method for solving a problem. The method needs to be adapted to the fundamental nature of the problem to be solved.

The starting point to understand how contingency and complexity interfere in selecting the method to solve a problem will go through the complexity of the meaning factor of the word improvement in the context of ergonomics.

The author states, "No papers in the mainstream ergonomics literature provide a clear, unambiguous, formal, and universally accepted definition of complexity." In most cases, the definition presents little more than what is possible from the dictionary definition, with expressions such as 'several parts' and 'involved, intricate or difficult' in some way (Allen, 1984). Therefore, the author brings together a multiplicity of perspectives, seeking to identify emerging patterns in these definitions and emphasizing that there is no single consensual definition.

Starting with the ergonomic vision of Woods (1988) is based on five attributes that, together, determine the complexity of the ergonomic point of view. The five attributes are multiplicity, dynamism, difficulty, uncertainty, and importance. Added to this perspective, Alberts, and Hayes (2006) also present their definition of complexity, considering three attributes: strength of information position, familiarity, and rate of change. The study concludes that three significant attributes, called themes, define the level of complexity of a problem and that, from the definition of this complexity, the solution method must be adapted. The three themes are:

1. multiplicity, with many parts and interconnections;
2. change and dynamism;
3. uncertainty/incomplete knowledge.

According to Marmaras et al. (1992), multiplicity refers to many interrelated variables in the system. These variables can be associated with interrelated causes, consequences, multiple highly complex interconnected tasks, complexly distributed teams, many roles and responsibilities, and many connected technologies and network distribution mechanisms.

Dynamism, the second attribute, is "the degree to which the system changes its state over time, without intervention." This attribute can be associated, for instance, with the execution time of tasks related to the resolution of the problem. A deliverable that needs to be done on a project with a series of related tasks, whose duration is often modified over time, is a deliverable with high dynamism.

Uncertainty is the third attribute and refers to vagueness, difficulty discerning the final state from the initial conditions, and foreseeing the correct way to solve a problem, for example. Uncertainty comprises the lack of knowledge and certainty about what something is. It refers to the impossibility of completely classifying something and admitting ambiguity regarding a problem that the problem can be "one thing and another" simultaneously.

The figure below represents a three-dimensional graph containing the three attributes that constitute the complexity of a system. Suppose each attribute is assigned a continuum with variation between low and high. Figure 7 depicts the growth of articles with the word "complexity" in their title over the last few decades, according to the author.

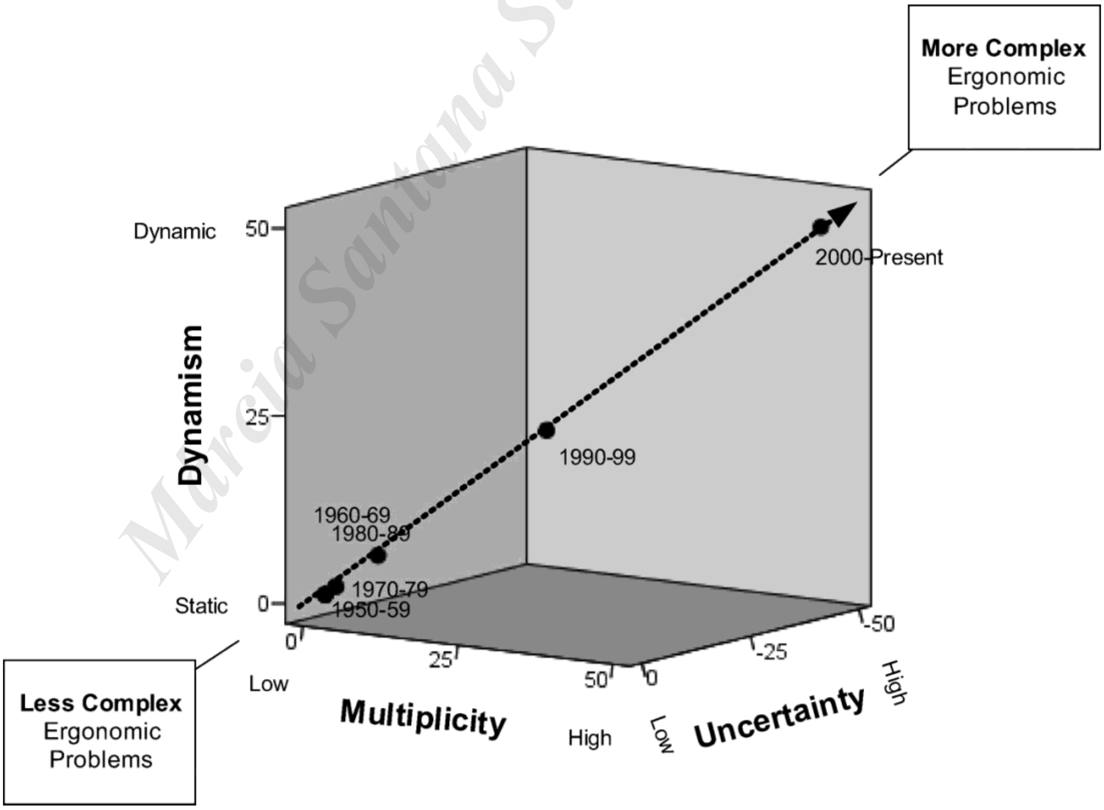

Figure 7: Complexity
Source: Walker et al. (2010)

The level of complexity of a system (the corner of space in figure 7 where the problem is) results in a series of characteristics that differentiate a less complex problem from a more complex one. Table 6 presents the differences in the change in focus of the problem to be solved as this problem migrates from a less complex environment to a more complex one.

Less complex	More complex
A focus on specialization.	Increasing integration of disciplines, specialism, and expertise.
A focus on what a system 'is' (i.e., requirements and functionality.	An increased emphasis on what a system 'does' (i.e., end value, effects, and capabilities.
An increasing level of criticality and dependability is required of less complex systems.	An increasing level of criticality and dependability is required of more complex systems.
A focus on constraining dynamism and imposing stable behavior.	A focus on responding and adapting to dynamism and change.
A focus on stand-alone systems.	An increased emphasis on interoperability.
An emphasis on controlling complexity.	An increasing emphasis on ever more complex systems and systems of systems.
A focus on end-products is often based on new technology to replace obsolete equipment.	An increasing trend toward through-life capability, integration of legacy systems, and reuse.
Increased computational power and the ability of entities and artifacts to exhibit complex but predictable behavior.	Increased computational power and the ability of entities and artifacts to exhibit complex emergent behavior.

Table 6: Broader trends are associated with opposite corners of the ergonomics problem space
Source: Boehm (2006)

Walker et al. (2010) present three types of states that a system can present, between total disorganization and control. The states are stability, complexity, and chaos.

Stability is related to permanence, invariance, and order. That attribute is related to closed, impermeable systems, not susceptible to variations from the outside. No matter what, they remain the way they were designed. From the point of view of problems, they are those whose answers are known and, therefore, can be planned. “Taylor’s and the design organization’s attempts along formally rational (i.e., bureaucratic) principles as well as concepts like “heavy automation” seem analogous to some extent.”

A system is considered chaotic if its behavior is highly unpredictable and volatile. It is a system whose interaction leads to total ignorance and the impossibility of predicting the future state. An analogy made by the author is that “if stability can be visualized as a solid, then chaos can be seen as a fluid,” within which “atoms fall on each other at random” (Waldrop 1993). From the point of view of problems here, it is possible to find catastrophic events, unknowable, until the moment they occur. Something that could not have been imagined. If it happens to be repeated, the fact that it was successfully solved in the past is no guarantee of success in the present.

According to Walker et al. (2010), complexity is between stability and chaos. It is a system in which volatility has some stability so that it is possible to learn and adapt from the identified patterns. An essential feature of complex systems is emergence.

Emergence is something more significant than the sum of the parts; it is “the phenomenon in which a complex and interesting high-level function is produced as a result of combining simple low-level mechanisms in simple ways” (Chalmers, 1990). This emergent behavior results from interactions between system agents and the system itself. An example of an emergent property, in a football game, for example, is the so-called “wave” or “human wave” in football matches. It is a phenomenon that occurs when groups of spectators briefly stand up, shout and raise their arms. Each viewer does this individually, and the result, the wave, is greater than the sum of the parts.

Finally, the research presents four different types of emergence from Bar-Yam (2004). These types are presented in table 7, considering the level of emergency and its respective type, the type of information and knowledge needed to understand the system's behavior, and the level of difficulty in diagnosing the collective behavior of the system.

Emergence	Type	Information is needed in order to make a diagnosis of the system's collective behaviors.	Difficulty in diagnosing system’s collective behavior
None	Type 0	Deterministic: Knowledge of individual system components sufficient to fully explain global system behavior.	(Relatively) Easy
Weak	Type 1	As for type 0 but with additional knowledge about the positions and dynamics of individual entities in a system, this is sufficient to describe the 'microscopic' and 'macroscopic' parts of the system.	More Difficult
Strong	Type 2	As for type 1, with additional knowledge of possible states and configurations, the system can adopt.	Extremely Difficult
Strong	Type 3	As for type 2, but with additional knowledge of the environment that the system resides in.	Extremely Difficult

Table 7: Four different levels for types of emergence
Source: Prepared by the author based on Elford (2012), Bar-Yam (2004), and Walker et al. (2010).

The model by Walker et al. (2010) is close to the objective of this study since the author concludes something taken as a premise for the present work. “It is not simply a question of being one thing or another, reductionism vs. complexity. Instead, the implication of this work is a complementary, contingent approach to ergonomics, which selects methods based on rational, theoretical considerations rather than merely a preference, habit, or loyalty” Walker et al. (2010).

Likewise, project management requires a rational and objective approach to selecting the best approach (answer) for managing a project which aims to solve a problem. The author concludes in his research that “It becomes possible to use this form of complexity as a contingency factor when selecting methods appropriate to particular ergonomics problems.”

The selection of the development approach is influenced by various variables related to the nature of the product, service, or result. Below is a list of variables that should be considered when selecting a development approach, according to PMBOK® Seventh Edition (2021).

• Degree of innovation: Products that have a well-understood scope and requirements, that the project team has worked on before, and that allow for initial planning are suitable for a predictive approach. Products that have a high degree of innovation or that the project team has no experience with are better suited for a more adaptive approach.

The degree of innovation of a product or service is an important factor to consider when selecting a development approach. Highly innovative products that have no past references or involve emerging technologies may be difficult to plan and control through a predictive approach. On the other hand, a more adaptive approach, which allows for continuous changes and iterations, may be more suitable. For example, the development of a new mobile application that incorporates emerging technologies like augmented reality or voice recognition may be considered a project with a high degree of innovation, requiring an adaptive approach to deal with uncertainty and potential changes in scope and requirements.

• Certainty of requirements: When requirements are well known and easy to define, a predictive approach is more appropriate. When requirements are uncertain, volatile, complex, and expected to evolve throughout the project, a more adaptive approach may be more appropriate.

The certainty of requirements is another determining factor in the choice of development approach. If the project requirements are clear, well-defined, and stable, a predictive approach may be the best option. However, if the requirements are uncertain and subject to change, a more adaptive approach may be more suitable. For example, the development of an enterprise resource planning (ERP) system in a company can be considered a project with well-defined and stable requirements that can be managed through a predictive approach. On the other hand, the development of a social networking application may require a more adaptive approach, considering the volatility of requirements and the need for continuous user feedback.

• Stability of scope: If the scope of the product is stable and not prone to change, a predictive approach is useful. If the scope is expected to have many changes, an approach closer to the adaptive side of the spectrum may be useful.

The stability of scope is an important factor in the choice of development approach. If the scope is well defined and stable, a predictive approach may be appropriate. On the other hand, if the scope is volatile and prone to changes, a more adaptive approach may be necessary. For example, the construction of a building can be managed through a predictive approach, as the scope of the project is well defined and should not change significantly during the construction process. However, the development of an e-commerce application may require a more adaptive approach, considering that the scope may evolve over time depending on user and market feedback.

• Ease of change: Related to the certainty of requirements and stability of scope, if the nature of the product makes it difficult to manage and incorporate changes, then a predictive approach is the best option. Products that can easily adapt to changes can use a more adaptive approach.

The ease of change is another important factor to consider. If the product or service is susceptible to frequent changes, an adaptive approach may be more appropriate. On the other hand, if the nature of the product makes it difficult to manage and incorporate changes, a predictive approach may be more suitable. For example, the development of a network security system may require a predictive approach, as frequent changes may increase the vulnerability of the system. The development of a language learning application may benefit from an adaptive approach, considering that frequent changes can improve the user experience and increase the effectiveness of the application.

• Delivery options: the nature of the product and whether it can be delivered in components influences the development approach. Products, services or results that can be developed and/or delivered in parts are aligned with incremental, iterative or adaptive approaches. Some large projects may be planned using a predictive approach, but there may be some parts that can be developed and delivered incrementally. Delivery options are an important factor to consider when selecting a development approach. If the product can be delivered in parts, an incremental, iterative, or adaptive approach may be more appropriate. On the other hand, if the product must be delivered as a whole, a predictive approach may be more suitable. For example, the development of an inventory management system can be done through an incremental approach, allowing for the delivery of individual modules (such as inventory control and orders) over time. On the other hand, the development of a new car model may require a predictive approach, considering that the car must be delivered as a whole and not as individual parts.

• Risk: products that are inherently high-risk require analysis before choosing the development approach. Some high-risk products may require significant planning and rigorous processes in advance to reduce threats. Other products may reduce risk by building them modularly and adapting design and development based on learning to take advantage of emerging opportunities or reduce exposure to threats. Risk is a critical factor to consider when choosing a development approach. Inherently high-risk products, such as projects in healthcare, aviation, finance, among others, require careful analysis before selecting an approach. Some high-risk products may require significant planning and rigorous processes in advance to reduce threats. On the other hand, high-risk products may benefit from an adaptive approach, where design and development are built modularly and adapted based on learning, allowing emerging opportunities to be seized or exposure to threats to be reduced. For example, the development of a fraud detection system in a bank may require a predictive approach, considering the sensitivity of the involved data and the need to ensure system security and reliability. On the other hand, the development of a new medical device may require an adaptive approach, allowing the product to be developed incrementally based on the learning obtained throughout the process.

• Safety requirements: products that have rigorous safety requirements usually use a predictive approach because there is a need for significant planning in advance to ensure that all safety requirements are identified, planned, created, integrated, and tested. Safety requirements are a critical factor to consider when selecting a development approach. Products that have rigorous safety requirements, such as air traffic control systems, traffic management systems, among others, usually use a predictive approach because there is a need for significant planning in advance to ensure that all safety requirements are identified, planned, created, integrated, and tested. For example, the development of an access control system for a commercial building may require a predictive approach, considering the need to ensure the security of users and proper access control. On the other hand, the development of an online dating app may require an adaptive approach, allowing the product to be developed incrementally based on user feedback and learning over time.

• Regulations: Environments that have significant regulatory oversight may need to use a predictive approach due to the required process, documentation, and demonstration needs. Regulations are a critical factor to consider when selecting a development approach. Environments with significant regulatory oversight, such as the healthcare and energy sectors, may need to use a predictive approach due to the required process, documentation, and demonstration needs. For example, the development of a new medication may require a predictive approach, considering the need for rigorous documentation and demonstration that the product is safe and effective for use in humans. On the other hand, the development of a task management application for internal use in a company may benefit from an adaptive approach, allowing the development team to test different features and functionalities based on user and client feedback.

It is important to emphasize that the selection of the development approach should consider all the contingent factors presented, and that choosing an inadequate approach can lead to delays, high costs, and in extreme cases, project failure. Therefore, the development team responsible should have a clear understanding of the product, service, or result characteristics and carefully evaluate the presented variables before deciding.

It is noted that the characteristics presented in the contingency factors are associated with the definition of “complexity” from the point of view of GH Walker, since the greater the complexity, the less certainty about the requirements (Requirements certainty), the less clarity about the scope to be developed (Scope stability), the greater the level of innovation, considering the fact that an innovative solution is not known, that is, it does not have its references in the past (Degree of innovation), requiring a greater level of iterations and adaptations (Ease of change) and thus increasing the risk of the project (risk).

2.2.2. The Cynefin Framework for Decision Making

Cynefin, a Welsh word meaning 'habitat' or 'place' - from Old Welsh, means a “place of multiple/true belongings.” Dave Snowden, the creator of the Cynefin Framework, presents the process used over a decade to build this model to understand the context and aid decision-making. The Cynefin Framework is a theoretical model for categorization of complex and uncertain situations that can be used as a management tool. It was developed by Dave Snowden, founder and head of research at Cognitive Edge, in the mid-1990s. The Cynefin framework, originating from knowledge management, is an investigative tool that helps people understand situations to make decisions (Snowden, 2002). It has now been applied to knowledge and strategy management, research, policy-making, and leadership training (Mark & Snowden, 2006).

According to Snowden and Boone (2007), the “Framework” classifies problems into five contexts defined by the nature of the causal relationship. Four of the contexts - clear, complicated, complex, and chaotic - require leaders to diagnose situations and then act with the appropriate response for the context. The fifth domain, confused, applies when there is no clarity about which of the other four contexts is predominant, as more than one is likely to be present in the decision.

Cynefin (figure 8) presents four decision-making models. The domain in which a problem is located, according to the Framework, will determine a sequence of responses as follows:

- Known-Known (Clear): Understand - Categorize - Respond
- Unknown-Known (Complicated): Understand - Analyze - Respond
- Unknown-Unknown (Complex): Probe - Understand - Respond
- Unknown-Unknowables (Chaotic): Act - Understand – Respond

Snowden and Boone (2007) point out that while clear and complicated contexts have apparent cause-and-effect relations and accept fact-based problem-solving, complex and chaotic contexts are unordered and ask for responses based on emerging patterns.

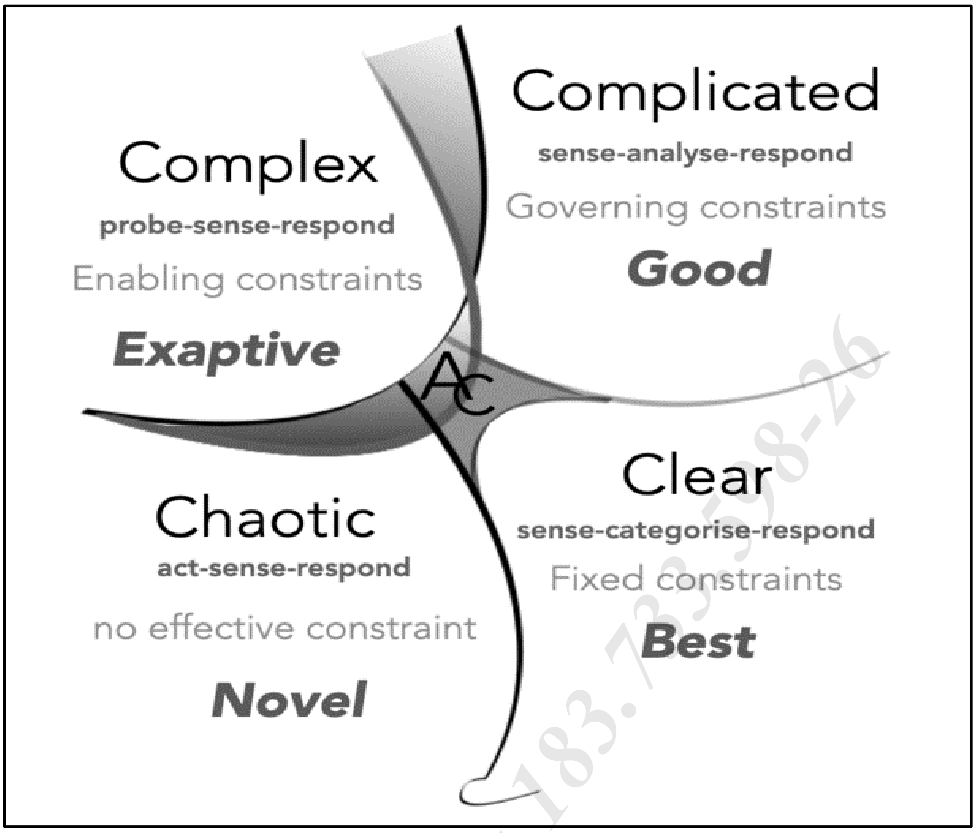

Figure 8: The Cynefin Framework
Source: Snowden and Boone (2007)

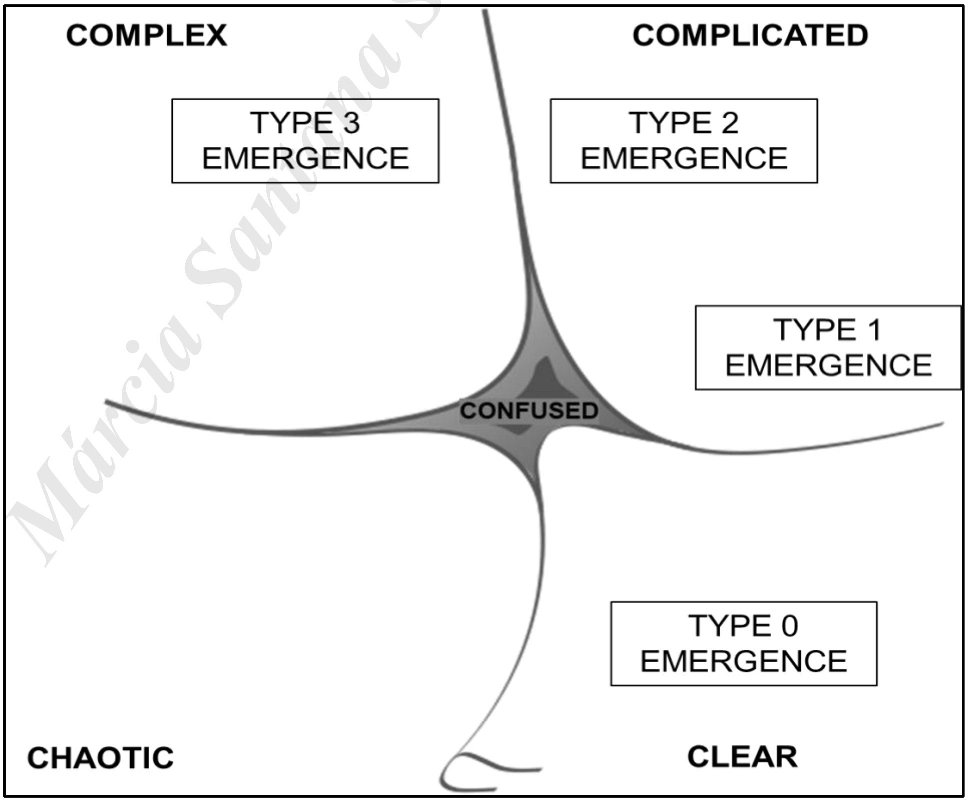

Figure 9: The Cynefin Framework with Bar-Yam Model
Source: Elford, W. (2012)

Clear Domain: The domain of best practices is characterized by stability and a clear cause-and-effect relationship. Decisions are unquestionable, and it is up to leaders and managers, in this context, to understand the problem, categorize (according to a database or catalog of best practices), and respond. In this context, the effect will always be known and predictable, just playing command and controlling. The mastery of legal frameworks, standard operating procedures, and practices has been proven to work (good practices). For instance, according to some project characteristics and the product it will deliver, it is possible to define which financing best fits. According to Kurtz and Snowden (2003), “single point forecasting, field manuals, and operational procedures are legitimate and effective practices in this domain. […] Structured techniques are desirable and mandatory in this space."

