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MÁSTER UNIVERSITARIO EN DIRECCIÓN DE PROYECTOS

TRABAJO FIN DE MASTER

MANAGING OF R&D PROJECTS: PROBLEMS AND GUIDANCE

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DATOS BÁSICOS DEL PROYECTO

- *Alumno:* Josu Ramón Rodríguez.
- *Directora:* Nerea Toledo Gandarias.
- *Departamento*: Expresión Gráfica y Proyectos de Ingeniería.
- *Título del Trabajo*: Managing of R&D projects: problems and guidance
- *Resumen*: El presente trabajo se centra en la gestión de proyectos de investigación y desarrollo, los cuales han tenido un gran crecimiento durante los últimos años. A través de una revisión bibliografía se identifican los principales factores más comunes que afectan a la gestión. Se propone además un marco de actuación para la gestión atendiendo a la especial naturaleza de este tipo de proyectos. Finalmente, se identifican y describen una serie de herramientas y soluciones con la intención de evitar los problemas previamente identificados.
- *Palabras clave*: Gestión de proyectos, I+D, Gestión de investigación y desarrollo, Innovación, Investigación industrial, Investigación en ingeniería, Proyecto colaborativo, Herramientas y técnicas, Buenas prácticas, Directrices.
- *Abstract*: This paper focuses on the management of research and development projects, which have been growing rapidly in recent years. A literature review identifies the main common factors affecting project management. A framework for management action is also proposed, taking into account the special nature of this type of project. Finally, a series of tools and solutions are identified and described with the intention of avoiding the problems previously identified..
- *Keywords*: Project management, R&D, Research and Development Management, Innovation, Industrial Research, Engineering research, Collaborative project, Tools and techniques, Best practices, Guideline

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LISTA DE ABREVIATURAS

TFM.....Trabajo de Fin de Máster
R&D…… Research and Development
INE……. National Statistics Institute (Spain)
EU…….. European Union
PM…….. Project Management
US……... United States
UK……..... United Kingdom
IT……. Information technology
PMI.....Project Management Institute
WIP……. Work in progress
RACI……... Responsible, Accountable, Consulted and Informed
SWOT……. Strengths, Weaknesses, Opportunities and Threats
SMART…….. Specific, Measurable, Achievable, Relevant, and Time-bound
BSC…… Balanced ScoreCard
PERT……. Program Evaluation Review Technique
GERT……. Graphical Evaluation & Review Technique
WBS……... Work Breakdown Structure
CBS…… Creativity Breakdown Structure
DBS…… Design Breakdown Structure

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1 INTRODUCTION

Over the last few years, the globalisation of companies has led to an internal evolution of companies, in particular in terms of innovation and new developments, the change has been even more abrupt. International competition and new customer requirements and trends have forced companies to increase their R&D expenditures in order to offer products and services that are more customised and differentiated from their competitors. In this way, businesses have experience a transformation, becoming more collaborative [1] and more organised in projects [2] to adapt this new situation.

However, increased spending on innovation projects does not always lead to satisfactory results. The uncertainty and risks involved make these projects time-consuming and costly if not managed correctly. Therefore, we will try to analyse and give visibility to the typical factors of these collaborative R&D projects and propose tools or solutions that help the project manager to carry out a special project management according to the nature of the project.

1.1 What is R&D Project management?

Project management is a method and a set of techniques based on the accepted principles of management used for planning, estimating, and controlling work activities to reach a desired end result on time, within budget, and according to specification.

A project is any series of activities and tasks that together achieve predetermined deliverables in accordance with:

- defined start and end dates
- funding limits
- a quality definition
- intermediate milestones
- utilization of resources such as equipment, materials, people

Research and experimental development (R&D) comprise creative work undertaken on a systematic basis in order to increase the stock of knowledge, including knowledge of man, culture and society, and the use of this stock of knowledge to devise new applications.[3]

One of the most difficult tasks in any organization is the management of R&D activities. These R&D activities are usually headed up by scientists, engineers, managers, employees, and even executives. All of these people, at one time or another, may act as R&D project managers. They start out with an idea and are asked to lay out a detailed schedule, cost summary, set of specifications and resource requirements such that the idea can become a reality. Unfortunately, this is easier said than done.[4]

Therefore, one could define R&D project management as the application of techniques, methodologies and best practices for the management of projects under the umbrella of innovation, where risk and uncertainty are high.

1.2 Project management: common methodologies

Over the years, project management has been able to adapt to the circumstances required by the industry. A clear example of this was the emergence of software developments, which are completely different projects to what the industry was used to.

In the following, we will review the most important methodologies to assess where innovation projects could fit in.

1.2.1 Traditional project management

Traditionally, project management focused in its beginnings on predictive project models, where objectives, milestones, cost and deadlines were perfectly defined, uncertainty was minimal due to the search for repeatability and control of changes, through statistical project control.