Complicated Domain: It is the domain of good practices. In this context, unlike the obvious or simple domain, there are several answers to the same question. Although there is a clear cause-and-effect relationship, it is not so evident that anyone can interpret and react to it. Here the presence of an expert is necessary to make a specialist select, among the good market practices, which may be the best practice for a given situation. In a complicated context, the leader or manager must understand the problem, analyze it (with the skills of an expert), and then respond. Data analysis referring to an exam or diagnosis to define the next step, for example, assumes that the existence of several good practices requires selecting the best practice for a given situation. The project to build a rocket is an example. Snowden (2002) says it is necessary to have an open mind for changes, so “management of this space requires the cyclical disruption of perceived wisdom.”

Complex Domain: The domain of emerging practices. Here, as Kurts and Snowden (2003) wrote, “relying on expert opinions based on historically stable patterns of meaning will insufficiently prepare us to recognize and act upon unexpected patterns.” While a complicated context presents at least one correct answer, this cause-effect relationship cannot be established in a complex context. In this domain, the understanding necessary to solve a problem does not come from the past. However, it suits an environment for experimentation and the search for an emerging pattern. A pattern will emerge from connecting the people involved and their ideas. The result will be the search for the answer. The complex domain is where the correct sequence for solving a problem is: taste, feel and respond. It is the domain of experimentation. Experimentation as a means for exploration and problem-solving has been shown to play a crucial role in corporate learning when exposed to high levels of uncertainty (West & Iansiti, 2003). The presence of the specialist in this context will not guarantee the correct answer.

Snowden and Boone (2007) cite an emblematic scene from the movie Apollo 13 when the astronauts encounter a severe crisis on the spacecraft, and Commander Jim Lovell, played by Tom Hanks, announces: “Houston, we have a problem.” At this point, the situation moves into a complex domain. A group of experts is placed in a room with a combination of different materials and pieces of plastic that reflect the resources available to astronauts aboard the spacecraft. Leaders tell the team, “this is what you have; find a solution, or the astronauts will die.” None of these experts knew beforehand what would work. Instead, they had to let a solution emerge from the materials at hand, and they succeeded. This is the environment for research and development (R&D), for instance, when there are already promising experiments previously tested in a laboratory environment, in which it is necessary to evolve in research or even develop a particular product or service for the first time, with a level still relevant uncertainty about the cause-and-effect relationship between the identified problem and the solution under construction.

Chaotic Domain: The domain of unheard-of practices. Searching for patterns, good practices, and the correct answers in a chaotic domain is useless, as the relationship between cause and effect is impossible to establish. Best practice protocols are of limited use as unprecedented circumstances call for novel responses Beurden et al. (2013). No patterns will change when we think a new pattern has been identified. When a problem presents itself in the chaotic domain, the manager should not invest efforts in the search for patterns. It must act as quickly as possible to try to stabilize the dramatic situation, then understand if the situation is, in fact, under control, and only then respond by adding predictability (and reducing uncertainties) to the situation so that it can migrate to another domain. This environment is ideal for radical innovations and disruptive discoveries when contained and managed. Exploratory research carried out with limited time and budget, for example, provides an ideal environment for novel practices to emerge. Challenges and hackathons are practices that promote controlled and confined chaos in a structured way but with time pressure and challenges that can promote innovative solutions.

Some of the possible applications of the Cynefin Framework include (but not limited to):

- Improved decision-making: The model can be used to help identify the proper context for decision-making and thus ensure that the correct approach is used.

- Team Alignment: Cynefin can be used to help align teams around the appropriate approach to different types of problems and situations.

- Project management: The model can be used to help identify the context of a project and thus ensure that the right approach is used in managing it.

- Strategy development: Cynefin can be used to help identify the context in which a strategy is being developed and thus ensure that the correct approach is used.

Especially on the application for selecting the best project management approach, this is where this study focuses, seeking to refine and precisely improve this application.

In terms of project management, the Cynefin Framework can help determine the appropriate approach based on the complexity and uncertainty of the project context. For example, if the project is in a complex domain, an agile approach may be more appropriate, as it allows for flexibility and adaptability in response to changes and uncertainties. On the other hand, if the project is in a simple or complicated domain, a predictive approach may be more appropriate, as it involves planning and control processes that aim to minimize risks and ensure project completion according to a predetermined schedule and budget.

The Cynefin framework has been utilized in the field of project management as a valuable tool for understanding and managing complexity, thereby indirectly influencing the choice of an appropriate management approach. The scope of the following sections is based on examples found in the literature up to the date of this study's last update.

Williams, Bertsch, Van Der Merwe, and Van Der Hoorn (2017) discussed the use of the Cynefin framework to comprehend complexity in engineering projects. They argued that Cynefin offers an effective means for categorizing complexity and can thereby contribute to the selection of a more suitable management approach.

Similarly, Pich, Loch, and De Meyer (2002) applied a conceptual framework akin to Cynefin to address uncertainty and complexity in projects, although without direct reference to Cynefin itself. They suggested that different management strategies should be adopted depending on the degree of uncertainty inherent in the project.

More broadly, Snowden and Boone (2007) explored the application of the Cynefin framework in project management, arguing that it can assist managers in identifying the nature of their problems and determining the most suitable context to address them.

Lastly, Kurtz and Snowden (2003) discussed the use of the Cynefin framework for managing complexity and change in various fields, including project management.

Although the literature does not present concrete examples of the use of the Cynefin framework for the direct selection of a project management approach, its usage for aiding in the understanding and management of complexity within projects is apparent, which may indirectly inform on the most suitable management approach.

2.3. TRL – Technology Readiness Levels

The Technology Readiness Levels – TRL is a scale used to estimate the level of maturity of a given technology during the initial phase of a project or program, developed by the National Aeronautics Space Administration (NASA) during the 1970s.

TRLs evaluate the level of maturity of a given technology from the moment of investigation of this technology, from the research perspective, through the development of this technology in a controlled environment, until the deployment in an operational environment. TRLs are based on a scale from 1 to 9, with 9 being the most mature technology.

In 2013 the TRL scale became an International Organization for Standardization (ISO) standard and a de facto standard within the space and weapons industry. (Héder, 2017).

After the Apollo program took the first man to the moon on July 16, 1969, NASA was already thinking about future challenges, including space stations. These challenges would require special attention to the technology used to assess whether (and how much) such technology would be ready to be incorporated into such a program. At this point, a technology readiness review was suggested (Mankins, 1995), which can be seen as the first reference to what would later be known as TRL – Technology Readiness Level.

Although the 1969 Space Base was never implemented (Johnson Space Center, 1997), the need to revise the technological readiness scale remained active, and it took 20 years for it to be introduced. Although the term "Technology Readiness Level" has not yet been used, the first reference to the TRL concept appears in a 1989 article by Stanley R. Sadin, Frederick P. Povinelly, and Robert Rosen, Sadin, et al. (1989), with the name "Technology Flight Readiness." While this article did not directly mention the space shuttle Challenger disaster on January 28, 1986, there are many apparent references to the Space Shuttle disaster, which served as a strong reason for a change in strategy towards a safer technology development model (Héder, 2017).

The Technology Readiness Level (TRL) scale can help in selecting the best approach, either agile or predictive, for managing a project. The TRL scale provides information on the maturity stage of the technology involved in the project, which can help to determine the level of certainty and predictability of the project outcomes.

From a project management point of view and choosing the best approach. If the technology is at a relatively low maturity stage (TRL 4 or 5), it may indicate that the project is more uncertain and unpredictable, and an agile approach may be more appropriate for managing it. An agile approach allows for flexibility and adaptability in response to changes and uncertainties in the project environment.

On the other hand, if the technology is at a higher maturity stage (TRL 7 or 8), the outcomes may be more predictable, and a predictive approach may be more appropriate for managing the project. A predictive approach involves planning and control processes that aim to minimize risks and ensure that the project is completed according to a predetermined schedule and budget.

In conclusion, the TRL scale can provide valuable information on the maturity stage of the technology involved in the project, which can help in selecting the best approach, either agile or predictive, for managing the project effectively.

The combination of the TRL scale and the Cynefin framework can be useful in choosing the best approach for managing a project. The TRL scale can provide information about the maturity stage of the technology involved in the project, while the Cynefin can provide information about the context in which the project is being developed.

For example, if the project involves a low maturity technology (TRL 3 to 5), Cynefin may indicate that the project is being developed in a complex context, which would require a different management approach than if the technology were in a more advanced phase (TRL 7 or 8).

Furthermore, combining the two scales can help to understand the implications for integrating the project into broader systems. For example, if the technology is in a demonstration phase (TRL 6) but the project is being developed in a complex context, a more rigorous management approach may be required to ensure successful integration.

In summary, the combination of the TRL scale and the Cynefin framework can help to understand the context in which the project is being developed, as well as the maturity stage of the technology involved, which can be useful in choosing the best approach for project management. project.

2.3.1. Use and applicability of the TRL scale in the market

Initially developed by NASA in the 1970s for space exploration technologies, many organizations have used the TRLs scale for their purposes, with specific organizations, such as the European Union (EU), further normalizing the NASA readiness-level definitions, allowing for more accessible translation to multiple industry sectors – not just space exploration. They are particularly useful in planning technology hand-offs between different groups, for example, a research and development group and a project group. (Olechowski, et al., 2015)

Table 8 shows a survey conducted in 2015 with organizations from different sectors that use the model for various purposes, from aircraft construction (Bombadier) to developing information technology products (Google).

#	Organization	Industry	TRL Experience	Role of Interviewee
1	NASA	Space	> 8 years	Office of the Chief Engineer Office of the Chief Technologist
2	Raytheon	Defense	> 8 years	Director of Engineering
3	BP	Oil & Gas	2 – 8 years	Technology Leader Engineering Manager Technology Manager Engineering Manager VP Technology Project Manager Independent Consultant
4	Bombardier	Aircraft	2 – 8 years	Senior Engineering Specialist Systems Integration, Advanced Design
5	John Deere	Heavy Equipment	2 – 8 years	Systems Engineer Systems Engineering Manager
6	Alstom	Power Systems	< 2 years	System Engineer Risk Expert Process Expert
7	Google	Electronics	< 2 years	Program Manager Product Design Lead

Table 8: Interview participants
Source: Olechowski, A., Eppinger, S. D., & Joglekar, N. (2015)

2.3.2. The seven-level technology readiness

Initially, TRL was created to suggest a standard categorization scheme between the Supporting Research and Technology (SRT) and Advanced Research Technology (ART) projects, which would also express how proven a given technology was. The first scale version featured the following seven levels:

- Level 1 - Observed and reported basic principles
- Level 2 - Validated Potential Application

- Level 3 - Proof of Concept demonstrated analytically and/or experimentally

- Level 4 - Validated component and/or board laboratory

- Level 5 - Component and/or board validated in a simulated or real space environment

- Level 6 - Suitability of the system validated in a simulated environment

- Level 7 - Space-validated system suitability

These levels were proposed to replace the previous denomination, which worked only in four stages, in a broader and less specific way: "basic research," "feasibility," "development," and "demonstration." It is possible to notice that the seven-level scale does not invalidate the previous concepts; on the contrary, it adds details that allow the subdivision of these four stages into three more.

2.3.3. The nine-level technology readiness scale

In the late 1980s, John Mankins added two more levels to the TRL scale. In 1995, a white paper updated the descriptions of the nine levels of the scale, making it more general (Mankins, 1995). The nine levels are presented below:

- Level 1 - Basic principles observed and reported

- Level 2 - Technology concept and/or application formulated

- Level 3 - Analytical and experimental critical function and/or characteristic proof-of-concept

- Level 4 - Component and/or breadboard validation in a laboratory environment

- Level 5 - Component and/or breadboard validation in a relevant environment

- Level 6 - System/subsystem model or prototype demonstration in a relevant environment (ground or space)

- Level 7 - System prototype demonstration in a space environment

- Level 8 - Actual system completed and “flight qualified” through test and demonstration (ground or space)

- Level 9 - Actual system “flight proven” through successful mission operations

Table 9, based on the ABNT NBR ISO 16290:2015 standard, presents a summary of the TRLs and their main definitions. The first column contains a description of the technology's maturity level. The second describes the milestone to be reached in each TRL, while the third describes the information to be documented to allow a proper assessment of the TRLs.

Technology Maturity Level	Milestone achieved by the element	Work done (documented)
TRL 1: Basic principles observed and reported	Potential applications are identified after baseline observations, but the concept of the element is not yet formulated.	· Expression of the basic principles provided for use. · Identification of potentials Applications.
TRL 2: Concept and/or application of formulated technology	Formulation of potential applications and preliminary concept of the element. No proof of concept yet.	Formulation of applications in potential. The preliminary conceptual design of the element provides an understanding of how basic principles can be used.

TRL 3: Proof of analytical and experimental concept of critical and/or characteristic function	The concept of the element is elaborated, and the expected performance is demonstrated by employing analytical models supported by experimental data/ characteristics.	• Preliminary performance requirements (can target multiple missions), including the definition of functional performance requirements. • Conceptual design of the element. • Experimental data entry, definition, and results of laboratory experiments. • Analytical element models for proof of concept.
TRL 4: Functional verification in laboratory am- biente of the component and/or maquete	Maquette tests in a laboratory environment demonstrate the functional performance of the element.	• Preliminary performance requirements (can target multiple missions) with the definition of functional performance requirements. • Conceptual design of the element. • Functional performance test plan. • Setting the maquette for functional performance verification. • Test reports with the maquette.

TRL 5: Verification in a rele-fore-back environment of the critical function of the component and/or maquete	The critical functions of the element are identified, and the associated relevant environment is defined. Models, not necessarily on a full scale, are constructed to verify the development through tests in a relevant environment, subject to scale effects.	• Preliminary definition of performance requirements and the relevant environment. • Identification and analysis of functions criticism of the element. • Preliminary element design, supported by appropriate models for verification of critical functions. • Test plan of critical functions. Effects analysis scale. • Setting the maquette for checking the critical function. • Test reports with the maquette.
TRL 6: Model demonstrating the critical functions of the element in a relevant environment	The critical functions of the element are checked, and performance is demonstrated in a relevant environment with representative formats, configuration, and function models.	• Definition of performance requirements and the relevant environment. • Identification and analysis of functions criticism of the element. • Element design, supported by appropriate models for checking critical functions. • Critical function test plan.

		• Definition of the model for critical function checks. • Test reports with the model.
TRL 7: Model demonstrating element performance for the operating environment	Performance is demonstrated for the operating environment on the ground or, if necessary, in space. A representative model, fully reflecting all aspects of the flight design, is built and tested with adequate safety margins to demonstrate performance in an operating environment.	• Definition of performance requirements, including a definition of the operating environment. • Definition and realization of the model. • Model test plan. • Test results with the model.
TRL 8: Complete and accept a real system for flight ("flight-eligible")	The flight model is qualified and integrated into the final flight-ready system.	• The flight model is built and integrated into the final system. • Acceptance for system flight final.
TRL 9: Real system "demonstrated in flight" through successful mission operations	The technology is mature. The element is successfully in service, for the designated mission, in the real operating environment.	• Commissioning in the initial phase of operation. • Operation report in orbit.

Table 9: Summary of the TRLs and their main definitions
Source: Neves (2019)

According to Hirshorn S., & Jefferies, S. (2016), using TRLs allows consistent and uniform discussions of technical maturity in different types of technology. The technology TRL is determined using the Technology Readiness Assessment (TRA), which examines project concepts, technology requirements, and demonstrated technology capabilities to verify the degree of maturity and fit into a TRL per the conditions and characteristics analyzed.

The TRLs indicates the stage of maturity and have several uses, such as allowing the organization of compatible funding structures for each stage (or a set of stages), structuring interdisciplinary and multifunctional teams for the stages, developing specific public policies to encourage research, development, and commercialization, compatible with TRLs, articulate actors according to maturity ranges.

Figure 10 presents a recap of the TRL scale, with the objectives of each of the stages and a brief description of what the readiness levels represent.

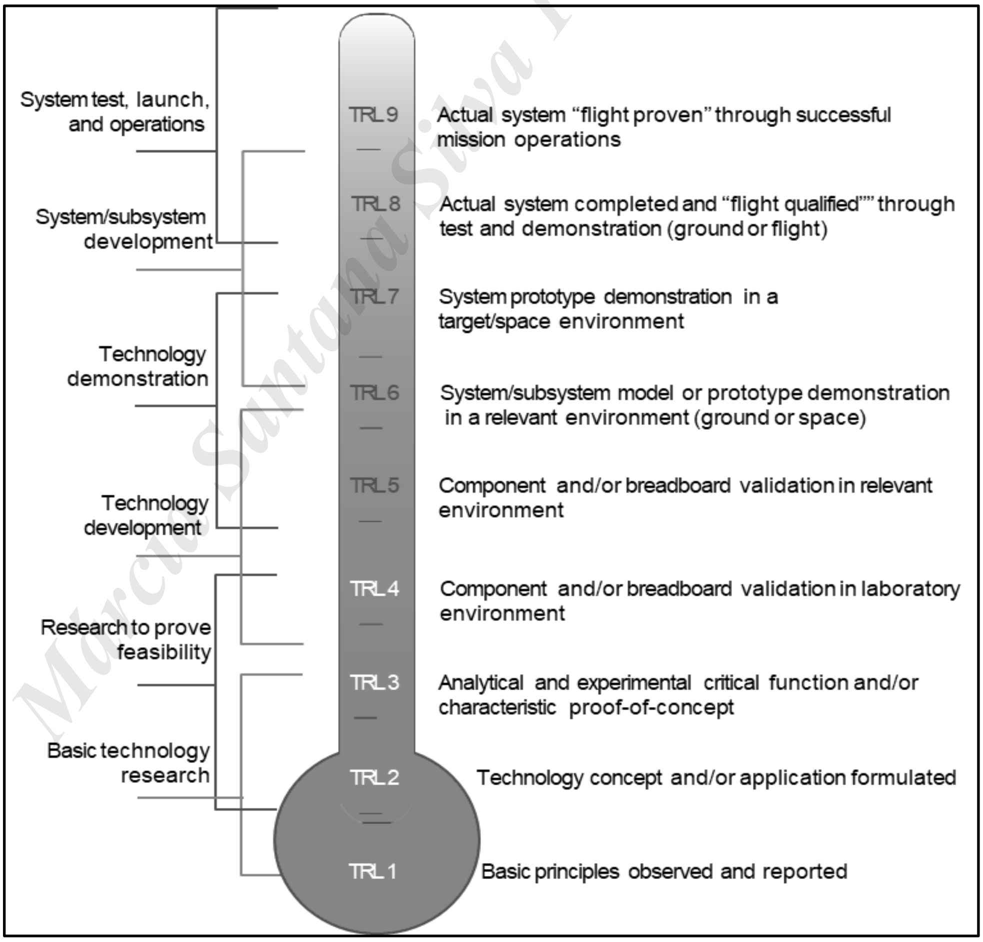

Figure 10: The TRL scale
Source: Hirshorn et al. (2017)

Because NASA created the TRL scale for technological assessment related to space programs, it is incomplete to assess other specific factors. Technology maturity assessment tools, such as the TRL, serve as systematic measurement systems used as entry and exit criteria for transitioning milestones and are integral to program risk management structures. However, the TRL has proven incapable of consistently capturing the human-related aspects of technology development and their association with technology readiness. (Phillips, 2010).

The application of the model takes place through a logical tree. The flowchart depicted in figure 11 demonstrates the questions to ask to determine TRL at any level of the assessment. Answering "YES" to a question determines the indicated TRL. The tree starts at TRL 9, with a "shortcut" to TRL 5 right after it, and then maintains a descending pattern until it reaches TRL 1.

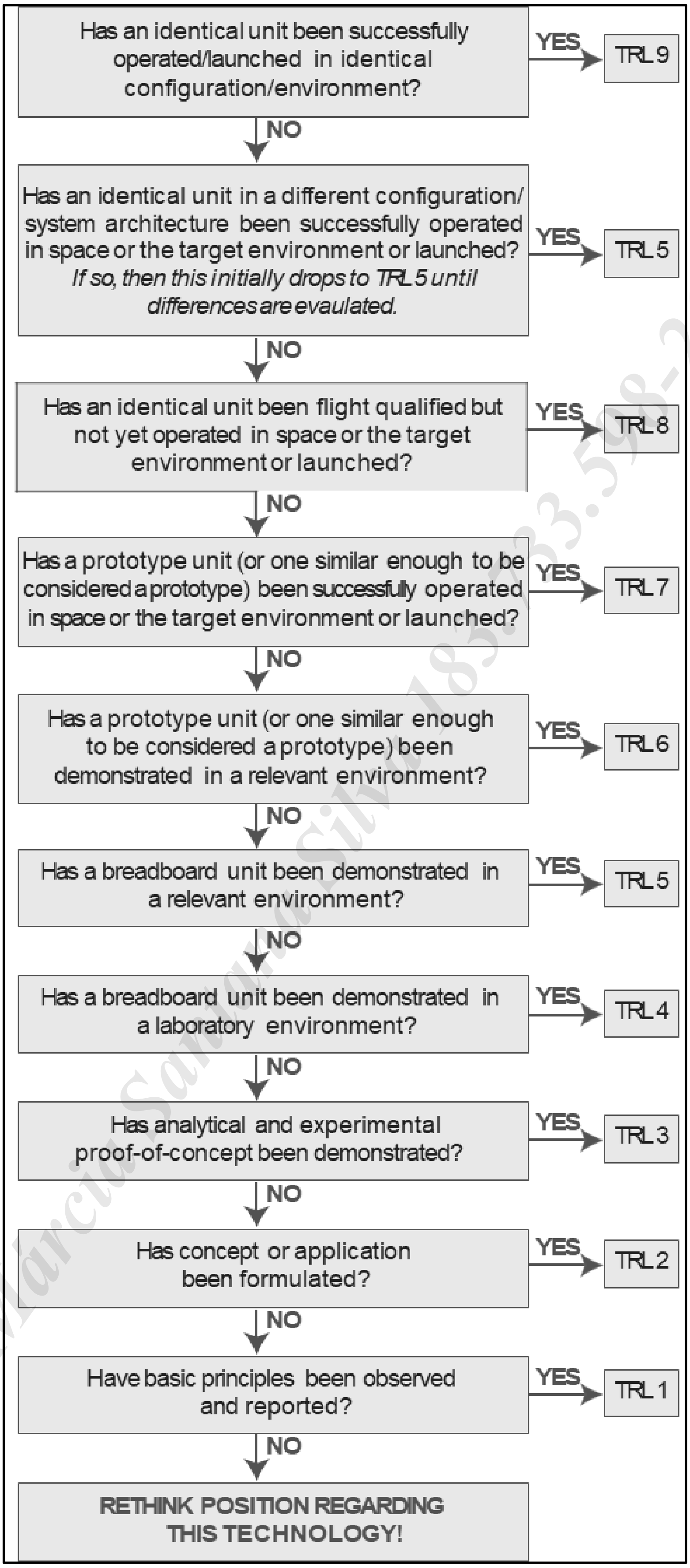

Figure 11: The flowchart to determine TRL
Source: Hirshorn et al. (2017)

2.3.4. TRL scale adaptations

The TRL scale was used as the basis for several other scales that, based on the TRL, developed their approach to measuring maturity. An example is the HRL – Human Readiness Level scale. According to the original paper, “the HRLs are used to identify the level of readiness or maturity of a given technology as it relates to its usability and its refinement to be used by a human(s).” (Phillips, 2010) The HRL is based on the foundation of the TRL scale through the mirroring of the nine levels to simplify the communications of human readiness to the management and engineering community. (Phillips, 2010)

Human Readiness Level	Description
1. Activation of Human Systems Integration: base-lining and commitment.	The lowest level of socio-technical readiness. HSI infrastructure is set up within Systems Engineering planning. Total system analysis from both functional relationship and organizational perspectives occurs. Activity examples include front-end analyses, preliminary functional allocation, and initial HSI assessment and plan.
2. Human Systems Integration analysis suite in support of component technology Development.	Significant HSI input to acquisition development and documentation occurs. Activity examples include initial human-machine interface assessment, generation of Target Audience Description, and threat/hazard assessment.

3. Component human touch point resolution (i.e., human-system interaction, to include hardware and software): refining requirements thresholds.	Multiple needs analyses and studies are conducted in support of requirement definitions. HSI domain assessments inform ongoing development actions, as well. Activity examples include human-in-the-loop analyses, sub-system hazard analysis, and HSI plan updates and revision.
4. Component human touch point engineering parameters and human performance indicators.	Iterative evaluation and analysis of each HSI domain takes place and provides critical items of consideration bearing on system design. Activity examples include usability testing, the development of human-centered source selection, and updating the human-machine interface assessment.
5. Limited system human performance parameters/demonstration.	Various HSI assessments and testing are performed to support the significant increase in the fidelity of breadboard technology. This includes supporting "high fidelity" laboratory integration of components. Activity examples include examining the safety and occupational health design features and cognitive task analyses.
6. Field (relevant environment) validation of human performance prototypes.	A representative model or prototype system is tested in a relevant environment. Evaluations of human performance embedded in the demonstration system occur, and HSI predictive models are updated. Activity examples include testing human reliability and usability of the prototype in a High-fidelity laboratory environment or in a simulated operational environment.

7. Final Developmental Test & Evaluation/human performance parameters.	Significant HSI participation in system test events occurs. Iterative evaluation and analysis of each HSI domain continue as well. Activity examples include errors and fault analysis to cover human error performance, equipment operability, safety procedures, and error recovery mechanisms.
8. Operational Test & Evaluation/human performance parameters.	Special human-centric analyses are conducted to update thresholds, objectives, and evolving criteria for Operational Tests & Evaluation. Iterative evaluation and analysis of each HSI domain continue as well. Activity examples include system hazard analysis and HSI domain tradeoff studies.
9. Sustainment: Initiation of capability gap feedback cycle.	Extensive and iterative review and verification of fielded system begins, as well as post-product improvement evaluations for the next incremental builds. Activity examples include post-fielding training evaluation analysis and sustaining a hazard analysis for the fielded system.

Table 10: Human Readiness Level (HRL)
Source: See and Handley (2019)

2.3.5. Innovation Readiness Level

Another model derived from the TRL scale, which demonstrates the possibility of using the technological readiness structure to assess conditions related to a given scenario, in this case, innovation, is the Innovation Readiness Level.

In an increasingly competitive economy, innovation is considered a critical success factor. However, there are many challenges to be overcome when it comes to sustainable innovation, especially with technological uncertainties (Day, Schoemaker, & Gunther, 2000). In this discussion, some scholars argue that successful innovation depends on the systematics used by organizations in developing products, services, production systems, and new businesses (Wychal, Mohanty, & Verma, 2011).

Most of the previous studies on innovation maturity described technology maturity. This comes from the general concept of measuring technology readiness levels, which originated from several studies carried out in the United States of America Departments of Defense (USA), the UK, Canada, and Australia. In the '80s, NASA established a seven-level Technology Readiness Level (TRL) metric, which would later become nine, in order to assess the risk associated with technology development (Board, 1999).

The primary purpose of using TRL is to assist management in making decisions regarding technology development and transition (DoD, 1998). Although TRL is a helpful method for measuring technology readiness, they fail to consider the negative aspects that immature technologies can introduce to the system. As an alternative to measuring the technology readiness level, the proposition of the IRL scale emerged (Tao, Probert, & Phaal, 2010). The objective of this model is to portray the development of innovation, from its conception to its evolution in the market, making it more effective throughout its life cycle, which are the six levels of readiness corresponding to the phases of the innovation life cycle.

The five key aspects of the IRL are:

1. Technology: It is the process by which humans change nature to meet their needs and desires. According to Alegre, Chiva, and Lapiedra (2005), technology is not just about artifacts such as computers and software, cell phones, automobiles, aircraft, and medical devices but about all the infrastructure and knowledge necessary for the design, manufacture, operation, and repair of technological artifacts.

2. Market: It is the core strategic responsibility for the customer-supplier relationship. It refers to the groups of consumers or organizations interested in

innovative technology or product and has the resources to buy them (Doyle, 2002).

3. Organization: It refers to the parts of the organization(s) involved in the innovation process whose objective is to implement the innovation, generate specific services, and/or produce goods throughout the life cycle.

4. Partnership: It is a type of business in which the partners share the profits or losses of it. It may include suppliers, resellers, and research partners.

5. Risk: According to Goffin & Mitchell (2005), risk refers to concepts that indicate a potential negative impact on innovation at the business level.

Doyle (2002) presents the 6 phases of IRL (six 'C'), which are:

1. Concept: Basic scientific principles of the innovation have been observed and reported, and the critical functions and/or characteristics have been confirmed through experiments (equivalent to TRL 1-3).

2. Components: Components have been developed and validated, and a prototype has been obtained to demonstrate the technology (equivalent to TRL 4-6).

3. Completion: Technological development has been completed, and the complete system functionality has been proven in the field (equivalent to TRL 7-9).

4. Chasm: It refers to the challenges and difficulties that innovation may encounter when first introduced to the market (early stage).

5. Competition: This is the mature phase of the market when it has reached a state of balance marked by the absence of significant growth or innovation (Moore, 1999). The primary mission in this phase is to maintain and enhance the position of innovation and to deal with competition.

6. Changeover/Closedown: The first one refers to the re-innovation of technology, the inauguration of new markets, the transformation of the business model, and corporate re-invention to seek and develop a competitive advantage. On the other hand, the

second one means the innovation has come to obsolescence and exits. Table 11 shows the emerging framework of IRL based on the literature review and four case studies presented by Lee, Chang, & Chien (2011), to confirm IRL's feasibility.

Technological Development			
	IRL 1 **Concept**	**IRL 2** **Components**	**IRL 3** **Completion**
Technology	-Basic scientific principles observed and reported; -Technology feasibility confirmed for radical innovation:	-Individual components tested -Prototypes demonstrated -IP protected	-Launch-Expertise formed; - IP protected - Technology/product documented; -Design platform - Production Website
Market	-Working with leading customers; -Customer need and demand observed For radical innovation:	-End-customer identified; -Detailed market launch plan issued -Intellectual capital	-Specific needs and requirements of customers known -Market segment, size, and share predicted; -Pricing & Launching issued

	-Locate the initial market		-Information management
Organization	-Strategy fit confirmed; -Informal, loose structure (mainly R&D team)	-Business analyzed and plan issued; -Key individuals involved	-Formalizing organization -Core management -Customer value creation -Collaboration platform
Partnership	-Potential partners identified	-Partners selected; -Calibration established -Customer's voice	-Partnership formally established -Supplier and collaborative patterns
Risk	-Technology risk considered	-Technological risk assessed -Organizational risk considered	-Technological risk assessed;- -Organizational risk assessed

Table 11: An emerging framework of Innovation Readiness Levels (IRL) - Technological Development
Source: Lee et al. (2011)

	Market Evolution		
	IRL 4 Chasm	**IRL 5 Competition**	**IRL 6 Changeover/Closed own**
Technology	-General availability to the whole market -After-sales supports -Design and facilitate continuous innovation - Dynamic Website	- R&D activities; -Technology maintenance enabled; -Technological service provided	-Disruptive innovation identified; -Learning from experiences and re-innovate or exit
Market	-Positioning in the market; -Business model established; -Customer-intimate marketing (feedback); -Competitors identified -Use partnership to compete	-Differentiate products; -Provide service and solutions; -Business model refined -Use partnerships to compete - Marketing strategy	-Declining market confirmed; -Market research for approval to re-innovate or exit

Organization	-Inter-organizational innovations organization -Co-operation between supplier and Designer	-Improved effectiveness and cooperation; -Organizational learning	
Partnership	-Cooperation within a dynamic network; -On-going management		-Cease partnership; -(Academic partners sought)
Risk	-Organizational risk periodically assessed	Organizational risk periodically assessed	-Consideration of the two options; -Changeover or closedown

Table 12: An emerging framework of Innovation Readiness Levels (IRL) - Market Evolution
Source: Lee et al. (2011)

The Technology Readiness Level (TRL) and Innovation Readiness Level (IRL) frameworks are widely used strategic instruments within their respective contexts to assist organizations in making investment decisions regarding new products and business models. To accomplish this, they assess the maturity and viability of emerging technologies. TRL and IRL have the same objective of assessing the maturity level of technologies or innovations. However, their scopes are distinct: TRL focuses primarily on the technical aspects and readiness to deploy a technology, whereas IRL provides a broader and more holistic view, considering market (including partners), regulatory, and organizational factors in addition to technical maturity.

Despite their undeniable advantages, it is equally important to thoroughly analyze their implementation to identify any obstacles that may prevent their full potential from being utilized in project management. The TRL and IRL frameworks are occasionally criticized for their potential subjectivity and bias, indicating that particular care should be taken when applying these models. When using these models for project management, it is essential to remember that their original emphasis was on the technology rather than the operational context in which it will be implemented. By refining this perspective, these tools can become even more effective by incorporating critical factors such as the target market, regulatory environment, and organizational culture – all of which can have a substantial impact on the successful execution of the project. Incorporating these distinctions, for instance, in the questionnaire design used to evaluate a specific technology or innovation against the model, is essential to ensuring that the questions make sense in the context in which they are used.

Even though the TRL and IRL frameworks were not designed specifically for project management and have limitations such as potential subjectivity and an apparent overemphasis on technology, this study acknowledges that their potential application in project management is intrinsically advantageous. Their application in this discipline can be highly advantageous. If their strengths and areas for improvement are understood, these frameworks could be adapted to effectively address the unique challenges and complexities that organizations face when managing projects, as proposed by this research when using the TRL as a basis for selecting the best approach for project management.

2.4. Project Management And Technology Readiness

The definition of technology is something difficult to determine. The word derives from the Greek words “techne,” meaning an art or a skill, and “logy,” meaning a science or study.

The literal meaning of the word technology is according to Webster’s New World Dictionary (Guralnik, 1984) and Webster’s Third New International Dictionary (Gove, 1993) , respectively as:

- The science or study of the practical or industrial arts, applied science; and
- The science of applying knowledge to practical purposes in a particular field.

Many authors attributed the term's origin to Jacob Bigelow's book, Elements of Technology. Treadwell & Bigelow (1829) states that technology was “understood to consist of principles, processes, and nomenclature of the more conspicuous arts, particularly those which involve applications of science, and which may be considered useful, by promoting the benefit of society, together with the emolument of those who pursue them”.

In many cases, it is possible to find the association between the definition of technology with the application of scientific knowledge. However, there are situations in which technology comes before science. While there is much controversy as to who was the first to fly a powered airplane, it is a fact that everyone tested the technology before the science of aerodynamics was developed. Technology may appear before science because “scientific understanding is not necessary to develop the technology. After all, it is possible to know how to produce an effect without knowing how it is produced.” (Nightingale, 2014).

In his research on the origins of technology, Nightingale proposes that the definition, or the way of thinking, about technology is directly related to the user of that technology. From engineers to sociologists, through philosophers and managers, the definitions are vastly different, as can be seen in table 13:

Way of Thinking about Technology	Exemplar user
Technologies are entities that produce artificial functions.	Engineers
Technologies are entities produced by a problem-solving process that changes and transforms the world so that it matches a preconceived Idea, plan, or design to generate a desired artificial function.	Innovation-Managers

Technologies are comprised of artifacts that generate artificial functions, techniques, and the broader institutional regime required for them to operate.	Sociologists
Technology is the outcome of a distributed co-evolutionary process in which functions, knowledge, artifacts, and their environment, mutually adapt to each other.	Historians of technology
Technology is all the knowledge, concepts, experimental processes, tangible and intangible artifacts, and broader socio-technical systems required to recognize technical problems and conceptualize, formulate, research, develop, test, apply, diffuse and maintain effective solutions to those problems as they change through time.	Tech-Governance
Technology covers the artifacts, systems, knowledge, and activities associated with the development, production, and use of artificial functions that have been developed after the conditions were in place for science and industrial production to converge and production to move from machinery to systems.	Historians of Tech-change
Technology is a way of seeing the world in instrumental ends means terms, that projects a bogus scientific objectivity, hides the power of technology, and mistakenly presents things as natural when they are not.	Philosophers

Table 13: Different Ways of Thinking about Technology
Source: Nightingale (2014)

The different definitions and perspectives on technology reinforce Ramanathan's view that “Technology continues to be treated as a “black box” by many managers and writers. It would be futile to ask managers to manage technology effectively when it is unclear what technology is.” (Ramanathan, 1994).

Ramanathan, in his study on the definitions of technology, seeking to “develop a universal definition for technology,” suggests that technology comprises four interrelated components, which receive the definition of “polytrophic components of technology” because they are interrelated and influence each other. Bacteriologists use the term "polytrophic" to refer to organisms that obtain nutrition from multiple sources. The four components, classified as polytrophic, are:

- Object-embodied technology which can be called Technoware,
- Person-embodied technology which can be called Humanware,
- Document-embodied technology which can be called Inforware,
- Institution-embodied technology which can be called Orgaware.

“Technoware consists of tools, equipment, vehicles, physical facilities, and others. Humanware refers to experiences, skills, knowledge, wisdom, creativity, and others. Inforware includes all documentation about process specifications, procedures, theories, and observations, along with others. Orgaware is required to facilitate the effective integration of Technoware, Humanware, and Inforware, and consists of management practices, linkages, etc.” Ramanathan, K. (1994).

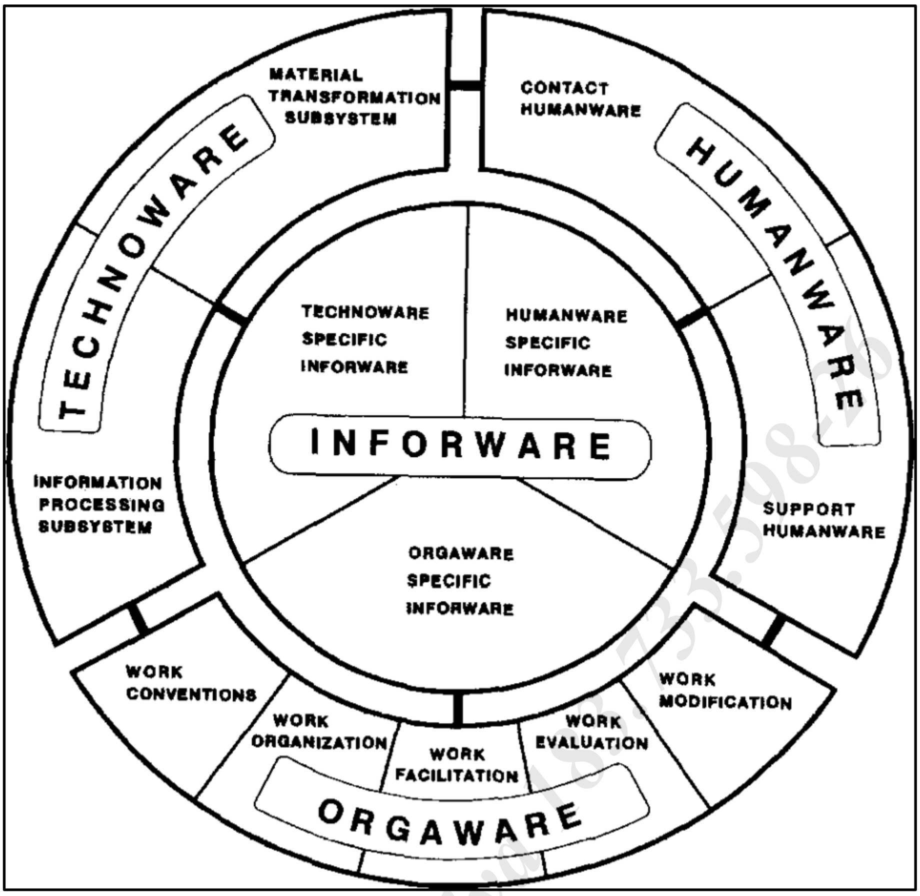

Figure 12: A schematic represen-tation of the components of technology
Source: Ramanathan (1994)

With technology, technologists try to achieve a particular outcome and know the desired result or effect they are looking for (Nightingale, 2014). A similarity can be seen with the definition of projects, “an individual or collaborative enterprise that is carefully planned to achieve a particular aim” (Stevenson, 2010), given that both seek to achieve an aim or result.

A high degree of uncertainty makes experimentation and iteration (to clarify both the objectives and the way to approach and meet them) necessary (Eisenhardt and Tabrizi, 1995).

The association between TRL and Project Management is not a recent idea. The research conducted by Högman & Johannesson (2013) presents a model integrating the Stage-Gate project management technique into the TRL, inserting decision-making stage gates at each TRL, stopping at TRL 6.

“The rationale for stopping at TRL 6 was that higher technology readiness levels are covered by product development which follows its dedicated stage-gate model. When a technology has reached a maturity level of TRL 6, it is ready to be implemented in a product or process, and further maturation is attained throughout that implementation” (Högman & Johannesson, 2013).