The methodology that has traditionally governed traditional project management is known as the waterfall method. This methodology is described in the PMBOK extensively, and commonly used in projects where requirements and activities are identified, fixed for the project framework, then planned, executed, controlled and finally concluded.

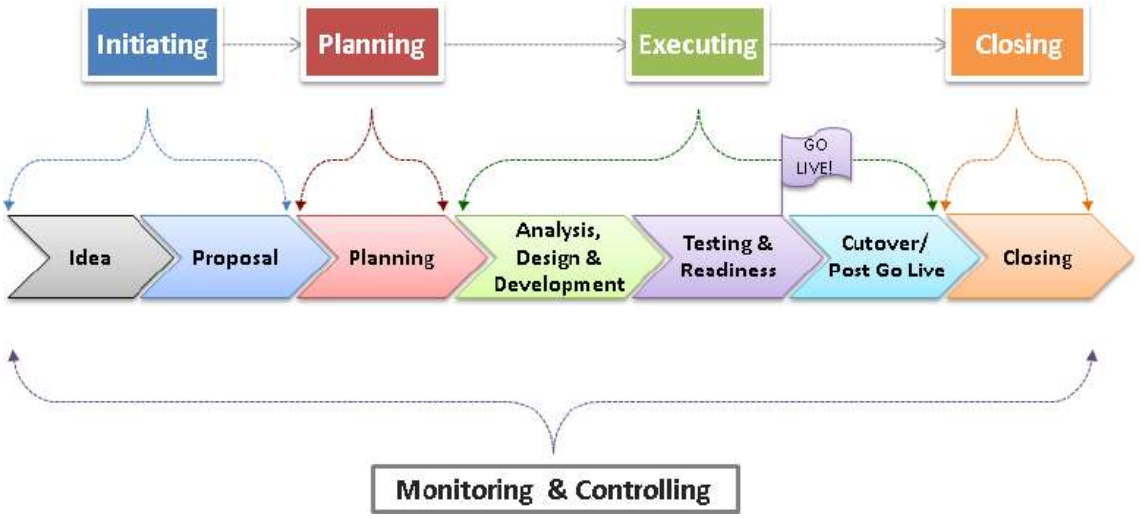


Figure 1. Traditional life cycle process[5]

While this methodology works very well when activities and requirements are well defined, it presents difficulties when new tasks, uncertainties or requirements are added that were not previously planned. Moreover, a project that is well executed, planned and controlled but nevertheless not useful is a waste of resources. In R&D, the natural uncertainty of the project always leads to an outcome, whether positive or negative. And it will be that outcome that drives and directs decision making in the next phase of the project.

Due to this and the development of new products and services, project management has adapted by creating new, more flexible and less structured methodologies.

1.2.2 Iterative method

Projects within an iterative life cycle are mainly based on analysis and feedback as tasks are developed. With the new information obtained once an activity is completed, the activity is redefined and repeated until the client's needs are met.

The iterative process is used when the complexity is high, changes are expected to be introduced in the project and when the initial objective is uncertain.

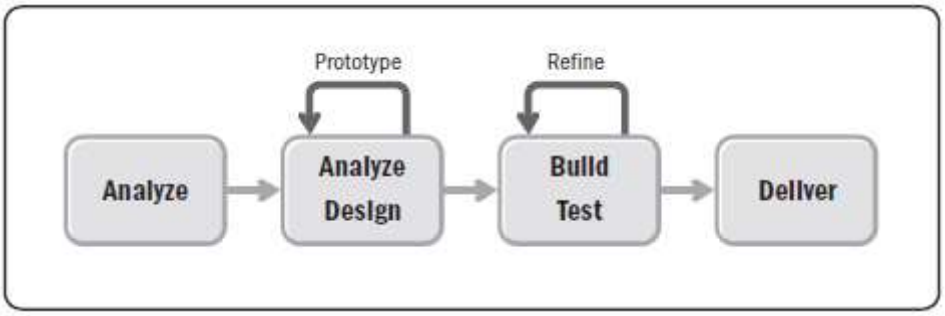


Figure 2. Iterative life cycle[6]

1.2.3 Incremental method

Some projects use the incremental methodology as they focus on optimising the speed of delivery, seeking to work on the first planned activities as soon as possible.

Changes that occur within the scope of the project are managed quickly as feedback on activities is continuous.