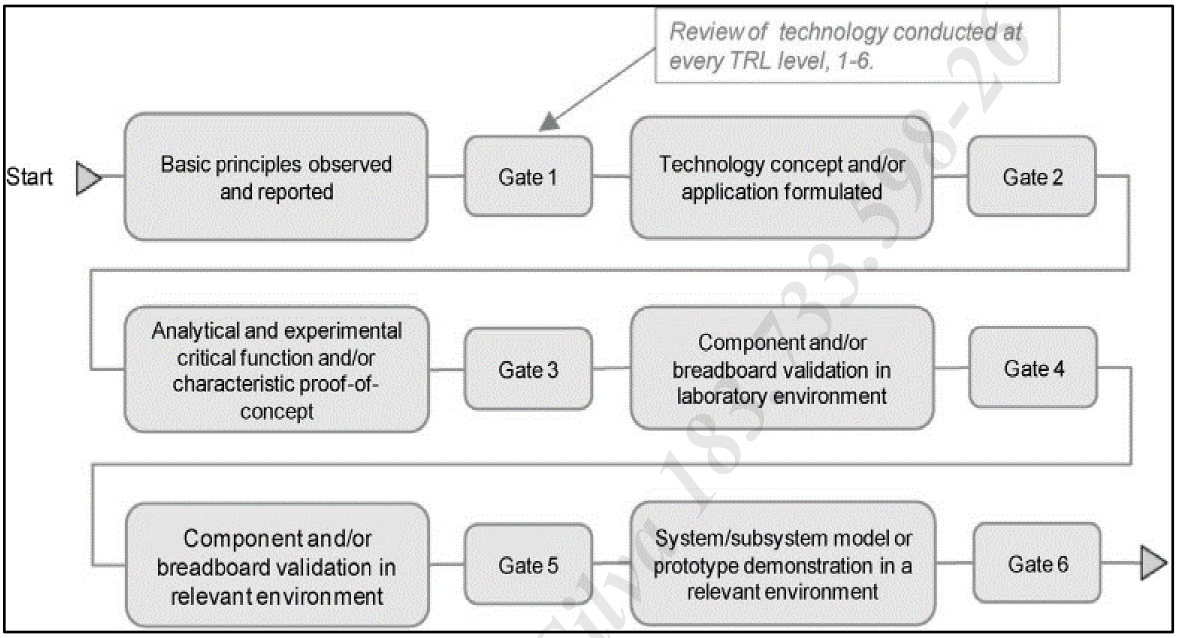

Figure 13: The new stage-gate model implemented in Company 1
Source: Högman & Johannesson (2013)

2.5. Trl Applied To Project Management

NASA's engineering manual, which presents the steps and recommendations for applying the TRLS, guides that, before applying the assessment, “a common set of terminology needs to be established. A primary cause of the difficulty is in terminology; e.g., everyone knows what a breadboard is, but not everyone has the same definition.” (Hirshorn et al., 2017)

Considering NASA’s recommendations, each of the original questions used for the TRL assessment was adjusted to contemplate the specificities related to Project Management. Since projects are a “temporary endeavor undertaken to create a unique product, service, or result.”, the original questions were decomposed into three more questions, except the question regarding TRL 1, which is unique and refers to understanding the problem. The answer "No" to this question, as in the original model, represents the need for a greater understanding of the problem before using the technology in question or, in the case of this research, the Project, that enables a broader coverage of the context of project management: product, services, or results.

The decomposition of the questions into three others can also help in the application of the questionnaire online and reduce the difficulties related to terminology and asymmetry of knowledge already known. NASA's manual for using TRL highlights the terminology-related difficulties when it mentions that: “At first glance, the TRL descriptions appear to be straightforward. It is in the process of trying to assign levels that problems arise. A primary cause of the difficulty is terminology; e.g., everyone knows what a breadboard is, but not everyone has the same definition. Also, what is a ‘relevant environment?’ What is relevant to one application may or may not be relevant to another.” (Hirshorn et al., 2017)

The application of the adapted TRL model follows the same pattern used by the original TRL, that is, from a logical tree, starting at TRL 9 up to TRL 1. Next, the adapter TRL scale will be presented, with the details of each of the twenty-five questions used to assess the level of project management readiness.

TRL 9 - Has an identical unit been successfully operated/launched in an identical configuration/environment?

1. Does a solution to a problem like this already exist, and has it been successfully executed?
2. Has the problem we are analyzing been solved multiple times with the same solution?
3. Is there a product or service available on the market to meet this need?

TRL 8 - Has an identical unit been flight qualified but not yet operated in space or the target environment or launched?

4. Has the problem in question been solved by you or someone else, but only once or for a small group?

5. Are there solutions to similar problems requiring analysis to determine which is best?
6. Is there a product or service ready to solve the problem, already tested and approved, and the next step is just to launch it?

TRL 7 - Has a prototype unit (or one similar enough to be considered a prototype) been successfully operated in space or the target environment or launched?

7. Are solutions available but not yet considered stable or fully reliable?
8. Has any solution to the problem already been built and tested under conditions very close to the real ones but still cannot be strictly considered "done"?
9. Has a unit very close to the product, such as a high-fidelity prototype or a candidate version, been successfully operated by users in the real environment?

TRL 6 - Has a prototype unit (or one similar enough to be considered a prototype) been demonstrated in a relevant environment?

10. Are there known solutions, but not yet fully available for us to use?
11. Has any solution to the problem already been built and tested under relevant conditions, but not exactly the same as the real ones, but still can't be exactly considered “done”?
12. Has a unit that is very close to the product, such as a high-fidelity prototype or a candidate version, been successfully demonstrated in a very close to the real environment?

TRL 5 - Has a breadboard unit been demonstrated in a relevant environment?

13. There are only mature and promising prototypes, but can't they be considered ready-made solutions?
14. Has a “Beta” version of the product, or a medium-fidelity prototype, already been made available for an initial group of users to test?

15. Are there solutions being tested with a small group of users in a controlled environment, unavailable to most users?

TRL 4 - Has a breadboard unit been demonstrated in a laboratory environment?

16. A solution exists conceptually, confirmed as technically and/or technologically viable, but we don't know if people will pay for it or change their behavior to use it?
17. Are there only prototypes in testing that have not yet been used by “real” customers.?
18. A solution to the problem has already been proposed and tested as a prototype, demonstrating to solve the problem potentially, but we do not know if the market will accept it?

TRL 3 - Has analytical and experimental proof-of-concept been demonstrated?

19. Has proof of concept of the idealized solution been demonstrated and indicated to be feasible?
20. Has a mid-level or low-level prototype version of the solution been built and tested, proving the potential of the idea?
21. Are there research experiments or articles demonstrating the feasibility of a particular project or idea?

TRL 2 - Has the concept or application been formulated?

22. Are there ideas for solving this problem described consistently, such as a scientific article or scholarly publication?
23. Is there a clear formulation of the application of a given technology to the solution of the problem?
24. One or more ideas for solving this problem have already been proposed, but there has not yet been confirmation of their feasibility?

TRL 1 - Have basic principles been observed and reported?

25. Are the basic principles of the problem to be solved known and documented?

Figure 14 shows how TRL relates to Walker's (four types of emergency) and Snowden's (Cynefin Framework) decision-making models.

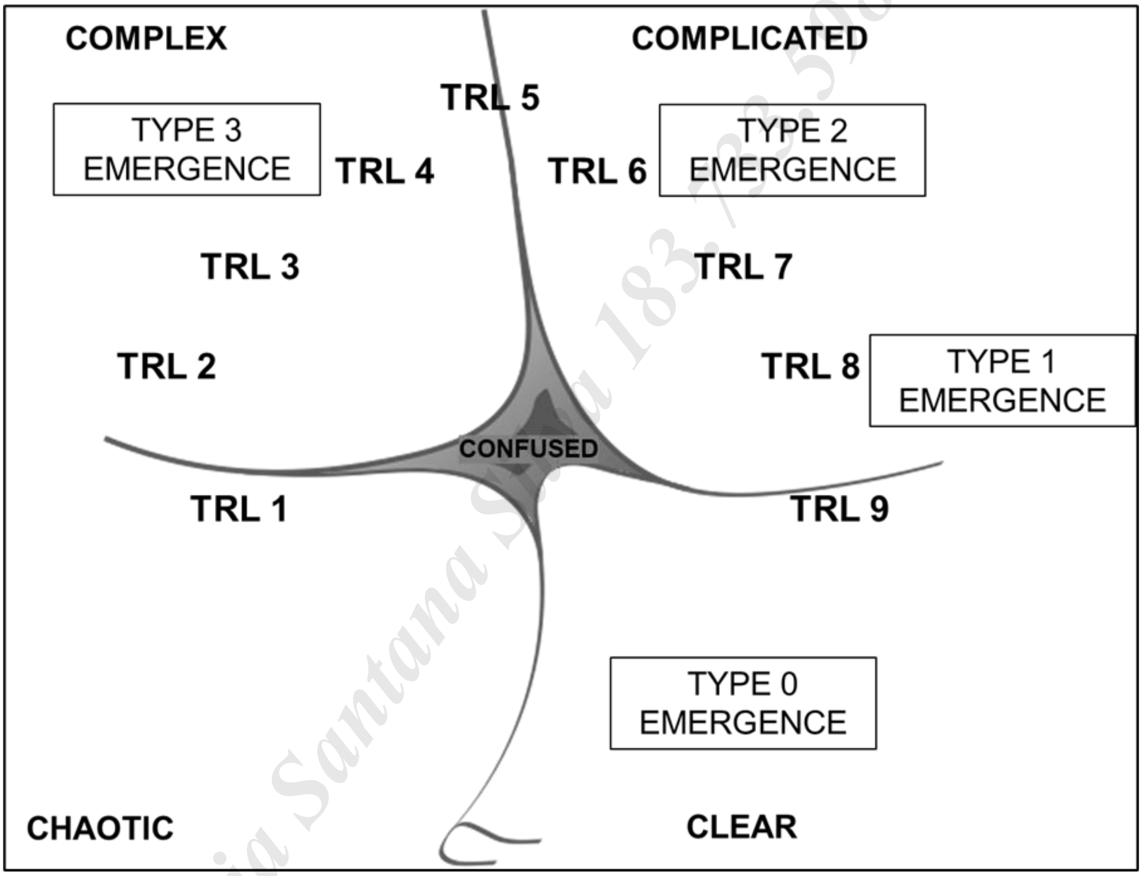

Figure 14: The Walker, Snowden, and TRL models
Source: Author

Type 0 emergence represents the Determinist approach: Knowledge of the system's individual components is sufficient to explain the system's overall behavior fully. This is beyond project management, as "fully explaining the overall behavior of the system" works at a very high level of predictability, which best resembles process management, predictable and repeatable. Therefore, it determines the limit of TRL 9, which will be on the border between the domain of Clear (best practice, repeatable and predictable) and Complicated (good practices, which require analysis).

According to Elford (2012), in the study "A multi-ontology view of ergonomics: applying the Cynefin Framework to improve theory and practice," type 0 relates to a deterministic situation. Types 1 and 2 are located in a systems-oriented approach with an emphasis on expert analysis, and Type 3 is presented here as taking the perspective of a complex system.

The following table 14 presents the association between the models of decision-making, problem-solving, and the project management view.

Type	System Type	Correlation with Project Management
Type 0	Closed, an orderly system with a fully predictive approach	Outside the limits of Project Management
Type 1	An ordered, known system with a predominantly predictive view	Predictive Project Management
Type 2	Ordered system, however, with a strong influence of the complex system	Between Type 1 and Type 3, maintaining a hybrid view of Project Management
Type 3	A complex system, with experimentation in a safe-to-fail environment.	In a complex environment, using adaptive or agile approaches

Table 14: Association between the models of decision-making, problem-solving, and the project management view

Source: Author

In the same way that Type 0 is outside the limits of Project Management, it is possible to notice that there is also a boundary beyond Type 3, in a counterclockwise direction, that precedes Project Management, which would be in TRL 1 and TRL 2, in what could be perceived as a phase prior to the structuring of a project, still in the understanding of the problem and proposition of the solution, during the research and development.

The following table presents the categorization of the project management approach and the respective TRL range. It is essential to note that an approach contains one or more methods, frameworks, and associated processes. For example, when the category references agile approaches, this includes techniques and frameworks such as Scrum, Extreme Programming (XP), Test Driven Development, and others.

Project Management Approach Category	Corresponding TRL range
Research and Development (prior to project management)	1 and 2
Agile Project Management	3, 4 and 5
Hybrid Project Management	6 and 7
Predictive Project Management	8 and 9

Table 15: Approach x TRL
Source: Author

2.6. Rationale of Hypotheses

This section will present the justifications for the research hypotheses supporting the model. The hypotheses were built considering the primary reference for the application of a TRL assessment, called Technology Readiness Assessment, available in the NASA Systems Engineering manual (Hirshorn, 2017).

The NASA manual says that Team members do not necessarily have to be discipline experts. The primary expertise required for a TRL assessment is that the systems engineer/user understands the current state of the art in applications. This shows that, although it is not necessary for the respondent to be an expert, the minimum level of knowledge is necessary for the correct application of the Technology Readiness Assessment; therefore, three hypotheses were built to test the impact of this knowledge on the answer to questions related to the model under development and, also, on the level of satisfaction with the method or approach used by the respondent in the reported project.

H1 – The TRL scale is more useful for Project Managers.

Can the level of knowledge about project management methodologies influence the selection of the best approach or methodology? This hypothesis seeks to validate whether people with different levels of knowledge can benefit more or less from using the TRL model. In some way, the level of knowledge in project management methodologies helps assess the professional's degree of knowledge in the subject. Recognized certification programs such as PMP - Project Management Professional, from the PMI - Project Management Institute, the IPMA - International Project Management Association certifications, levels A and B and PRINCE 2 Practitioner seek to assess, in addition to knowledge, the professional's experience in Project Management. In the case of the first two, inclusive, it is necessary to prove experience through documentation.

The NASA manual for using the TRL scale has a specific section to identify the profile of the "Assessment Team." This session emphasizes that "Team members do not necessarily need to be discipline experts. The key expertise required for a TRL assessment is for the systems engineer/user to understand the current state of the art in applications." This hypothesis seeks to test how important the professional's level of knowledge is for selecting the best approach for managing a project.

Although there are several types of certification in project management, with different levels of difficulty and processes to prove knowledge and experience, it is. It is also clear that professionals can have deep knowledge about project management and, by personal choice, not have any certification. Therefore, it is not possible to say that a person who does not have a certification does not know, but it is possible to say that having a certification, somehow, requires some study on the subject.

H2 – The TRL scale is more useful for professionals who have a high level of knowledge about the problem to be solved

To Walker et al. (2010), “Rather than new methods, a better understanding of the problems to which they apply seems to represent an equally fruitful avenue of future research and innovation” therefore, for the construction of the hypotheses, the level of knowledge of the respondents regarding the problem was an important factor considered.

This hypothesis seeks to verify how much the exploration of the problem can be critical for the selection of the best approach or methodology to manage a project from the TRL scale.

H3 – The TRL scale is more useful for specific project types

The research will consider projects of different natures and approaches, agile, predictive, and hybrid. This hypothesis aims to verify if the TRL scale has the same effectiveness for all types of projects, regardless of the nature of the problem that the project intends to solve.

3. Research Methodology

3.1. Research Model

According to the context and structure defined for the research, the approach adopted was the Comparative Method. This choice is based on the concept presented by Esser & Vliegenthart (2017) that a critical issue in conducting comparative empirical research is to ensure equivalence, that is, the ability to validly collect data that are indeed comparable between different contexts and to avoid biases in measurement, instruments, and sampling.

This research also employs a pragmatic methodological stance, combining qualitative and quantitative research techniques. Hypotheses will be developed to determine which factors influence the selection of a project management approach. Through a questionnaire, issues will be addressed that allow the evaluation of the project's context as indicated by respondents and, using the TRL questionnaire adapted for project management, the most appropriate TRL for the presented project will be determined. A quantitative analysis will be conducted from the collected responses to compare the management approach chosen by respondents to the TRL indicated by the model as being the most appropriate. On this basis, the constructed hypotheses will be validated, the determining factors for selecting the methodology will be identified, and the utility of the TRL scale for determining the optimal approach will be assessed.

Lijphart (1975) defines the comparative method as a method of testing hypothesized empirical relationships among variables based on the same logic that guides the statistical method, but in which the cases are selected in such a way as to maximize the variance of the independent variables and to minimize the variance of the control variables.

In general, the problems of reliability and validity, according to Lijphart (1975), are smaller for the comparative method researcher. It can analyze a smaller number of cases more thoroughly and is less dependent on data it cannot properly evaluate. He can also use the availability of reliable data as a subsidiary criterion in the selection of his cases.

According to Esser & Vliegenthart (2017), comparative research differs from non-comparative work in that it attempts to reach conclusions beyond single cases and explains differences and similarities between objects of analysis and relations between objects against the backdrop of their contextual conditions.

Generally, according to Esser & Vliegenthart (2017), comparative analysis performs several essential functions that are closely interlinked: comparison allows for the testing of theories across diverse settings and for the evaluating of the scope and significance of certain phenomena, thereby contributing to the development of a universally applicable theory (generalization); comparison prevents scholars from over-generalizing based on their own, often idiosyncratic, experiences and challenges claims to ethnocentrism or naïve universalism (relativization).

Based on the concepts presented about the comparative method, the research was structured as follows:

1 – selection of groups of comparable responses so that it is possible to identify differences and similarities;

2 - definition of the variables to be compared, observing the dependence between them.

3 – analysis of common elements among the selected cases to obtain inputs for validating the applied theory.

In order to assess whether the TRL scale could be useful for selecting the best approach to managing a project, the survey was organized as follows: first, data were collected through a Survey form. The answers from the collected data will be unified, presenting the demographic groupings related to the area of activity, and level of knowledge about project management, along with others., still without separating the valid answers from the invalid ones.

The second step of the research considered only the valid answers and, based on them, sought to evaluate which approach was initially selected by the respondents. The TRL indicated by the model for each indicated project, according to table 16, separates the data into two groups: the group (1) that considered the TRL useful and the group (2) that did not find the TRL useful.

The third stage of the research verified if any pattern emerged from the group in which the TRL scale proved useful, seeking to identify under which conditions the model could be applied.

Statistical analysis was performed by applying descriptive and inferential statistical methods. The distribution of absolute and relative frequencies presented qualitative variables. In the inferential part, the following methods were applied to evaluate the distribution of qualitative variables, the Chi-square test of independence was applied when the restriction $npq<5$ occurred, Fisher's Exact test was applied, and the G test for independent samples, as recommends Ayres et al. (2007). An alpha error was previously set at 5% for rejection of the null hypothesis, and the statistical processing was performed in BioEstat version 5.3 and SPSS Version 27.

For the design of this comparative research, according to Aragão & Mendes Neta (2017), as the study aims to make comparisons, with the objective of verifying similarities and explaining the divergences in order to understand human behavior better, it will be collected through the method of survey research, with exploratory purpose, which according to (Freitas et al., 2000) can be quantitative and qualitative and aims to familiarize oneself with the topics and identify their initial concepts, emphasizing in which cases should be measured, in order to open up new possibilities and dimensions of the investigated population.

3.2. Sample and Descriptive Statistics

The survey received 418 responses from individuals connected to the researcher through the project management community, encompassing agile and predictive methods. Owing to the researcher's extensive experience with project offices and long-standing relationship with the Project Management Institute, a large portion of the population connected with him through this channel. Notably, the researcher was among the pioneers in adopting agile methods in Brazilian public service. Additionally, the researcher has offered courses on agile methods to tens of thousands of people, further strengthening his ties to this community. Thus, the panel comprises a diversity of professionals with varied knowledge and experiences, reinforcing the relevance and breadth of the collected data. This factor is pivotal to the research, as the interplay between the different project management methods and the understanding of using the porposed model may be influenced by different contexts and experiences.

Starting with the demographic profile of the sample, which consists of 58,9% of respondents who declared men and 40.4% of women, and 0.7% who preferred not to declare, as shown in figure 15 - Gender below.

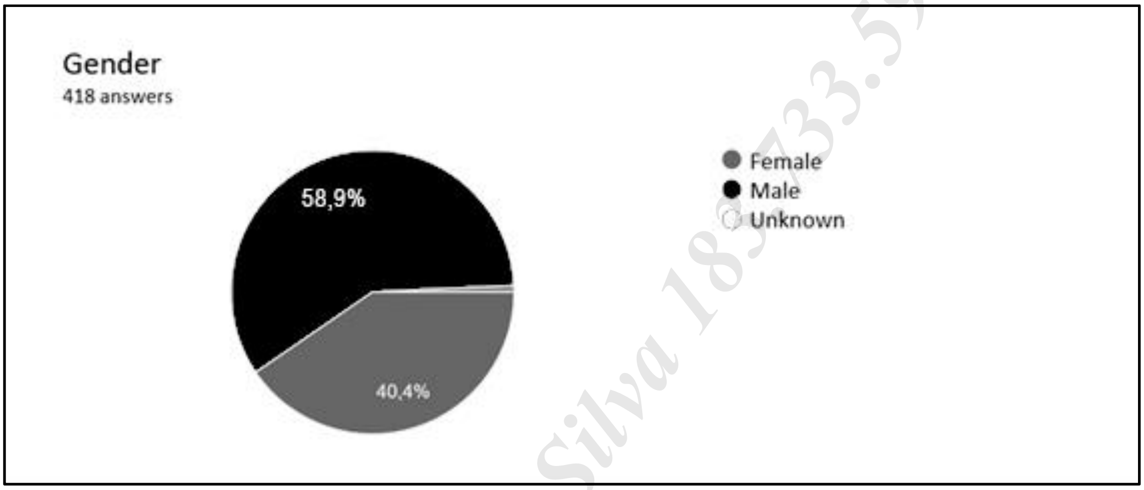

Figure 15: Gender
Source: Author

The next question presented the respondent's level of knowledge about project management methodologies. For this question, a Likert scale was used, in which 1 represented “Little knowledge” and 5 “Deep knowledge.” The answers show 70% of respondents with levels 4 and 5 of knowledge and 30% between intermediate levels. No respondent declared little knowledge of project management methodologies. Because it is a self-declaration, the answer is subjective since the parameter of “little” or “deep” knowledge is relative, and the parameters are individual. What one respondent understands as deep knowledge may not match another respondent's understanding. Therefore, the purpose of this question is to consult the participants' self-assessments rather than compare them to one another.