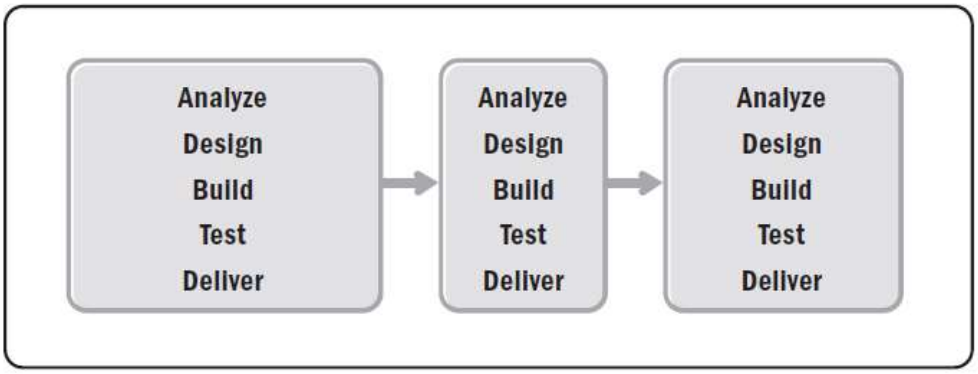


Figure 3. Incremental life cycle[6]

In the case of innovation projects, there is no client to indicate the requirements they are looking for, therefore this type of project would not fit directly into the R&D field. However, the idea of analysing the results continuously with the project team and before moving on to the next activity would fit in, as it would allow decisions to be taken before moving forward and wasting resources.

1.2.4 Agile method

The agile methodology tries to structure the work in such a way that results are achieved quickly, adding value and interacting with the customer to meet their requirements. With

this process, the value added to each delivery is what measures the progress of the project and serves to adapt to the uncertainty and changes that can be generated.

The most common life cycle for agile developments is known as Scrum framework, which could be represented by the following way:

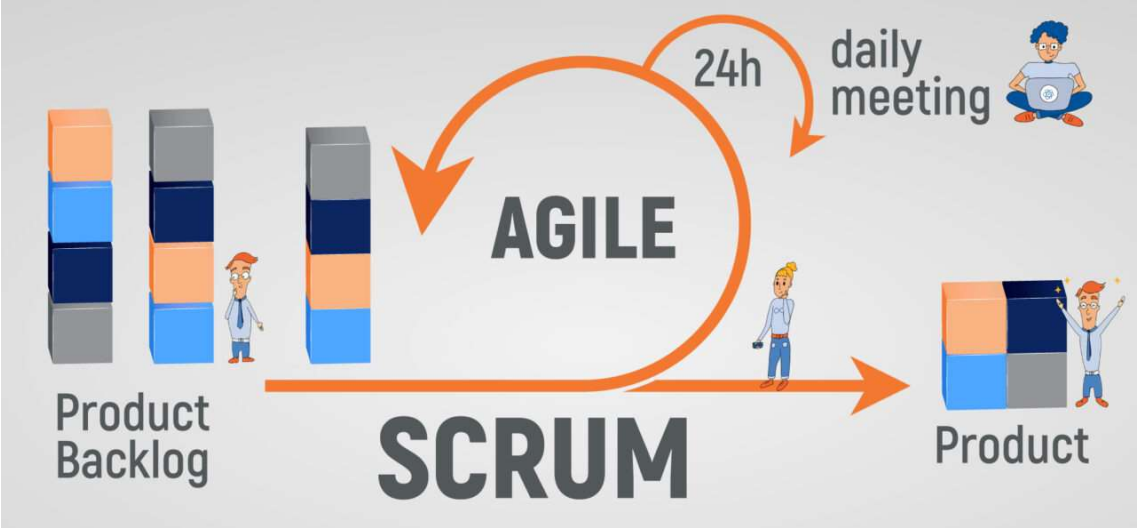


Figure 4. Scrum process [7]

As far as R&D projects are concerned, the communication between the different team members involved in the Agile process is very well adapted to innovation projects that require information exchange between researchers and, in the case of collaborative projects, with different entities.

2 OBJECTIVE AND SCOPE OF WORK

2.1 Objetive

This paper focuses on the difficulties of managing and directing research projects. The main objectives to be developed are defined as follows:

- Review of existing methodologies applied to the management of R&D projects.
- Identification of failure factors and difficulties in R&D projects.
- Selection and description of the most potentially useful tools for the management of research projects.

2.2 Scope

Throughout the work, both the research and the proposed solutions for project management and governance will focus on the field of research projects, with other types of projects being excluded from the scope. Internal research projects may be considered as individual or collaborative research projects, i.e. as part of a consortium including one or more partners, such as universities and/or technology centres.

2.3 Success criteria

The aim of the project is to provide tools and a framework for action in R&D projects that can overcome the difficulties that are inherent to this type of project. Therefore, the success criteria of this document will be the identification of potential problems and the proposal of tools that help project managers to deal with innovation and research in projects.

It should be noted that these proposals will not be mandatory to ensure the success of the project, as each project manager will have to assess their own situation and see which tools can be most useful in their own project. In this way, a target number of tools to be proposed for each difficulty will not be established, as this may vary depending on the problem to be overcome.

3 CONTEXT

This section will show the evolution of R&D in Spain, analysing the results obtained by the Cotec Foundation based on the latest data from INE and Eurostat on R&D activity in Spain until 2021.[8]

3.1 Evolution of R&D in Spain

Focusing on investment in Spain in 2021 since the 2008 financial crisis, there has been an annual growth of 9.4%. This is the seventh consecutive year of growth in investment in research activities.

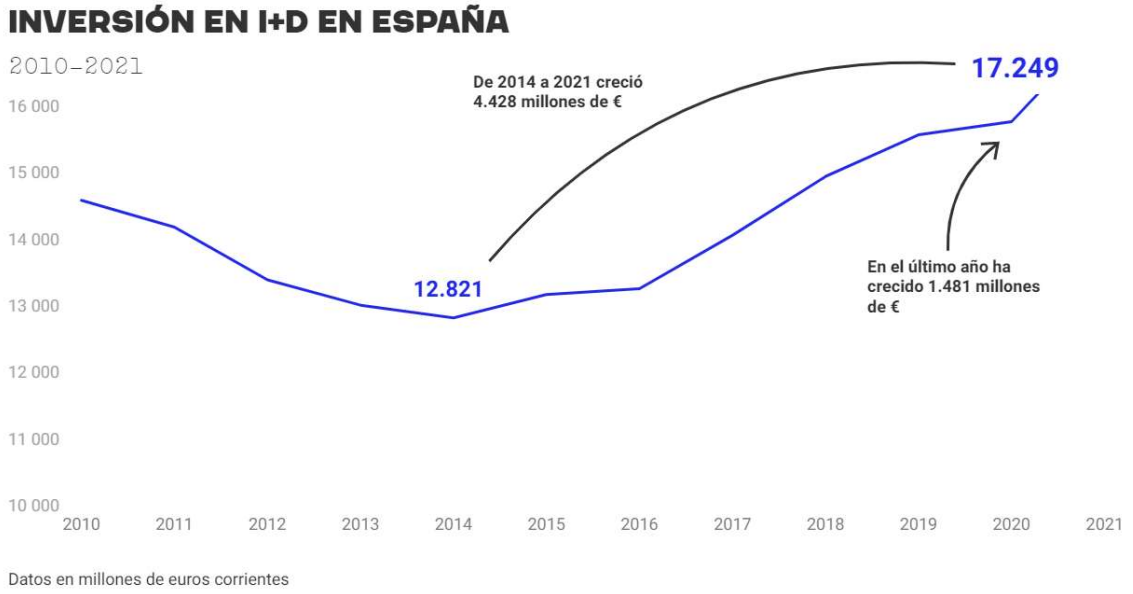


Figure 5. Evolution of Spanish investment in R&D [8]

From this study conducted by COTEC, it can be concluded that the investment recorded in 2021 far exceeds the pre-pandemic levels (2019) and the previous peak that occurred during the financial crisis (2010).

Now, if we further discretise the results, we obtain that the growth in R&D investment at the Spanish territorial level has increased at different rates. The highest increase is registered in Castilla La Mancha with 30%, but La Rioja has only had a 3% increase. In addition to Castilla-La Mancha, notable growth rates were observed in Extremadura (18.9%), the Basque Country (14%), Aragon (13.9%), Catalonia (12.7%) and Cantabria (10.9%).

However, if we extend the time range to the pre-crisis period, there are only 11 territories that exceed the levels to date, highlighting in descending order: Murcia, Balearic Islands, Catalonia, Valencia, Castilla La Mancha, Basque Country and Madrid.

Figure 6. Variation in Spain of R&D investment from financial crisis until 2021 [8]

According to the latest data published by Eurostat, all economic agents operating in Europe invested a total of 328,488 million euros in R&D in 2021, which represents a growth of 5.95% more in nominal terms. This progress contrasts with the figure observed in 2020, when European R&D investment fell by 0.59% due to the pandemic. In addition, 26 of the EU-27 countries show an increase in investment in 2021, except in Ireland.