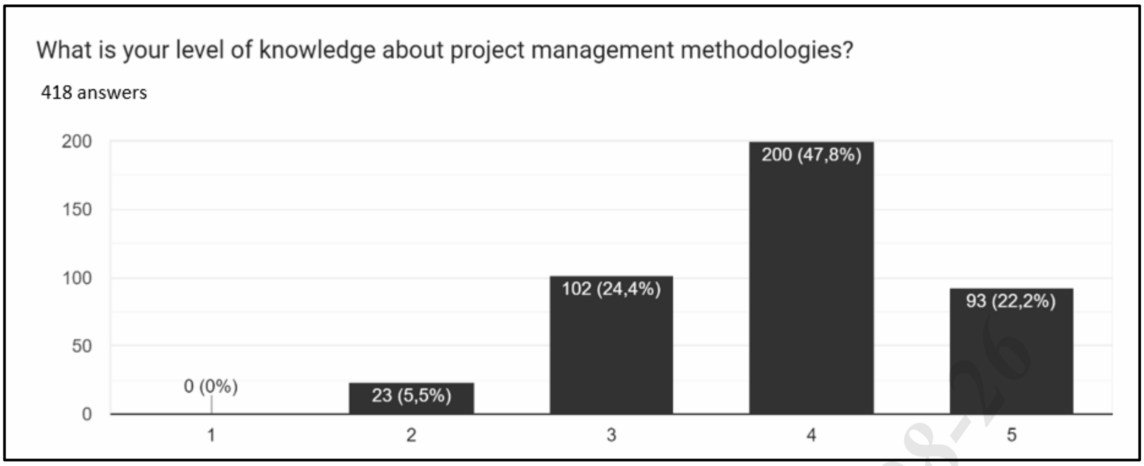

Figure 16: What is your level of knowledge about project management methodologies?
Source: Author

Regarding certifications in Project Management, 52.4% of the respondents declared having some certification, while 47.6% declared not to obtain it. An important point concerning this issue is that there was no distinction between certifications, although there are particular certifications and different levels of depth.

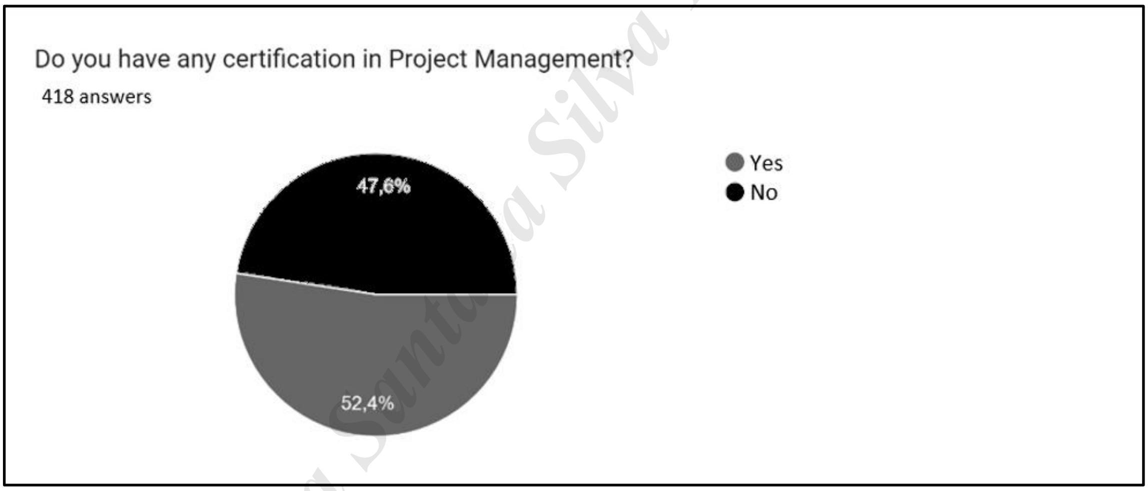

Figure 17: Do you have any certification in Project Management?
Source: Author

About how much the respondent considers the level of knowledge about the problem that the project intends to solve to be necessary. The questionnaire used a Likert scale from 1 to 5, with one being unimportant and five being considered essential. It is possible to see that most respondents recognize this importance, with 91.2% of responses. Only 2.7% do not consider this prior knowledge necessary. This question qualifies the sample of responses, as one of the premises for using TRL is knowledge about the problem being solved.

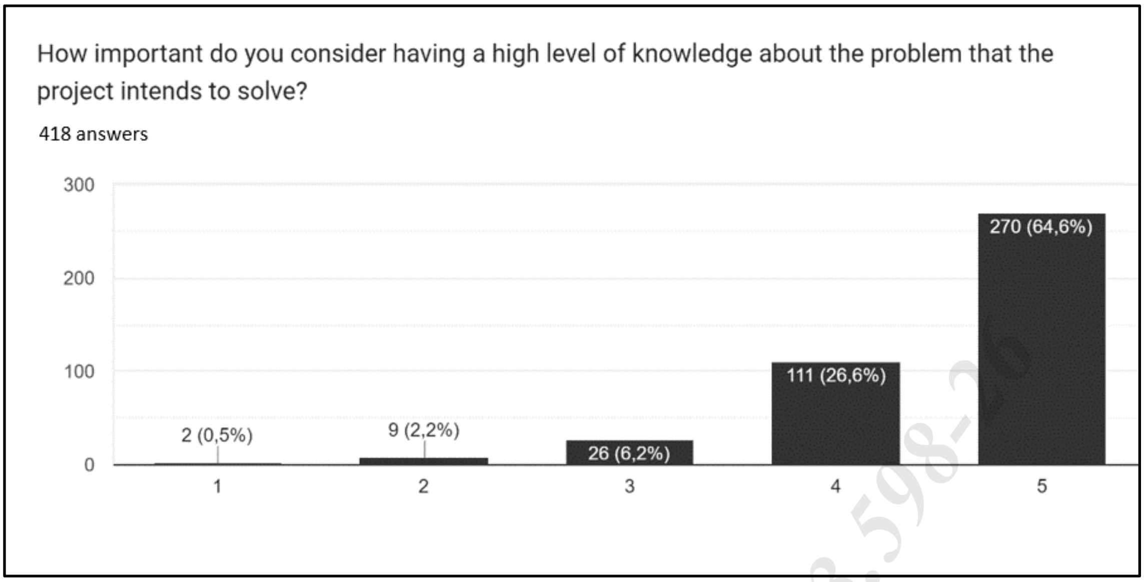

Figure 18: How important do you consider having a high level of knowledge about the problem that the project intends to solve?
Source: Author

Although this question is not directly addressed in the main questions to be answered through this research, it is interesting, in order to know the limitation of the application of this instrument and if the phase in which the project was evaluated, in some way, can influence the applicability of the model or on the participant's level of satisfaction with the selected method or approach. 45.5% of respondents reported ongoing projects, and 33.7% reported completed projects, which suggests that there has already been enough time for interaction between the project and the respondent to assess the degree of satisfaction with the selected method or approach. The other initial stages, which correspond to 20.8% of respondents, have less project time; therefore, the satisfaction level may be more likely to change over time.

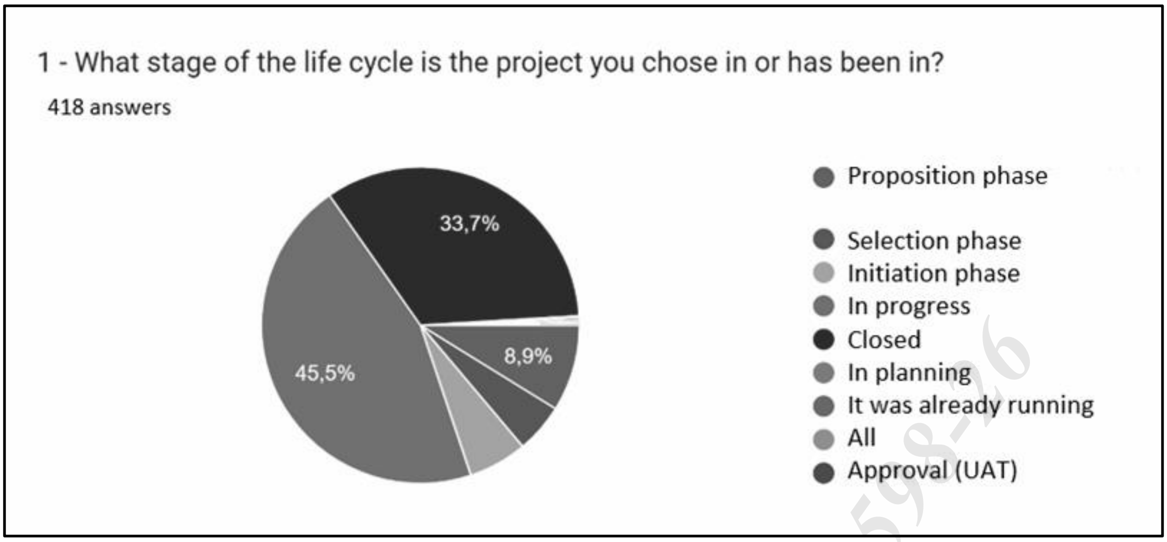

Figure 19: What stage of the life cycle is the project you chose in or has been in?
Source: Author

This question is fundamental for validating all the hypotheses of this research since the participants' level of satisfaction with the approach or method selected for project management was the factor used to divide the groups into "TRL was useful" and "TRL It was not helpful." Before any analysis of the data, observing this response in isolation, the result is expressive for the highest indices. A Likert scale from 1 to 5 was used to assess the level of satisfaction, with level 1 being somewhat satisfied and level 5 being very satisfied. 75.2% of respondents reported being satisfied or very satisfied with the selected method or approach, 18.5% reported not being satisfied or dissatisfied, and only 6.3% reported being dissatisfied.

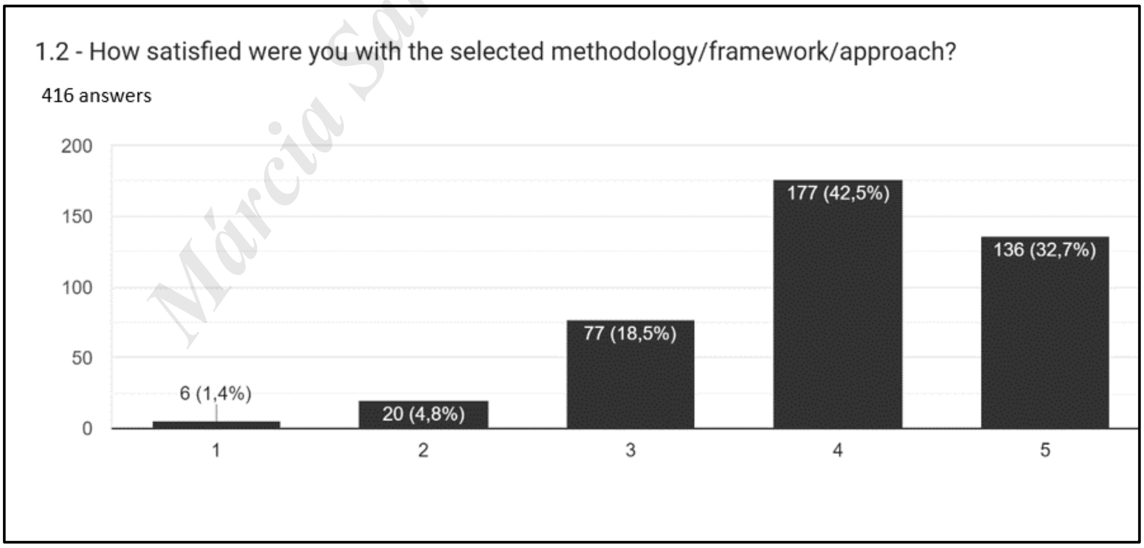

Figure 20: How satisfied were you with the selected methodology/framework/approach?
Source: Author

Are respondents evaluating the problem to be solved before selecting the project management approach or method to be used, or is this selection a posteriori? The answers indicated that practically half of the respondents selected the approach before understanding the nature of the problem, 49.8%.

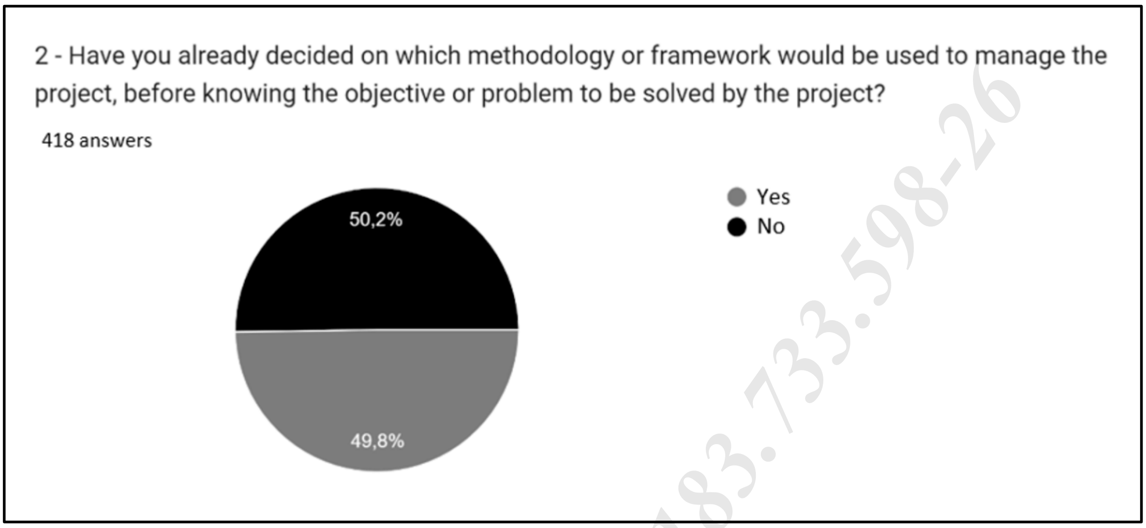

Figure 21: Have you already decided on which methodology or framework would be used to manage the project before knowing the objective or problem to be solved by the project?
Source: Author

This question seeks to verify how much time respondents spent on finding a solution to the problem that the project intends to solve. Data show that 41.4% dedicate ten or more hours to looking for a solution to the problem, while 23.4% of respondents do not dedicate any time.

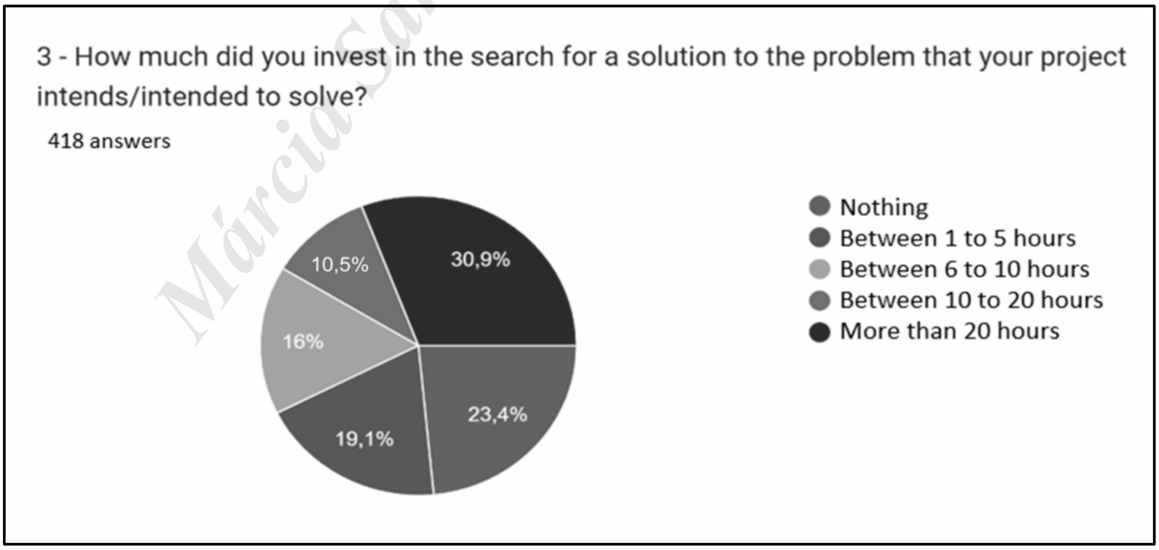

Figure 22: How much did you invest in searching for a solution to the problem your project intends/intends to solve?
Source: Author

This question aims to assess how much the respondent knows about the problem being solved through the project. A Likert scale from 1 to 5 was used for this question, with 1 representing little knowledge and five deep knowledge. Of the total number of respondents, 63.6% reported a high or deep knowledge of the problem, which, when compared with the previous responses, suggests that knowledge of the problem may not be directly related to the number of hours dedicated to search for a solution, in the perception of the respondents.

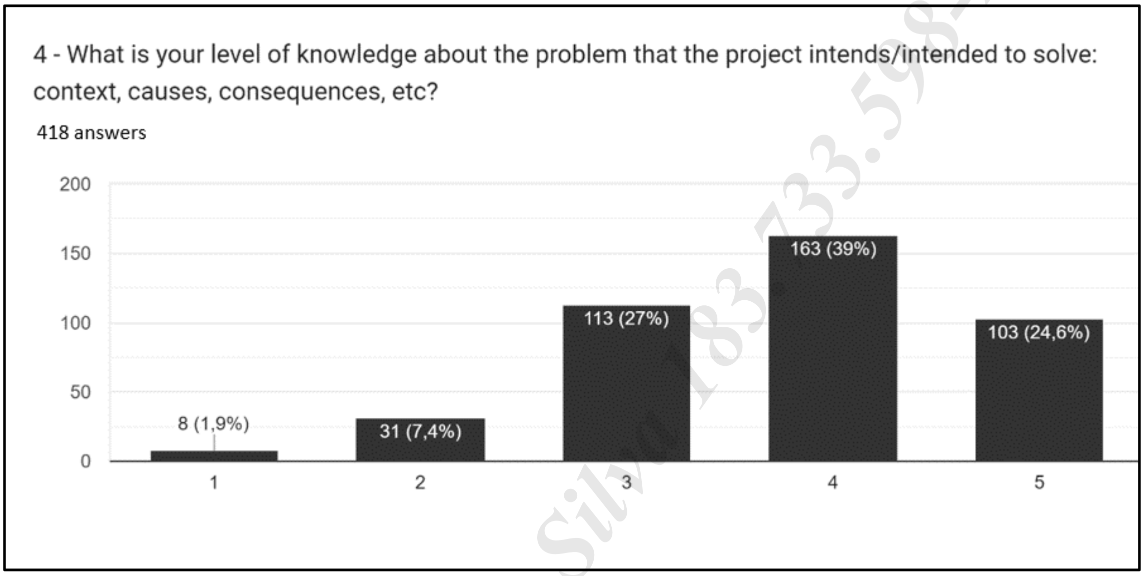

Figure 23: What is your level of knowledge about the problem that the project intends/intended to solve: context, causes, consequences, etc.?
Source: Author

The last question regarding data qualification presents the respondent's role in the reported project. Project-related roles stand out, with 36.8% project managers and 19.9% project coordinators. Roles related to agile methods, such as Scrum Masters and Agile Coaches, represent 14.8%.

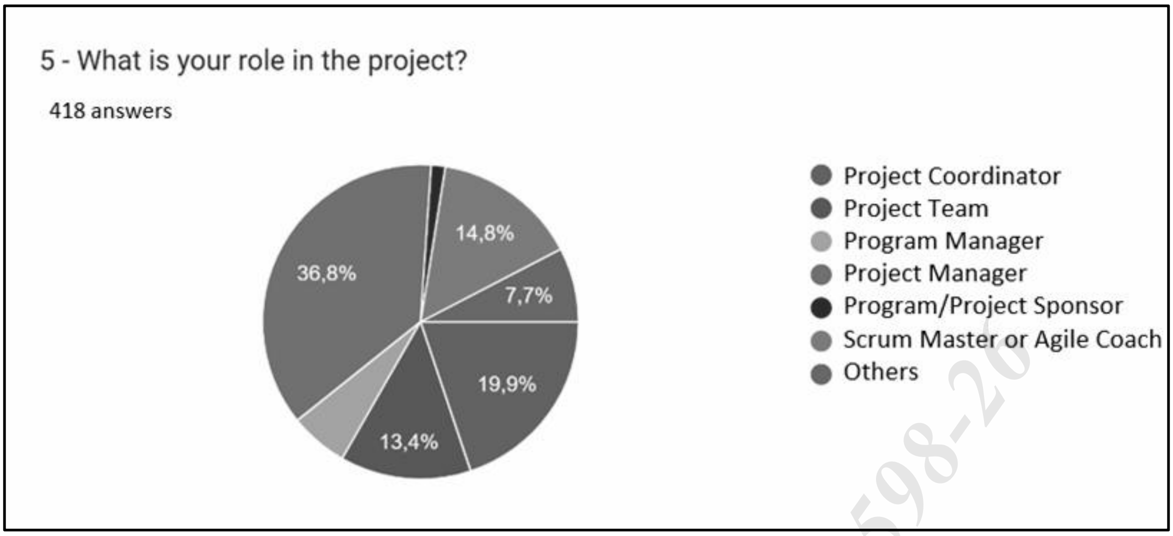

Figure 24: What is your role in the project?
Source: Author

From the 418 initial responses, only those responses were considered valid:

1) In which there was a project management methodology selected initially; otherwise, it would not be possible to determine the respondent's initial satisfaction level, given that it is necessary to classify them into one of the groups: (1) that the TRL scale is proved useful and (2) that the TRL scale was not useful.