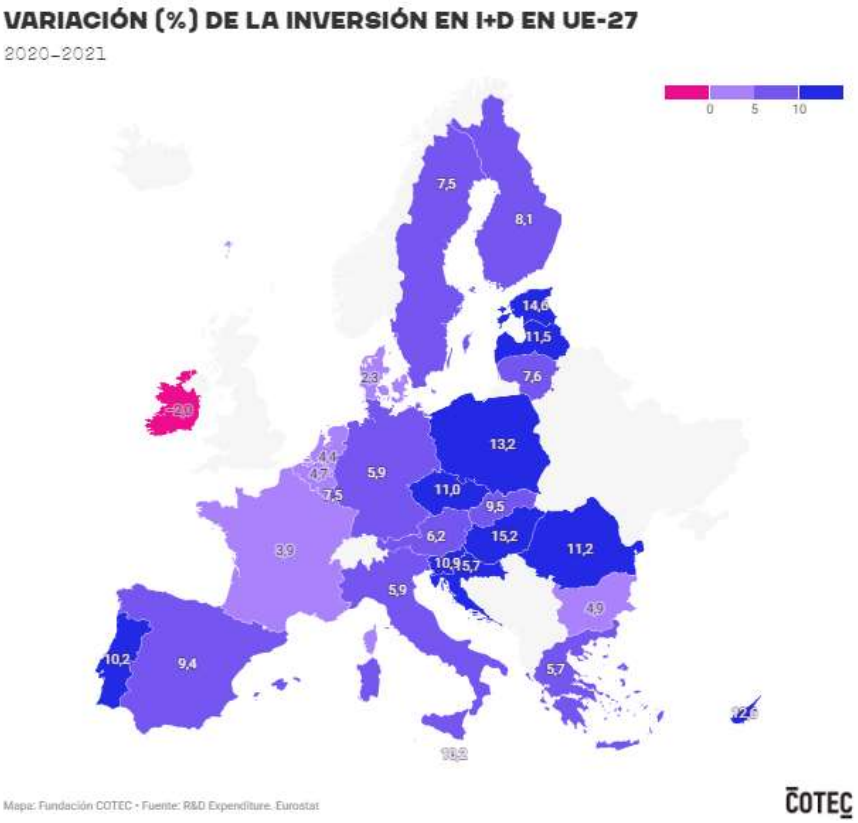


Figure 7. Variation in EU of R&D investment from 2020 until 2021 [8]

4 METHODOLOGY

This section of the project aims to show the methodology followed for the development of the project, which will help to better understand the document. For this purpose, the following scheme is presented with the different phases that have been developed:

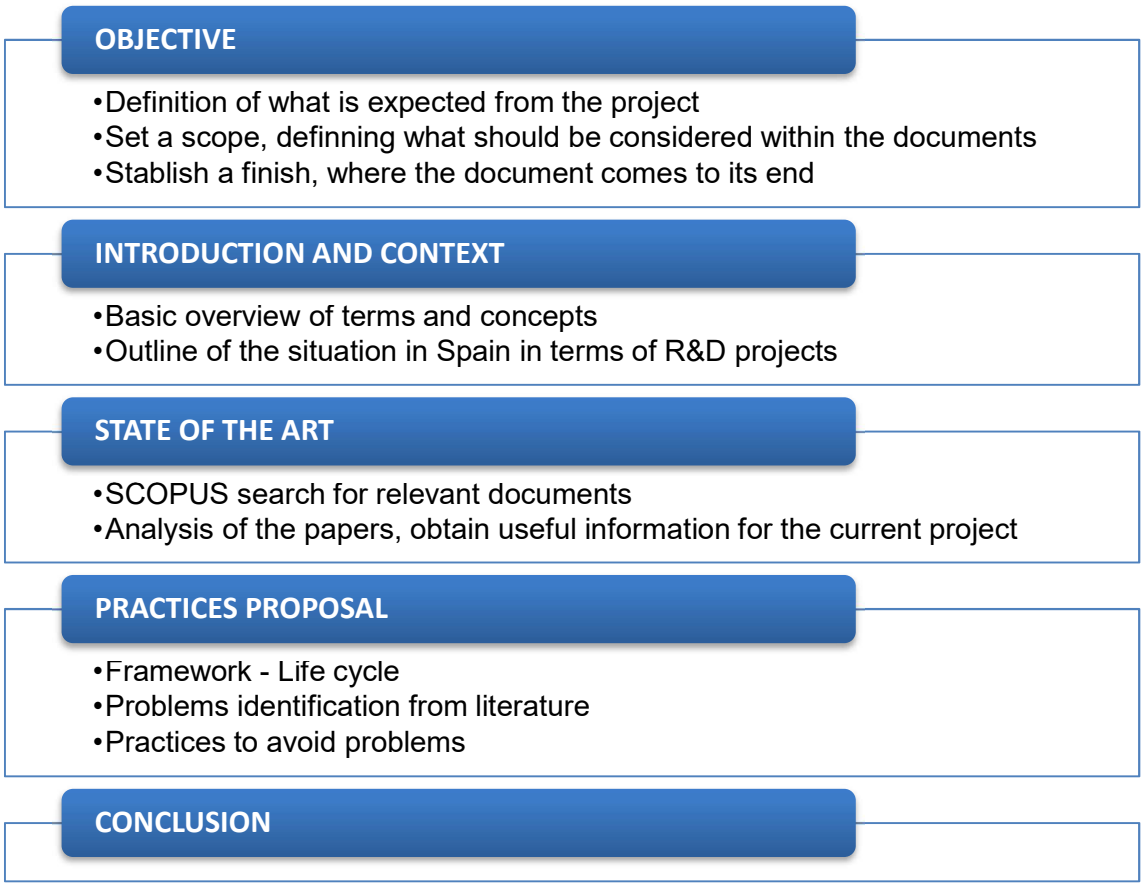


Figure 8. Outline of methodology followed

First of all, the aim of the project is to define the objective of the project in order to understand how far we want to go by defining the limits through the scope. After this, with a brief introduction, the aim is to situate the reader in the scope of the work with a brief explanation of the different methodologies most commonly used in project management.

In order to justify the relevance of the work, the evolution of R&D projects in Spain is shown, offering results of the investment that has increased over the years.

Afterwards, a bibliographic search is carried out to observe the contributions made by other researchers on the subject in question, looking at proposals for solving the problem and common factors of failure when managing innovative projects.

Once the proposals and critical factors have been identified, the aim is to offer a framework for the management of R&D projects and different tools that can improve the problems that these projects present by their very nature.

5 ANALYSIS OF THE STATE OF THE ART

5.1 Key words

As the project is about project management in R&D environment, the following words have been initially identified as key:

1. Project management
2. R&D
3. Innovation
4. Collaborative project
5. Management framework
6. Tools and techniques
7. Best practices

5.2 Scopus research

Once the initial keywords have been identified, the next step is to perform an advanced search in the SCOPUS database[9] (it could be done in another research databases like Google Schoolar). In order to have an accurate and advanced search, Boolean operators are used:

TITLE-ABS-KEY ("Project management" AND ("R&D" OR "Research and development")) AND TITLE-ABS-KEY ("Innovation" OR "Collaborative" OR "Management framework" OR "Tools" OR "Techniques" OR "Best practices")

Then once the search is done, now keywords of the papers searched are analysed:

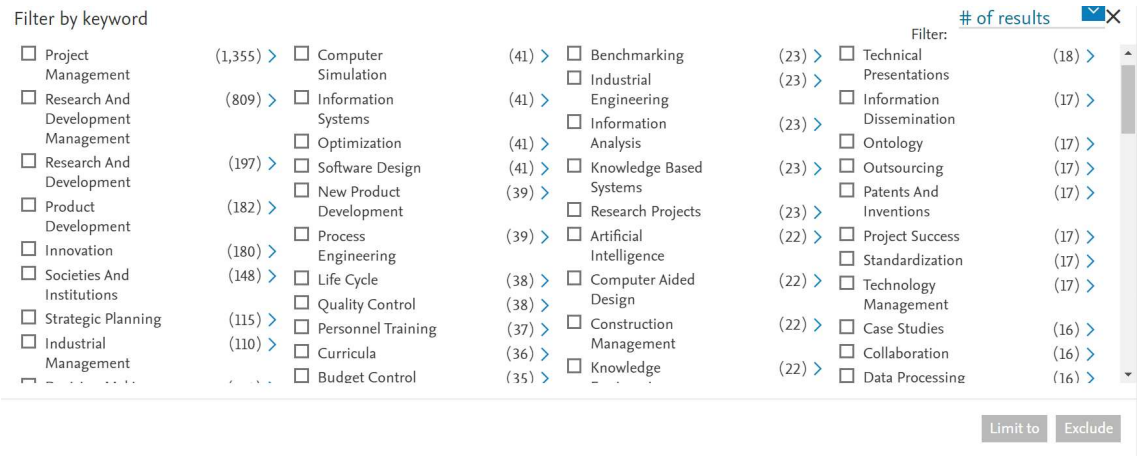


Figure 9. Keyword results obtained from Scopus search

Taking into account the initial searched keywords and the ones that appear in the paper search, the final keyword list is defined. This is done because the webpage SCOPUS allows to see which the most repeated keywords are used. Therefore, in order to prepare a more precise search the final selection is:

1. Project management
2. R&D

3. Research and Development Management
4. Innovation
5. Industrial Research
6. Engineering research
7. Collaborative project
8. Tools and techniques
9. Best practices
10. Guideline

The Boolean search will be the following:

TITLE-ABS-KEY ("Project management" AND ("R&D" OR "Research and development" OR "Innovation")) AND TITLE-ABS-KEY ("Collaborative" OR "Industrial research" OR "Engineering research") AND TITLE-ABS-KEY ("Tools" OR "Techniques" OR "Best practices" OR "guideline")

With this better and accurate search, the results has varied from 1564 to 305. Then, the results will be filter by the following boundaries:

- Type of documents: only reviews, conferences and articles
- Language: English

This final search offers 279 documents, which are going to be analysed using Scopus to show the evolution of the publications:

- Documents by year: It is interesting that mainly the concern about the topic is growing. However, there is a decrease between 2008 and 2011, this could be due to the financial crisis during those years, it could be logical because the reduction in the investments of R&D project.