24 responses did not use a project management methodology and were excluded from the analysis

2) Responses that after answering the 25 questions referring to the TRL scale, they were classified between TRL 1 and 9. It means there was a minimum understanding of the problem to be solved. Considering these answers would make it impossible to compare the approach initially selected by the respondent and the approach indicated by the model, as there would be no correspondence with the TRL scale.

Eight responses did not fit any TRL classification and were therefore excluded.

3.3. Descriptive Analysis of the Technology Readiness Level Indicator

The present study performed data analysis of n=386 participants, who were classified into two groups according to the agreement between the methodology chosen by the participant in relation to the suggestion issued by the application of the TRL. The groups were established according to the criterion “Was TRL useful?”. N=101 participants formed the Yes group (1). N=285 participants formed the No (not useful) group (2).

1) Respondents classified in Group 1 – Yes Group, are those who:

   a) The approach/methodology used by the respondent in the registered project matched with the indication of the model presented, and the respondent declared to be satisfied or very satisfied with the choice made; you

   b) The approach/methodology used by the interviewee in the registered project does not match the indication of the model presented. The interviewee declared to be dissatisfied, very dissatisfied, or undecided about his satisfaction with the choice made. If he/she could choose another approach/methodology for the project, he/she would select the approach/methodology indicated by the model.

2) Respondents classified in Group 2 – No Group are those who:

   a) The approach/methodology used by the respondent in the registered project does not match with the indication of the model presented, and the respondent declared to be satisfied or very satisfied with the choice made; or

   b) The approach/methodology used by the respondent in the registered project does not match the indication of the model presented. The respondent declared to be dissatisfied, very dissatisfied, or undecided about his satisfaction with the choice made and, if he could choose another approach/methodology for the project, would not select the approach/methodology indicated by the model.

Figure 25 presents a visual model that helps to visualize the two groups (yes and no) specified above.

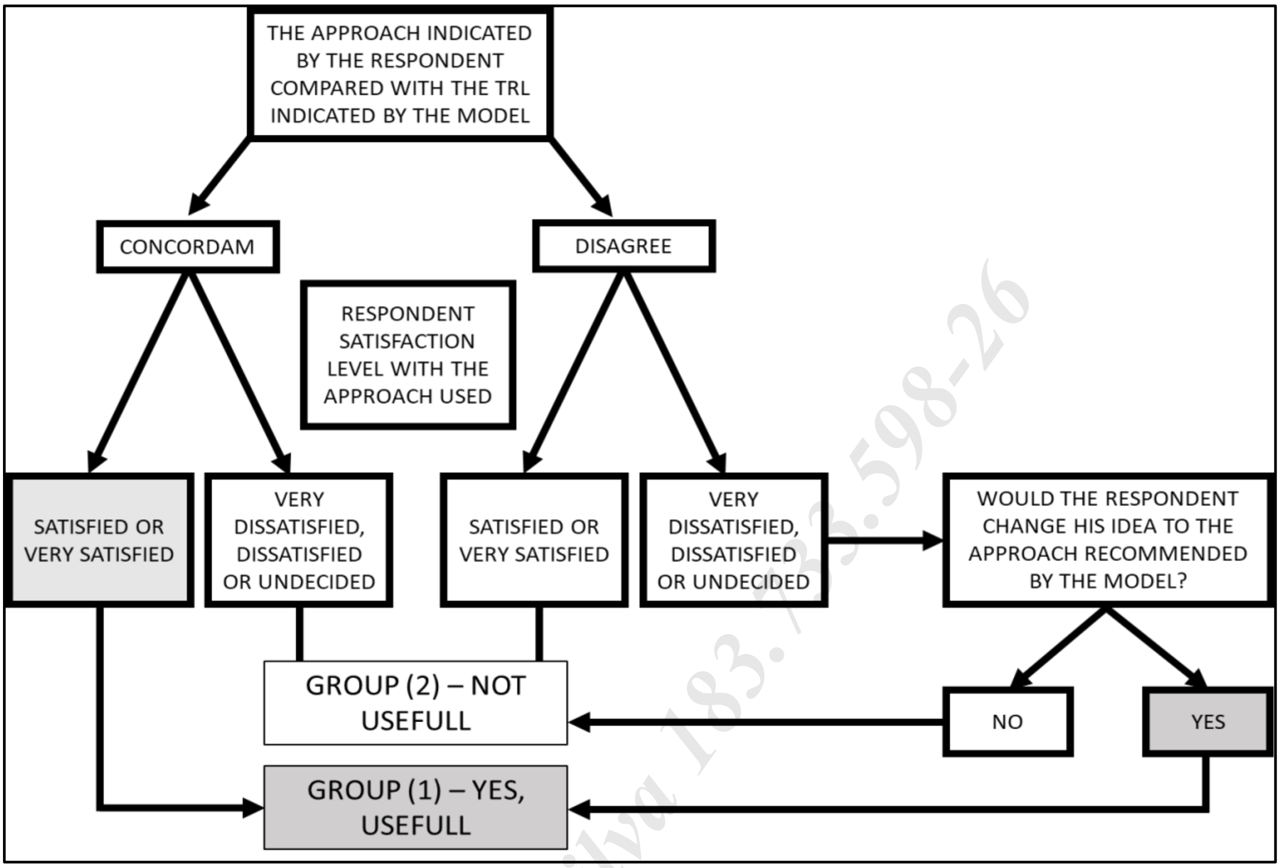

Figure 25: Was TRL useful?
Source: Author

Of the total 386 participants, there are two groups

- Group YES, n=101, agree with TRL (In 1st or 2nd option)
- Group NO, n=285, disagrees with TRL.

The p-value <0.0001*indicates that, comparing the proportions, professionals tend to reject the indication of the TRL scale.

Group YES is formed by n=101 (26.2%). These have the following characteristics:

1. The 1st Option agrees with the TRL suggestion and is satisfied (4 or 5 points of satisfaction). These are n=92 (91.9% of the YES group)

2. 1st Option agrees with the TRL suggestion but has low satisfaction (1, 2, or 3 satisfaction points) and would switch to agree with the TRL. These are n=9 (8.9% of the YES group).

Table 16 presents the gender, certification, and project phase of the n=386 participants. The gender distribution showed that the majority is Male (58.8%) and 40.4% Female. The evaluation of gender distribution according to the utility of TRL resulted in a p-value = 0.0917, which indicates that the difference is insignificant.

The distribution of the variable “Has a certificate” showed that the majority do not have certification (54.7%). The evaluation of the Certification distribution according to the TRL's utility resulted in a p-value = 0.2733, indicating that the difference is insignificant.

The answers to the question “What stage of the life cycle is the project you chose in or has been in?” showed that the most frequent category is “In progress” (47.7%). The evaluation of the distribution of responses according to the utility of the TRL resulted in a p-value = 0.4375, which indicates that the difference is not significant.

Responses to “What is your role in the project?” The most frequent answer was 38.6% of Project Managers. The evaluation of the distribution of answers according to the utility of the TRL resulted in p-value = 0.0435, which is statistically significant, pointing to the Yes (It is useful) group since the category "Project Manager" (45.5%) presented a significant above expected.

	Was TRL useful?						
Question/Answers	**Yes**	**%**	**No**	**%**	**Participants**	**%**	**p-value**
What is your gender							**0.0917**
Woman	33	32.7	123	43.2	156	40.4	
Man	68	67.3	159	55.8	227	58.8	
Prefer not to say	0	0.0	3	1.1	3	0.8	
Do you have any certificate							**0.2733**
No	51	50.5	124	43.5	175	45.3	

Yes	50	49.5	161	56.5	211	54.7	
What stage of the lifecycle is the project you have chosen or been in?							**0.4375**
Proposal	9	8.9	20	7.0	29	7.5	
Planning	0	0.0	1	0.4	1	0.3	
Selection	4	4.0	15	5.3	19	4.9	
Execution	39	38.6	145	50.9	184	47.7	
Initiation	6	5.9	16	5.6	22	5.7	
Already running	0	0.0	1	0.4	1	0.3	
Homologation	0	0.0	1	0.4	1	0.3	
Closed	43	42.6	85	29.8	128	33.2	
All	0	0.0	1	0.4	1	0.3	
What is your role in the project?							**0.0435***
Project Coordinator	21	20.8	51	17.9	72	18.7	
Project team	12	11.9	39	13.7	51	13.2	
Program Manager	10	9.9	14	4.9	24	6.2	
Project manager	46	45.5	103	36.1	149	38.6	
Others	3	3.0	23	8.1	26	6.7	
Project/Program Sponsor	1	1.0	5	1.8	6	1.6	
Scrum Master or Agile Coach	8	7.9	50	17.5	58	15.0	
Total	**101**	**100**	**285**	**100**	**386**	**100**	

*Chi-squared independence test.

Table 16: Gender, certification, the role played, and project stage
Source: Author

Table 17 shows the distribution of answers for [What is your level of knowledge about project management methodologies?]. The p-value = 0.9993 indicates that the distribution of responses does not indicate a fundamental difference according to the usefulness of the TRL methodology. The most frequent response was [Above average], with 48.7%, considering all participants.

What is your level of knowledge about project management methodologies	**Was TRL useful?**				**Participants**	
	Yes	**%**	**No**	**%**	**Freq.**	**%**
Very poor	0	0.0	0	0.0	0	0.0
Below average	4	4.0	12	4.2	16	4.1
Averege	23	22.8	68	23.9	91	23.6
Above average	50	49.5	138	48.4	188	48.7
Excellent	24	23.8	67	23.5	91	23.6
Total	101	100	285	100	386	100

χ2(p-value, df =4) = 0.9993

Table 17: Level of knowledge about the project management methodologies
Source: Author

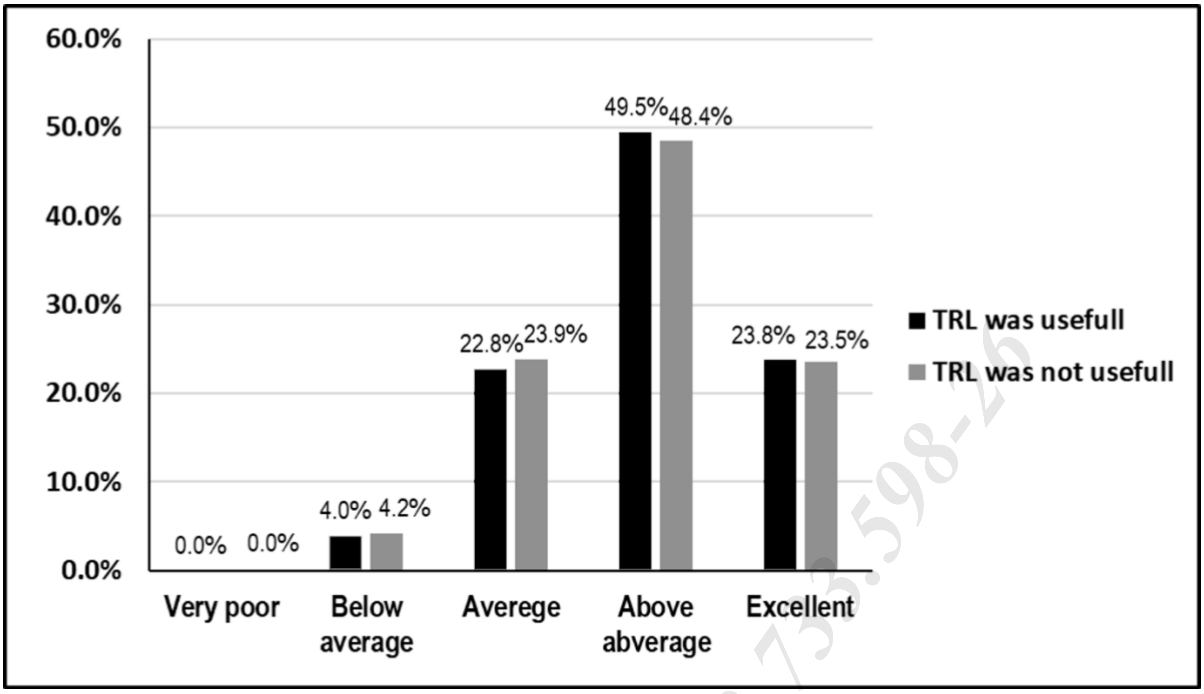

Figure 26: Level of knowledge about the project management methodologies
Source: Author

Table 18 shows the distribution of answers for [How important do you consider having a high level of knowledge about the problem the project intends to solve?]. The p-value = 0.7192 indicates that the distribution of responses does not indicate a fundamental difference according to the usefulness of the TRL methodology. The most frequent answer was [Very important], with 64.7%.

How important do you consider having a high level of knowledge about the problem that the project intends to solve?	**Was TRL useful?**				**Participants**	
	Yes	**%**	**No**	**%**	**Freq.**	**%**
Not importante	1	1.0	1	0.4	2	0.5
Slightly	4	4.0	5	1.8	9	2.3
Moderately	6	5.9	18	6.3	24	6.2
Important	27	26.7	74	26.0	101	26.2

Very importante	63	62.4	187	65.6	250	64.8
Not importante	1	1.0	1	0.4	2	0.5

χ2(p-value, df =4) =0.7192

Table 18: Importance of knowing the problem
Source: Author

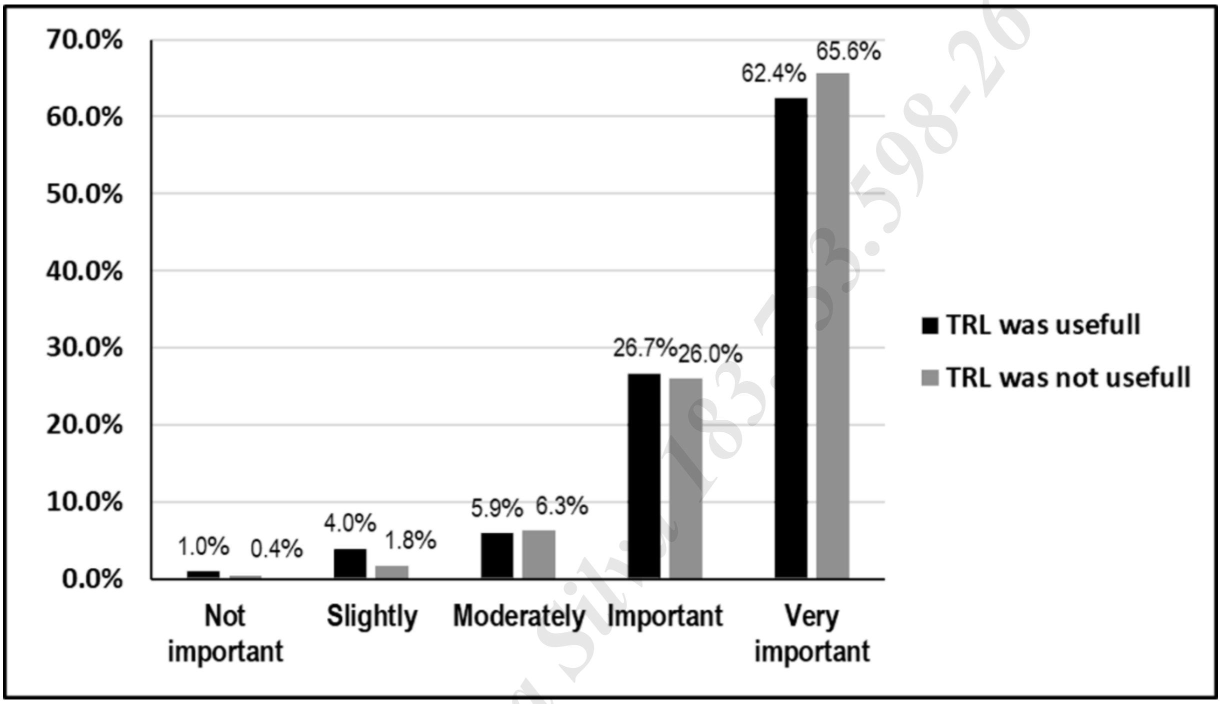

Figure 27: Importance of knowing the problem
Source: Author

Table 19 shows the distribution of responses to [How much did you invest in the search for a solution to the problem that your project intends/intended to solve?]. The p-value = 0.0807 indicates that the distribution of responses does not indicate a fundamental difference according to the usefulness of the TRL methodology. The most frequent answer was [More than 20 hours] with 31.1%.

How much did you invest in searching for a solution to the problem your project intends/intends to solve?	Was TRL useful?				Participants	
	Yes	%	No	%	Freq.	%
No time	30	29.7	61	21.4	91	23.6
1 to 5 hours	18	17.8	54	18.9	72	18.7
6 to 10 hours	9	8.9	52	18.2	61	15.8
10 to 20 hours	8	7.9	34	11.9	42	10.9
More than 20 hours	36	35.6	84	29.5	120	31.1
No time	30	29.7	61	21.4	91	23.6

χ2(p-value, df =4) =0.0807

Table 19: Time invested
Source: Author

Table 20 shows the distribution of responses to [What is your level of knowledge about the problem that the project intends/intended to solve: context, causes, consequences, etc.?] The p-value = 0.0928 indicates that the distribution of responses does not indicate a fundamental difference according to the usefulness of the TRL methodology. The most frequent response was [Above abverage] with 39.6%.

What is your level of knowledge about the problem that the project intends/intended to solve: context, causes, consequences, etc.?	Was TRL useful?				Participants	
	Yes	%	No	%	Freq.	%
Very poor	2	2.0	4	1.4	6	1.6
Below average	4	4.0	26	9.1	30	7.8
Averege	35	34.7	65	22.8	100	25.9
Above average	32	31.7	121	42.5	153	39.6
Excellent	28	27.7	69	24.2	97	25.1
Very poor	2	2.0	4	1.4	6	1.6

χ2(p-value, df =4) =0.0928

Table 20: Knowledge about the problem
Source: Author

4. Discussion

To understand the usefulness of the TRL scale for choosing the best approach/methodology for managing a project, this work studied the application of the TRL scale adapted to Project Management. Thus, seeking to understand the usefulness of this model from the point of view of the Project Manager or equivalent role, this session will discuss the possibilities of results from the hypotheses, the results of each of the hypotheses, and the general contributions of the proposed model.

4.1. Presentations and the possibility of results from the hypotheses

From the universe of 386 participants, there were n=101 (26.2%) participants whose opinion agreed with the TRL suggestion (opinion in the first choice or the second choice agreed with the TRL), a group for which the model proved to be useful. On the other hand, there were n=286 (73.8%) participants whose choice disagreed with the TRL, a group for whom the model was not useful.

NASA's official manual for using TRL highlights the difficulties related to terminology when it mentions that: “At first glance, the TRL descriptions appear to be straightforward. It is in the process of trying to assign levels that problems arise. A primary cause of the difficulty is terminology; e.g., everyone knows what a breadboard is, but not everyone has the same definition. Also, what is a “relevant environment?” What is relevant to one application may or may not be relevant to another.” (Hirshorn, 2017).

The manual points out that many of the terms used in the TRA (Technology Readiness Assessment) assessment had their origins in the field of engineering, which results in the use of very specific terms that, perhaps, make it difficult to understand what the question wants to solve. Predictive project management has its origin intrinsically connected with engineering. Snyder (1987) noted that modern project management was started in 1958 with the development of CPM/PERT, which may explain the fact that predictive projects had greater affinity with the TRL scale since its origin also refers to the field of engineering and, therefore, the terminology would retain greater similarity than, for example, agile and hybrid projects. (Snyder, 1987)

Taylor's scientific management presents a reductionist and mechanistic approach, task-oriented and division of labor into its smallest task or unit to discover the universal law or "the best way" to do each job. According to Whitty & Schulz (2007), Henry L. Gantt, usually remembered as the inventor of the Gantt Chart and a great name for the history of project management, began his professional association with Taylor at Midvale Steel Company in 1887. Taylor's vision influenced Gantt's work and is connected to Modern Project Management's beginnings.

The strong correlation between the origins of project management, scientific management, and predictive approaches may have influenced the terminology of the TRL scale and, thereby, its interpretation, favoring respondents with more experience in traditional project management. The work of Stephen Jonathan Whitty, as portrayed in Figure 28, discusses the impact of Puritan ideology on aspects of project management and presents some key points that enable the observation of the correlation between modern project management and Taylorism. This influence of Taylorism on project management may have introduced a bias into the TRL scale. Taylorism, in its pursuit of efficiency through standardization and control, might have shaped the questions of the TRL scale in a way that resonates more with predictive project management approaches.