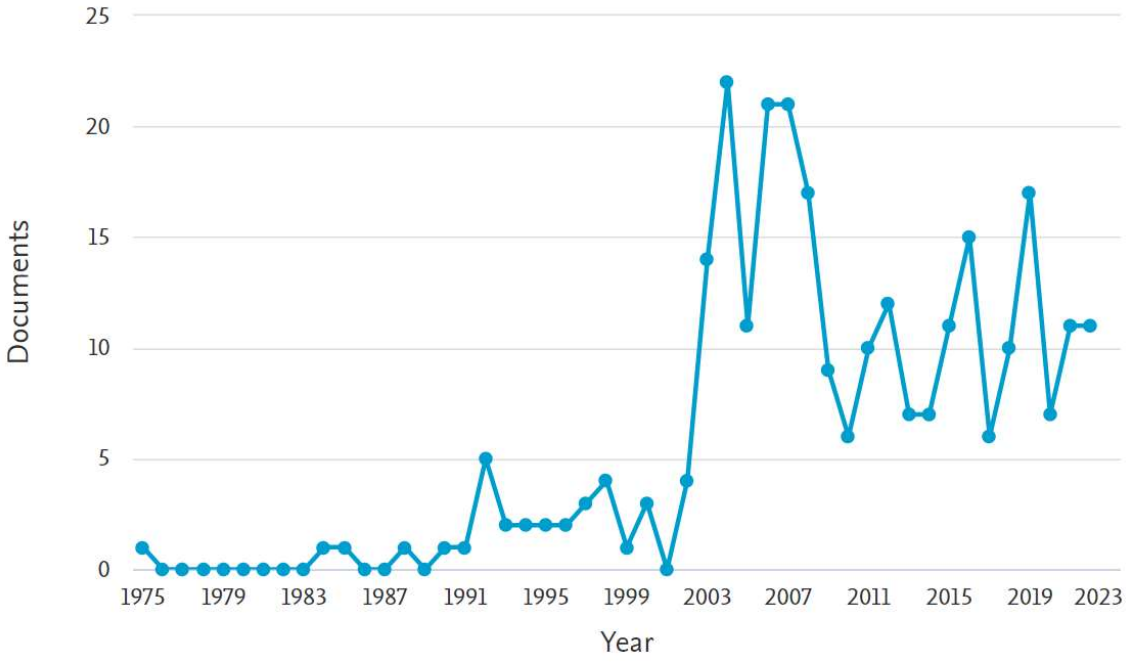


Figure 10. Evolution of documents publications related to the search

- Documents by author: regarding the topic of R&D management, three are the authors that publish more documents in the recent years (G. Fernandes, Machado R.J. and Pinto E.B.).

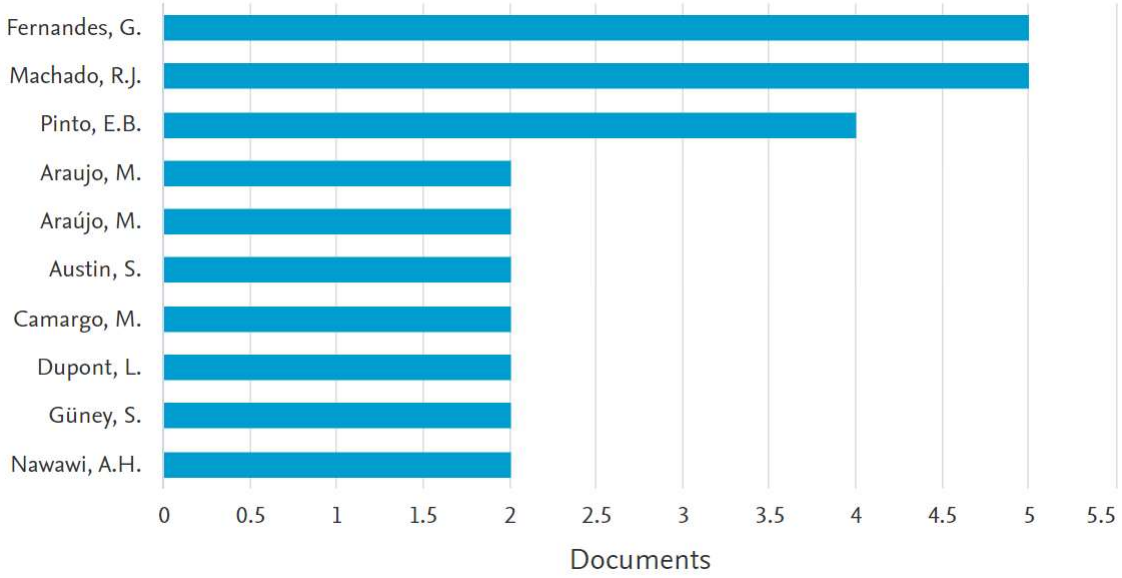


Figure 11. Main authors related to the search

- Documents by territory or country: clearly US is the country that contributes with more documents to the searched topic, then there is UK and China and also different countries from Europe. So, this is also interesting because it is a global corcern.