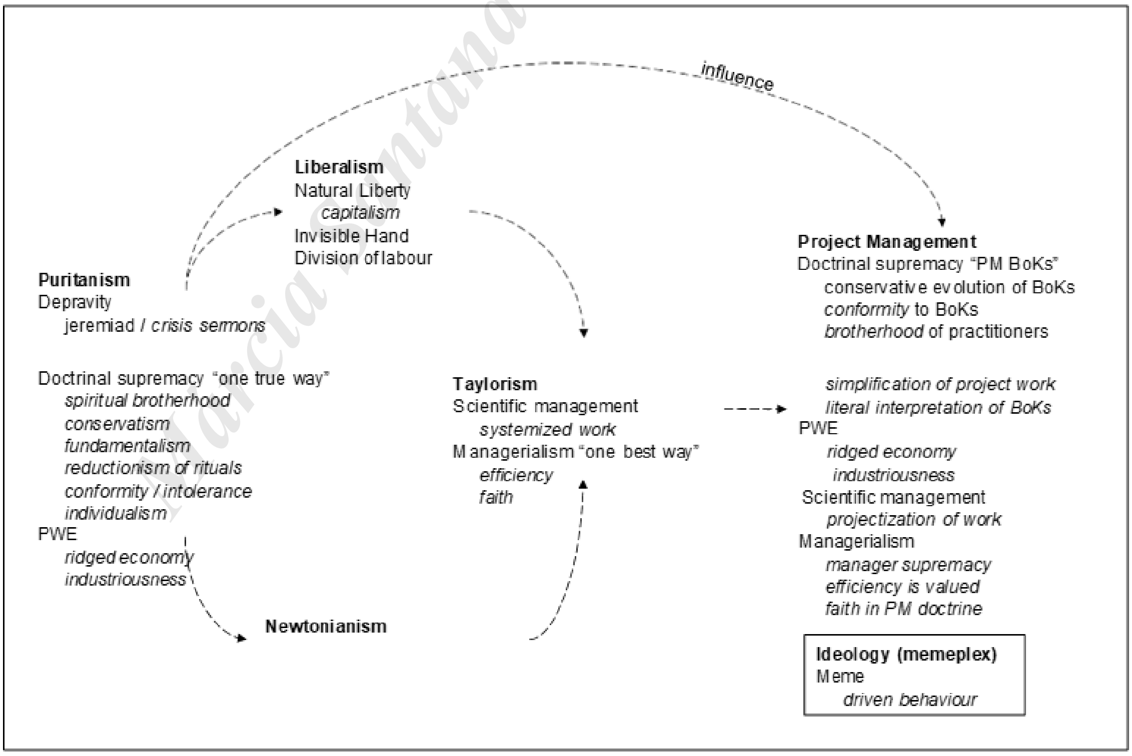

Figure 28: The evolution of Puritan memes and their influence on PM.
Source: Whitty & Schulz (2007)

Table 21 summarizes the hypotheses investigated in this research and the extent to which the data obtained were sufficient to support them. Each of the hypotheses will be discussed in detail in the following topics.

Hypotheses	P-Value	Result
H1 – The TRL scale is more useful for project managers	0.0435	Supported
H2 - The TRL scale is more useful for professionals who have a high level of knowledge about the problem to be solved	0.0807	Not supported
H3 - The TRL scale is more useful for specific project types	0.027	Supported

Table 21: Hypotheses formulated
Source: Author

4.1.1. H1 - The TRL scale is more useful for Project Managers.

Responses to "What is your role in the project?" The most frequent answer was 38.6% of Project Managers. The evaluation of the distribution of answers according to the utility of the TRL resulted in p-value = 0.0435, which is statistically significant, pointing to the Yes (It is useful) group since the category "Project Manager" (45.5%) presented a significant above expected. Figure 29 compares the other papers referring to the answers presented. The research concludes that, for project managers, the TRL scale proved to be useful. This means that the indicated TRL, after answering the 25 questions of the model, 45.5% of the Project Management Category can be classified in one of the following two conditions:

1) The approach/methodology used by the respondent in the registered project coincides with the indication of the model presented, and the respondent declared to be satisfied or very satisfied with the choice made.

2) The approach/methodology used by the respondent in the registered project does not coincide with the indication of the model presented. The respondent declared to be dissatisfied, very dissatisfied, or undecided about his satisfaction with the choice made and, if he could choose another approach/methodology for the project, would select the approach/methodology indicated by the model.

A possible explanation for this significant difference is in NASA's manual for applying the TRL, in which Hirshorn, & Jefferies (2016) introduces the Technology Readiness Assessment. In this publication, the authors point out that, in order to have a "well-balanced, experienced assessment team," it is not necessary that they be experts, but that the primary expertise required is that the person responsible for the assessment "understands the current state of the art in applications.", being people who understand the challenges of inserting technology at various stages of the product life cycle. Professionals with a great deal of knowledge about the project would possibly have a better condition for using the TRL scale and, therefore, would find and perceive greater utility in its application.

The perception of the scale's usefulness can also be observed in the research of Högman & Johannesson (2013), that created a method based on TRL and Stage Gates, "Applying stage-gate processes to technology development," analyzing the experience from six hardware-oriented companies. After applying the model presented in the research, especially with Project Managers, the authors found that for professionals with knowledge in project management who were very satisfied with the model, the reason was that "their projects reached a very high level of maturity, with clearly expressed objectives and limited need for iteration."

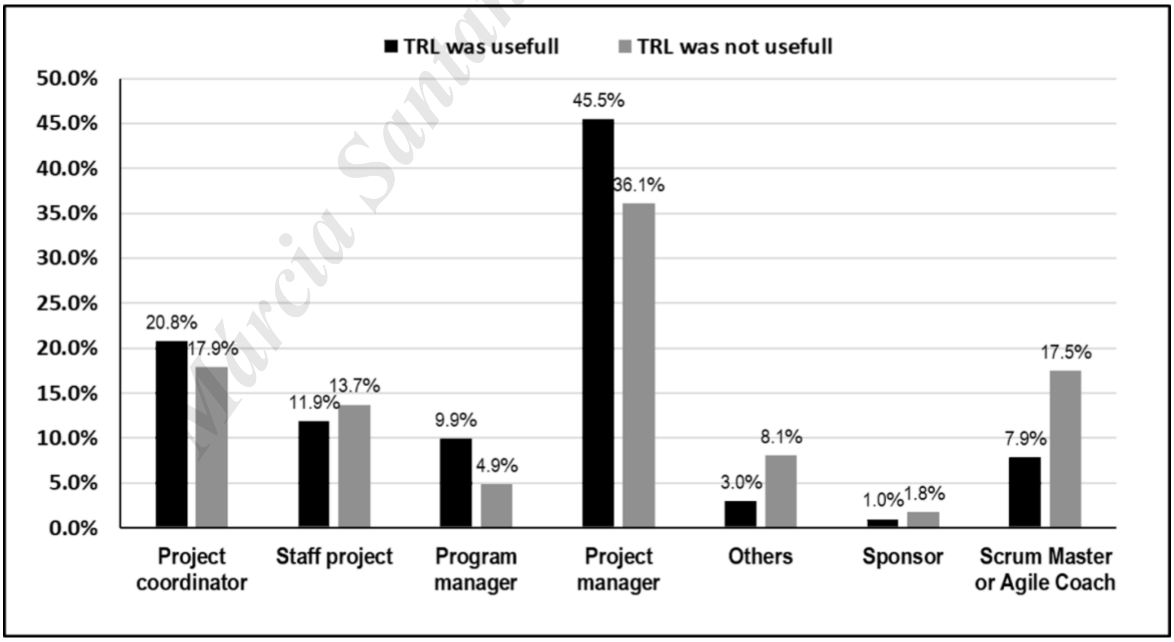

Figure 29: What is your role in the project?
Source: Author

In the research "Understanding project success through the analysis of the project management approach" regarding Project Management Certifications, the author concludes that "we found no difference in importance ratings between certified and non-certified project managers. However, on high-performing projects, certified project managers scored significantly higher in project success than non-certified ones." (Rolstadås et al., 2014). This research also showed no difference between certified and non-certified Project Management Professionals regarding the usefulness of the TRL scale (p-value = 0.2733).

4.1.2. H2 – The TRL scale is more useful for professionals who have a high level of knowledge about the problem to be solved

The quote, "If I had an hour to solve a problem, I would spend 55 minutes thinking about the problem and five minutes thinking about solutions.", attributed to Albert Einstein, summarizes the main objective of this hypothesis.

The data collected show that 91.2% of respondents consider it reasonably important, important, or very important to know about the problem the project intends to solve. Once the importance of understanding the problem was recognized, respondents were invited to state their understanding of the problem. 63.6% reported a high or deep knowledge of the problem that the project intends/intended to solve, as well as the context, causes, consequences, and others.

This question sought to assess the time devoted by respondents to understand the problem before starting to solve this problem through a project. Data show that 41.4% dedicate ten or more hours to understanding the problem, while 23.4% of respondents do not dedicate any time.

The responses indicate that they did it in addition to understanding the importance of knowing the problem. The biggest finding regarding this hypothesis comes with the answer to the question to verify if the respondents are evaluating the problem to be solved before selecting the project management approach or method to be used or if this selection is a posteriori. The answers indicated that practically half of the respondents selected the approach before understanding the nature of the problem, 49.8%.

The answers indicate that, although the respondents understand the importance of understanding the problem and dedicating efforts to it, the selection of the approach/methodology does not necessarily occur after understanding the problem. This may explain the analysis presented in figure 30, which shows the distribution of responses to [How much did you invest in the search for a solution to the problem that your project intends/intended to solve?] from the point of view of the usefulness of the TRL scale. The question that got the p-value = 0.0807 indicates that the distribution of responses does not indicate a real difference according to the usefulness of the TRL methodology. However, the most frequent answer was [More than 20 hours] with 31.1%.

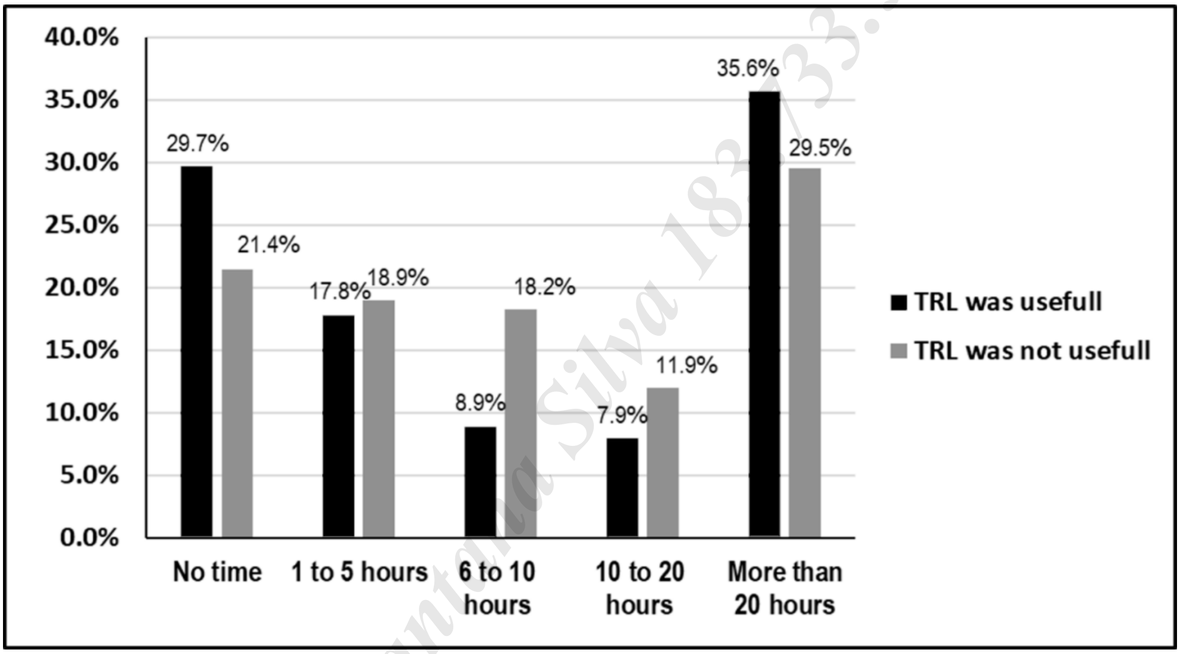

Figure 30: Time invested
Source: Author

Figure 31 shows the distribution of responses to [What is your level of knowledge about the problem that the project intends/intended to solve: context, causes, consequences, etc.?] The p-value = 0.0928 indicates that the distribution of responses does not indicate a real difference according to the usefulness of the TRL methodology. The most frequent response was [Above abverage] with 39.6%.

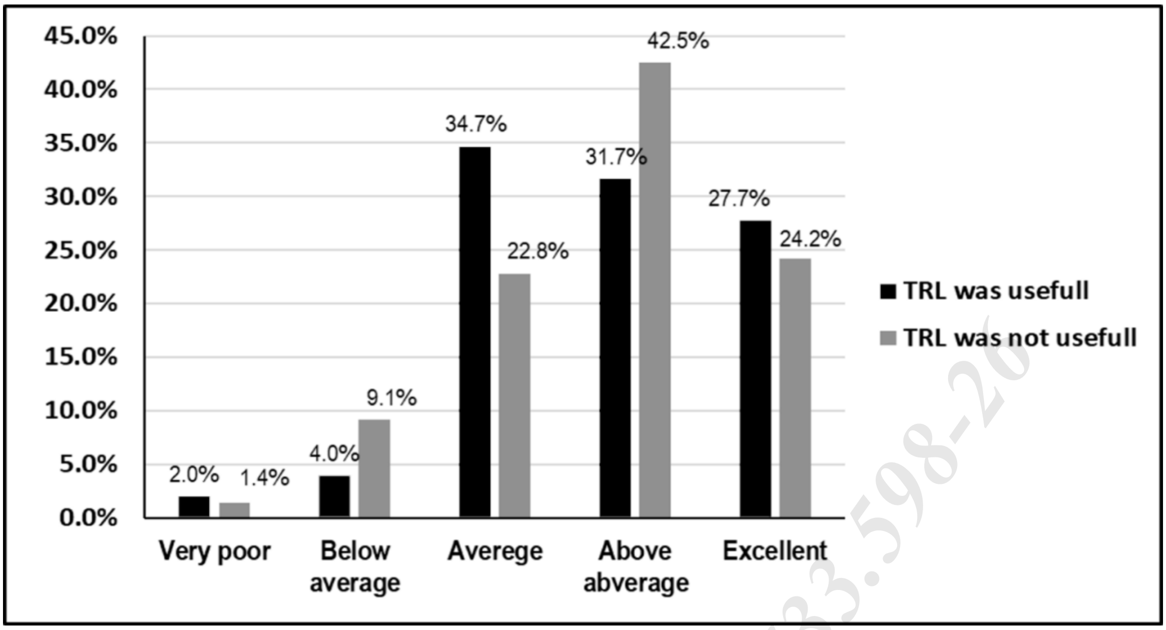

Figure 31: Knowledge about the problem
Source: Author

Figure 32 presents the assessment of the TRL scale's usefulness level when the respondent chose the project management approach/methodology. The choice of a methodology before understanding the problem occurred in 50% of the participants. The evaluation of the previous choice according to the usefulness of the TRL methodology resulted in p-value =0.0054* (statistically significant), which indicates that when a previous choice of a methodology is made (62.4%), the usefulness of the TRL is significantly above the expected percentage.

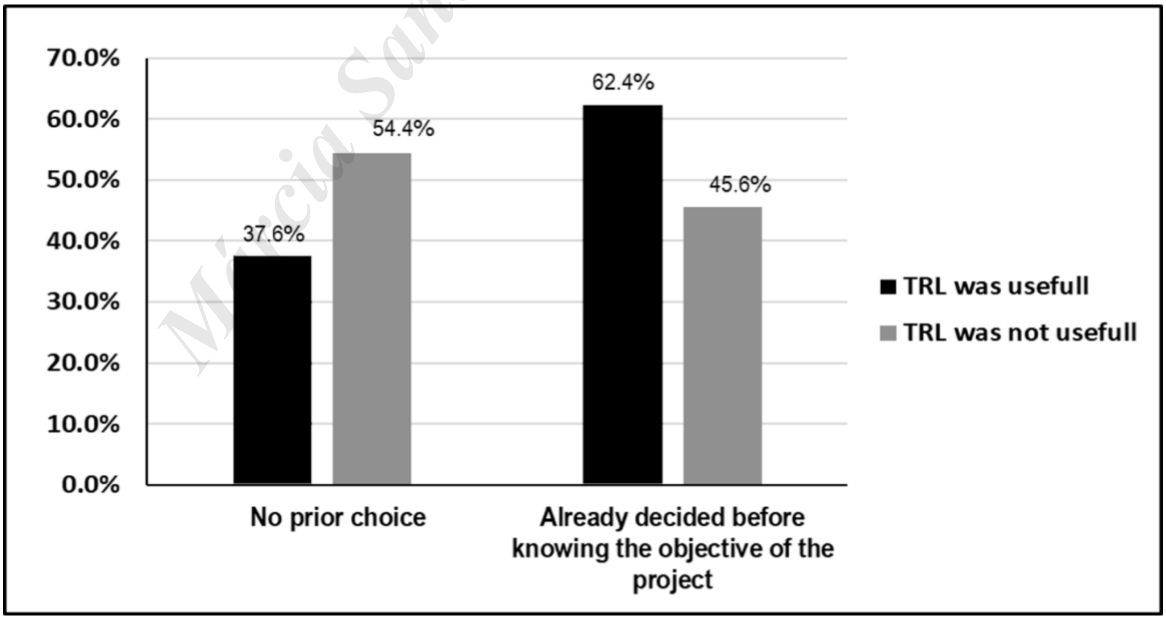

Figure 32: Already decided before knowing the objective of the project
Source: Author

Although the literature on projects suggests that understanding the problem comes a priori: "Problem exploration is most typically recommended in the initial stages of the project so that the generation, evaluation, and communication of design ideas build on a well-developed understanding of the problem being addressed" (Vasconcelos, 2016), the hypothesis is not supported by the data and raises more questions about the relationship between the success of a project and prior knowledge of the problem it intends to solve.

The questions that emerge from the non-validation of this hypothesis are:

1) Was the TRL scale most useful for people who selected the project management approach/methodology after understanding the problem?

2) Suppose the respondents had selected the project management approach/methodology after understanding the problem. Would the indication of the TRL scale coincide with the option of greater satisfaction for the respondents?

4.1.3. H3 – The TRL scale is more useful for specific project types

The parameter "level of satisfaction" was what this research chose to understand how much an approach/methodology is useful for the professional who participated as a project manager or equivalent role.

In the group that agreed with the TRL suggestion (n=101), there were 84.2% (n=85 participants) satisfaction level was compared (Agile x Hybrid x Predictive), using the Kruskal-Wallis test (p-value =0.0058 *, H statistic = 10.3, Degrees of freedom =2, is highly significant) which confirmed the following levels of satisfaction: Agile (satisfaction 3.5±1.0), Hybrid (satisfaction 3.5±1.2) and Predictive (satisfaction 4.3±0.6). Essa comparação aponta para as abordagens preditivas como as apresentaram maior índice de satisfação.

Another comparison carried out found that in the (NO) group, in which TRL was not useful (n=285), the level of satisfaction was lower (3.9±0.0 satisfaction) when compared with those in the (YES) group, who chose the Predictive methodology, the p-value =0.0046* (U Statistic = 9555.4, Mann-Whitney U Test) indicates statistically significant difference.

Figure 33 shows that the most frequent first-choice methodology was Agile (46.6%). The evaluation of the first choice according to the usefulness of the TRL methodology resulted in a p-value <0.0001* (highly significant), which indicates that it points to the Predictive methodology (84.2%) with a higher than expected frequency within the Yes group (it was useful).

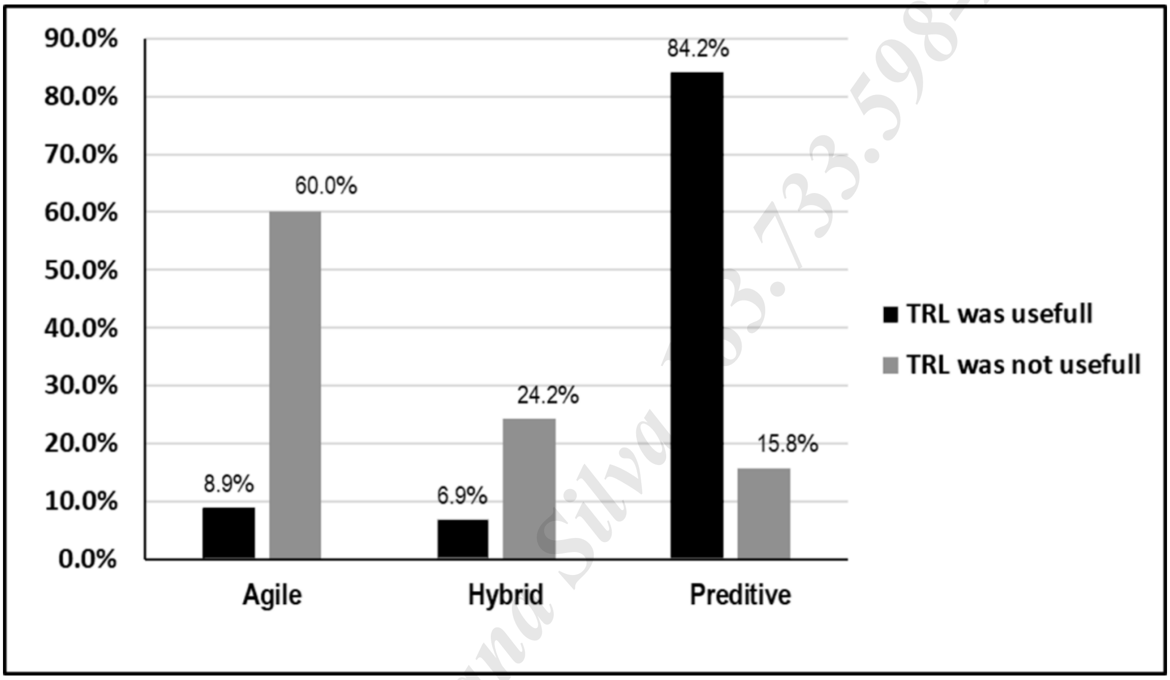

Figure 33: Methodology, first choice.
Source: Author

The methodology most frequently suggested by TRL was Predictive (85.8%). The evaluation of the usefulness of the methodology suggested by the TRL resulted in p-value =0.0027* (statistically significant), which indicates that the Agile methodology (7.9%) had a higher frequency than expected within the Yes group (it was useful), as can be seen in figure 34.

According to the research "Applying stage-gate processes to technology development Experience from six hardware-oriented companies," Högman & Johannesson (2013) conclude that "In particular, projects with low maturity in problem formulation or solution, requiring, in turn, repeated experimentation and iteration, were unsuccessful when trying to use the model.", which confirms the fact that predictive projects attested to greater utility of the TRL scale.

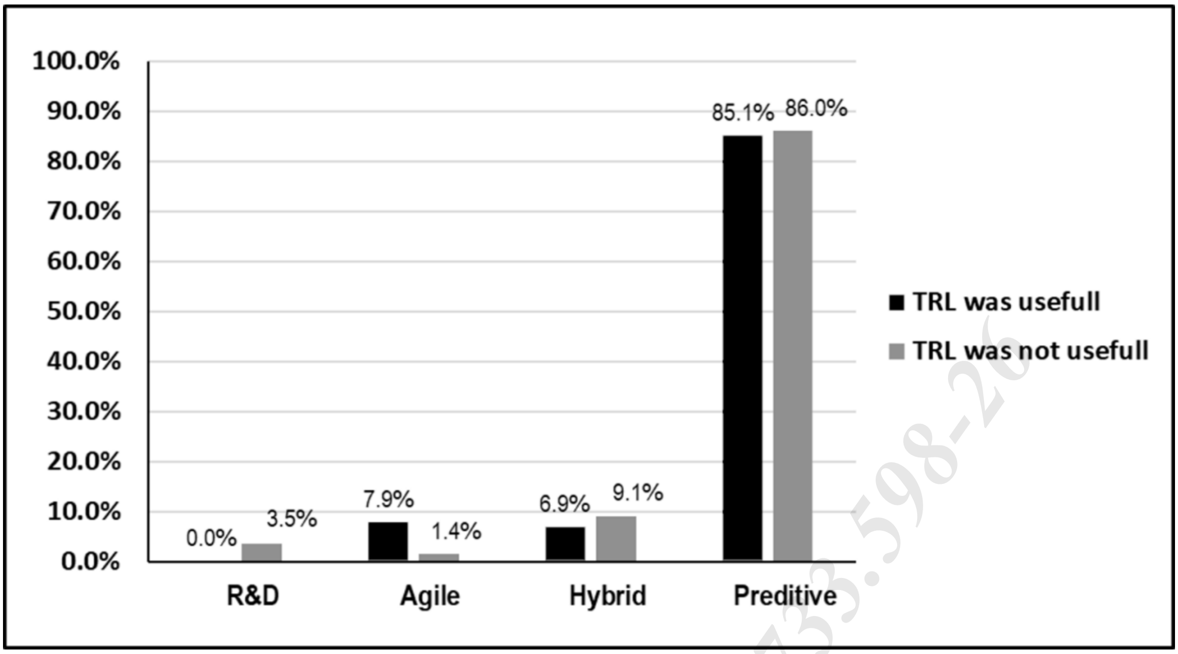

Figure 34: Methodology suggested by TRL
Source: Author

The approach suggested by the most frequent TRL was approach #9. The evaluation of the usefulness of the TRL methodology according to the suggested approach resulted in p-value =0.0072* (statistically significant), which indicates that when the suggested approach is #9 (71.3%), the usefulness of the TRL is significantly above the expected percentage.

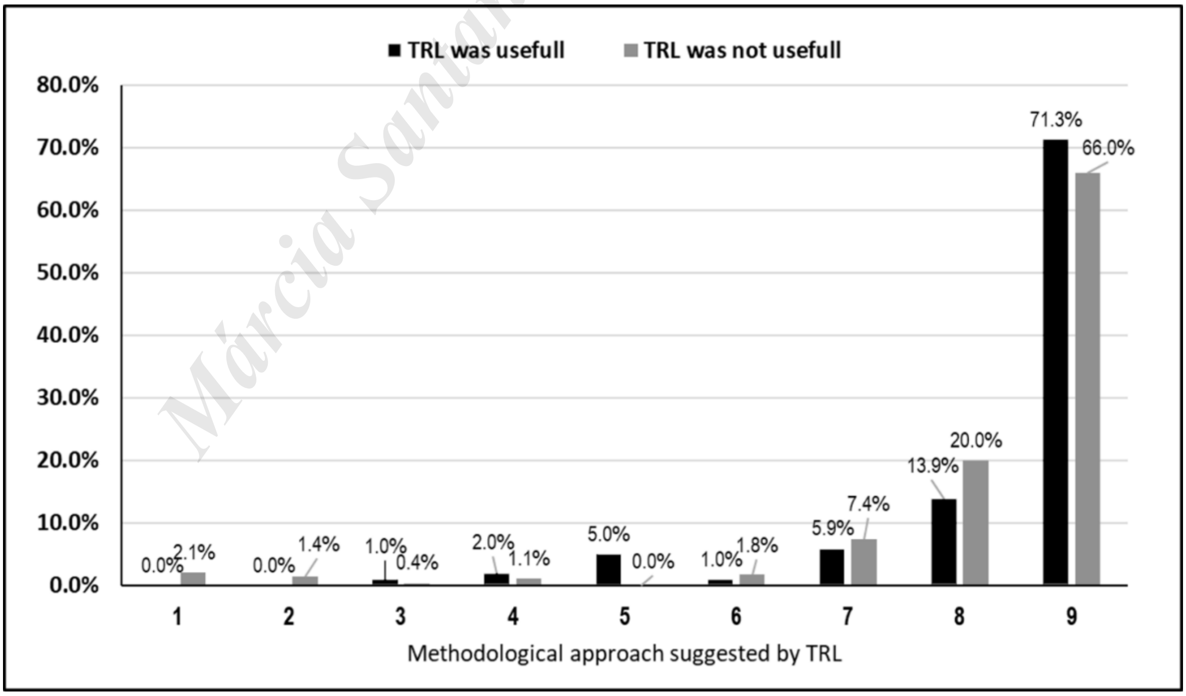

Figure 35: Methodological approach suggested by TRL
Source: Author

Table 22 presents details on the participants' choice of methodology and the suggestions obtained by applying the TRL methodology.

	Was TRL useful?						
	Yes	**%**	**No**	**%**	**Participants**	**%**	**p-value**
Methodology, first choice.							<0.0001*
Agile	9	8.9	171	60.0	180	46.6	
Hybrid	7	6.9	69	24.2	76	19.7	
Predictive	85	84.2	45	15.8	130	33.7	
The methodology suggested by TRL							**0.0027***
R&D	0	0.0	10	3.5	10	2.6	
Agile	8	7.9	4	1.4	12	3.1	
Hybrid	7	6.9	26	9.1	33	8.5	
Predictive	86	85.1	245	86.0	331	85.8	
Already decided before knowing the objective of the project							**0.0054***
No	38	37.6	155	54.4	193	50.0	
Yes (early choice)	63	62.4	130	45.6	193	50.0	
The methodological approach suggested by TRL							**0.0072***
1	0	0.0	6	2.1	6	1.6	
2	0	0.0	4	1.4	4	1.0	
3	1	1.0	1	0.4	2	0.5	
4	2	2.0	3	1.1	5	1.3	
5	5	5.0	0	0.0	5	1.3	
6	1	1.0	5	1.8	6	1.6	
7	6	5.9	21	7.4	27	7.0	
8	14	13.9	57	20.0	71	18.4	
9	72	71.3	188	66.0	260	67.4	

*Chi-squared independence test.

Table 22: Methodology, first choice, and the suggestions obtained by applying the TRL
Source: Author

The approach most suggested by the TRL scale, predictive, in TRL 9, adhered to the group that also showed the highest rate of satisfaction with using the model, the group who chose the predictive methodology. The model, then, proves to be more useful for higher TRLs, for people who managed their projects using predictive approaches, which may be associated with the greater familiarity of Predictive Project Managers with the terminology of the TRL scale, with a strong influence from the field of engineering and, as already presented in this study, with a strong connection with Traditional Project Management. (Snyder, 1987).

4.2. Discussion of the Contributions

The selection of an appropriate project management approach or methodology is critical to the success of a project. However, this decision is often challenging for project managers, especially when dealing with complex problems that have a high level of uncertainty and volatility. The lack of objective guidance in the literature can make the process of selecting an approach more complicated.

The Cynefin Framework, developed by Snowden (2007), highlights the different types of problems that exist and how they should be solved. Similarly, Walker et al. (2010), based on the work of Bar-Yam (2004), identified the types of emergencies that require different approaches for resolution. These frameworks show that different problems require different solutions, and project managers need to choose the most appropriate approach based on the problem at hand.

Despite the growing interest in agile project management, there is still a lack of clear guidance on how to select the appropriate approach for a given project. This can be attributed to the fact that predictive project management approaches have a strong scientific foundation, while agile approaches are relatively new and lack established reference models.

However, as Rittel & Webber (1973) pointed out, the definition and identification of problems in complex systems is a challenging task, and this highlights the need for a more adaptive approach to project management. The objectives of this research include exploring the relationship between the level of knowledge and understanding of the problem and the selection of the most appropriate project management approach.

By investigating the secondary objectives of this study, we aim to provide guidance to project managers on how to select the most appropriate approach based on the specific problem they are trying to solve. Our findings will contribute to the development of a more objective and adaptive project management approach that can help project managers to navigate complex problems and make informed decisions about the approach that will best suit their needs.

Rittel and Webber's study shows the need to review forms of planning due to the complexity of the problem for over 40 years. This work contributes to constructing an objective method with scientific bases for choosing an approach/methodology for project management, which is rarely addressed in the bibliographic references for this research.

It is possible to state that the work contributes to the beginning of this construction because the number of people who would benefit from using the model is still significantly lower than those who would not perceive the model's usefulness. The hypotheses supported by the work show that, initially, the model would be useful to tell Project Managers, specifically, when to use a predictive approach. For agile and hybrid approaches, the result suggests the need to review the terminology to be used so that the model's accuracy is calibrated and, perhaps, it can be equally useful for agile and hybrid approaches.

The study also opens new discussions from the hypotheses not supported by the research, such as, for example, the importance of knowledge about the problem that the project intends to solve for the choice of management approach/methodology to be used.

From a managerial point of view, according to Maes et al. (2022) in their article "The Relationship Between Uncertainty and Task Execution Strategies in Project Management," when project management is faced with complexity and uncertainty, the connection and references "between uncertainty and task execution strategies is very generic and does not provide systematic guidance to project managers." The need to improve the depth of the discussion about uncertainty and adaptability in project management in organizations is increasingly current and latent.

This work presents significant contributions due to organizations' high expenses incurred in digital and agile transformations worldwide. "Digital Transformation may be considered as a management fashion” (Reis et al., 2018). A model that brings a solid basis to assist organizations in selecting their project management approaches can help reduce reports of how organizations and professionals in organizations often “present agile methods as a panacea for all the ills of software development, often focusing on the proposed practices' possible benefits” (Cao & Ramesh, 2008). A survey conducted in 2022 by management consultancy Deloitte revealed that “Firms continue to invest in digital transformation with new technologies that improve the client experience, gain operational efficiencies, and potentially generate alpha. Leadership can help drive these changes effectively with communication to foster collaboration across departments to achieve transformative results.” (Deloitte, 2022)

The development of a model utilizing the Technology Readiness Level (TRL) scale can make a substantial contribution to the management of projects from a managerial standpoint, especially when determining the most suitable approach for the management of agile, hybrid, or predictive projects. This model provides a systematic method for assessing the maturity and viability of new technologies and can be a valuable resource for organizations selecting the optimal project management approach.

Organizations must make informed decisions to remain competitive in today's swiftly changing and complex business environment. By providing a clear comprehension of the maturity and readiness of the technology under consideration for a project, the TRL model can aid organizations in making informed decisions. This data can be used to determine the level of risk associated with the project and to identify the resources and support required for its successful implementation.

In addition, the TRL model can assist organizations in aligning their project management approach with the project's goals and objectives. By contemplating the level of maturity and viability of the technology in relation to the project's requirements and constraints, organizations can ensure that the chosen project management approach is suitable for the project's particular needs and requirements.

In the case of agile, hybrid, or predictive projects, the TRL model can provide valuable information about the maturity and viability of the technology, enabling organizations to make informed decisions regarding the most effective method for managing their projects. For instance, an agile approach may be more suitable for projects involving highly innovative technologies, whereas a predictive approach may be more suitable for projects requiring a more structured and predictable outcome.

From a managerial standpoint, the construction of a model utilizing the TRL scale can make a substantial contribution to the management of projects, particularly when selecting the most suitable approach for the management of agile, hybrid, or predictive projects. Utilizing the TRL model can assist organizations in aligning their project management approach with their objectives and minimizing the risks associated with the implementation of new technologies.

Nonetheless, the research enables organizations to use the model for predictive projects, given the validation of the model's perceived utility in these conditions, which would already result in more secure decision-making for predictive projects.

Finally, corroborating the conclusion of Maes et al. (2022) in his research, who worked with a model for assessing the level of complexity of a project, even though the model has not been fully validated, “the mere process of consciously breaking down the project into tasks and reflecting on their levels of uncertainty in a structured way according to our task model, has a highly beneficial effect on project managers and teams. They become aware of uncertainties and consequently take them into account in their project management strategies.’

After the discussions, proceeding to the study's conclusion is possible.

5. Conclusion

The objective of this research was to apply a model derived from the Technology Readiness Level (TRL) scale to retrospectively evaluate the project management approach and methodology used by Project Managers or professionals with equivalent roles. Specifically, the study aimed to assess whether the approach/methodology indicated by the proposed model would coincide with the approach/methodology used in the project, and to determine the professional's level of satisfaction with their choice.

The research investigated several conditions to establish the applicability of the TRL scale, including the phase of the project life cycle, the methodology/framework used for project management, level of satisfaction with the approach, the potential for choosing a different approach in retrospect, and the decision-making process for selecting the approach. Additionally, the study explored the participants' knowledge of the problem the project aimed to solve, the resources invested in seeking a solution for the problem, and the role of the individual in the project.

The research results have the potential to provide valuable insights into the effectiveness of the TRL scale in project management. The study sought to determine the conditions under which the TRL scale can be useful, and to identify the specific factors that determine the usefulness of the scale. By examining these factors, the study aimed to improve the decision-making process for project managers, and to enhance the likelihood of successful project outcomes.

The findings of this research can help to establish the most appropriate project management approach, based on the TRL scale, and to guide project managers in making data-driven decisions that are better aligned with the requirements of the project. The study highlights the importance of considering the specific conditions and factors that influence the choice of project management methodology, and the relevance of assessing the level of knowledge and resources invested in seeking a solution for the problem.

Based on the results obtained, it can be concluded that the "Technology Readiness Level (TRL) scale" can be a useful tool in choosing the best approach to manage a project, especially for project managers with in-depth knowledge of the problem to be solved and who use predictive approaches. The data also indicate that, although understanding the problem to be solved is considered important, the selection of the project management approach or methodology does not always occur after such understanding. Furthermore, the research suggests that certification in project management does not seem to significantly influence the perceived usefulness of the TRL scale.

Based on the hypotheses raised in this research, the results obtained allowed confirming some of the proposed premises. Regarding the " H1 - The TRL scale is more useful for Project Managers" hypothesis, it can be affirmed that the TRL scale is more useful for professionals with project management roles, as evidenced by the distribution of responses and the obtained p-value. The perception of the usefulness of the TRL scale was also corroborated by other research that indicated greater satisfaction with the use of the scale in projects that achieved higher levels of maturity, where the objectives were clearly defined and there was a limited need for iteration.

Regarding the " H2 – The TRL scale is more useful for professionals who have a high level of knowledge about the problem to be solved" hypothesis, the results indicated that although understanding the problem is seen as important, almost half of the respondents selected the project management approach before understanding the nature of the problem that the project aims to solve. The obtained p-value did not indicate a statistically significant difference regarding the usefulness of the TRL scale. However, it is interesting to note that most of the respondents dedicated a considerable amount of time (more than ten hours) to understand the problem before selecting an approach.

Regarding the " H3 – The TRL scale is more useful for specific project types" hypothesis, it was found that the predictive approach was the most indicated by the TRL scale, and this approach was associated with a higher degree of usefulness of the scale. Although this can be explained in part by the familiarity of predictive project managers with the terminology of the TRL scale, it is important to highlight that the application of the TRL scale is more effective for projects that already have higher levels of maturity in terms of problem definition and solution.

The research conducted has demonstrated the potential of the TRL scale as a valuable tool for project management. The study's results emphasize the importance of evaluating the suitability of different project management methodologies, and the potential for data-driven assessments to enhance the decision-making process for project managers. The research provides valuable insights into the factors that determine the applicability of the TRL scale, and the conditions under which it can be most useful for managing a project.

The results of this research contribute to the advancement of knowledge in project management, highlighting the usefulness of the TRL scale in choosing project management approaches or methodologies. The study also emphasizes the importance of understanding the problem to be solved but emphasizes that such understanding may occur before or after the selection of the project management approach. Furthermore, the findings can be useful for managers and professionals who want to select the best approach to manage their projects more effectively. Future research may investigate other variables that may influence the perceived usefulness of the TRL scale, as well as explore the applicability of this tool in other types of projects.

Thus, the objectives of this work were to understand if the TRL scale can help to choose the best approach to manage a project; if the level of understanding about the problem that the project intends to solve influences the satisfaction with the method or approach chosen to manage the project; and whether the level of knowledge about project management influences satisfaction with the method or approach selected to manage the project.

The research concluded that there is a gap between understanding the problem that a project intends to solve, and the approach used to manage this project. A considerable portion, which corresponds to practically half of the respondents (49.8%), defined the project management approach prior to becoming aware of the problem, which reinforces the understanding that there is no association between the nature of the problem, its level of complexity and the answer through the approach/methodology that will manage the project designed to solve this problem.

This gap may explain why the model was not useful for most respondents (73.8%), given that, to use a TRL scale, it is necessary to understand the problem previously. It is precisely the understanding of the technology readiness level which will enable the assessment of the current state and then, the planning of the necessary actions to reach the future state or the next level on the TRL scale.

The author has conducted extensive theoretical research to find answers for this identified GAP, without success. This gap, where the understanding of the problem a project aims to solve and the chosen management approach are not correlated, presents as a largely unexplored area. This suggests a significant opportunity for future research. Delving into this area could assist in improvements in the application of project management approaches, ensuring that the selected methodology aligns with the nature and complexity of the problem.

On the other hand, in the context in which the model proved useful, specific patterns make it possible to understand under what conditions the model can be applied with good acceptance. These conditions are related to the project management experience and the nature of the problem that the project intends to resolve. Professionals who declared themselves Project Managers demonstrated greater acceptance of the model, considering the high compatibility between the choices made by members of this group and the proposed model. The model also proved useful for predictive projects, which have clarity of the problem and the solution to be built to solve the problem. In this context, the model's indication is strongly compatible with the choice of professionals.

These conditions can be illustrated as contingency factors, i.e., factors that influence the specific situation and dictate the circumstances under which the TRL model may be most effective. An experienced project manager, for instance, might be more familiar with the nuances of assessing technological readiness and hence can apply the model more effectively. Similarly, a predictive project, with a clear definition of the problem and solution, provides a favorable context for using the model.

5.1. Summary of theoretical findings

For theoretical/academic purposes, we can conclude that the work represents an important starting point for the theoretical deepening of how the TRL scale can be used. This first step, which is already useful in the context of predictive projects, can be the basis for further refinement, particularly about the assessment terminology used in the model, so that the accuracy of the responses can make it more useful for adaptive (agile) and hybrid contexts.

The study also opens up new questions and the possibility of extending research on the importance of understanding a problem, its complexity, context, and nature, among other aspects, prior to choosing the approach/methodology that will be adopted for project management, serving as a reference so that new research can be conducted in this area to measure the dimension of the impacts that the choice prior to understanding represents when compared to the choice a posteriori.

5.2. Managerial findings

As managerial contributions, this work brings important contributions to project management in organizations as it offers objectivity in choosing the best approach/methodology and reduces losses resulting from wrong choices, as well as can reduce the volume of investment in training, acquisition of software and tools and in the management of organizational changes, especially in the context of digital transformations and agile transformations, when organizations are faced with highly complex change initiatives, in an environment of uncertainty.

Applying validated knowledge to select the best approach/methodology for project management may help organizations in knowledge management and organizational learning.

5.3. Limits and extensions

A limitation of this study came from the COVID-19 pandemic, which made it impossible to collect data through face-to-face interviews, which would clarify the respondents' questions regarding the questions presented in the model. For future studies, it can be highlighted that the need to adapt the terminology according to the profile of the public and, therefore, both a prior selection of the profile of the respondents and the possibility of “live” monitoring of the answers to clarify questions and make terminology adaptations.

Still, and not less important, for future studies, it includes the possibility of assessing, for cases in which the respondents declared that they did not understand the problem prior to the selection of the project management approach/methodology, how much the satisfaction of this group with the choice would change if subjected to a situation in which prior knowledge of the problem exists.

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