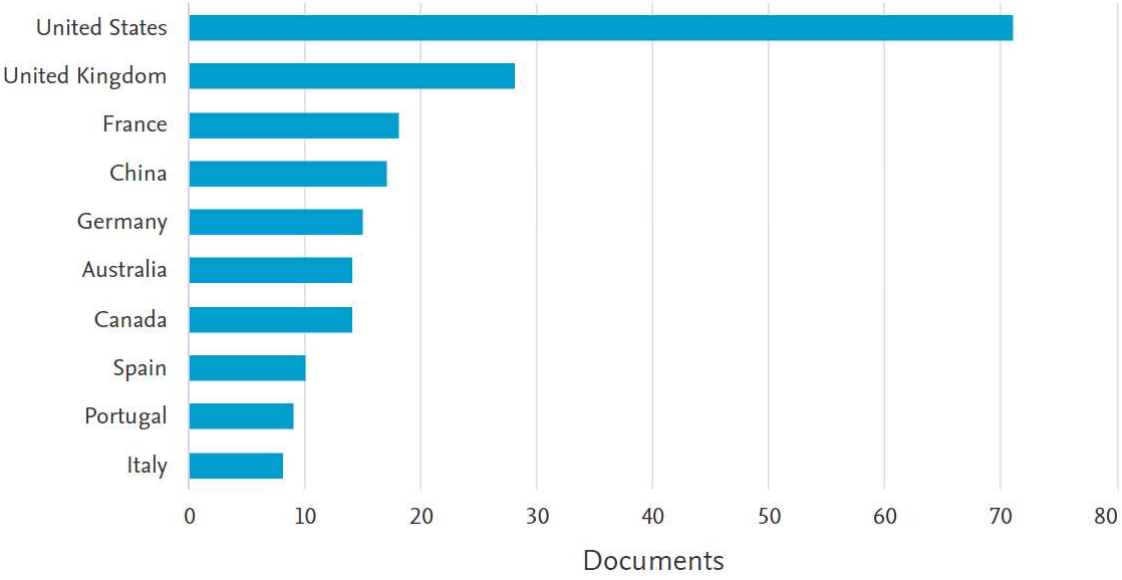


Figure 12. Country with more publications related to the search

Now it would be necessary to define the most relevant articles within the area of knowledge searched. For this, h-index will be used, which is an indicator that relates the productivity and impact of the identified publications.

First of all, all the publications are organized depending on the number of citations from higher to lower. In the following list, it is only show the first 20 documents most cited:

	Documents	Citations	<2017	2017	2018	2019	2020	2021	2022	Subtotal	>2022	Total
		Total	2072	220	247	245	327	328	418	1785	14	3871
1	Market learning and radical innovation: A cross case compari...	1998	218	15	13	12	17	13	6	76	1	295
2	Governmentality Matters: Designing an Alliance Culture of In...	2002	146	13	15	16	16	17	12	89		235
3	Effects of cooperative procurement procedures on constructio...	2011	72	25	30	20	18	15	26	134	3	209
4	Maximizing productivity in product innovation	2008	108	14	12	13	11	9	7	66		174
5	Algorithms for rapid outbreak detection: A research synthesi...	2005	105	12	4	7	7	3	1	34		139
6	Managing collaborative research projects: A synthesis of pro...	2015	5	12	16	14	21	22	19	104		109
7	Key resources for industry 4.0 adoption and its effect on su...	2021					1	22	78	101	3	104
8	An Interactive Approach to R&D Project Selection and Ter...	1988	73	5	3	5	4	4	1	22		95
9	Managing collaborative R&D projects development of a pra...	2006	42	1	8	6	13	14	6	48		90
10	A hierarchical structural model of assessing innovation and ...	2005	43	8	2	7	4	7	9	37		80
11	Key success factors for technological entrepreneurs' R&D...	2004	59		1	9		4	2	16		75
12	The management of industry-university joint research project...	2013	16	10	9	9	11	12	7	58		74
13	Procuring service innovations: Contractor selection for part...	2007	44	4	6	4	8	1	4	27		71
14	The many views of a process: Toward a process architecture f...	2009	44	6	8	4	2	3	3	26		70
15	Didactic strategies to promote competencies in sustainabilit...	2019				4	20	27	15	66		66
16	Information system support as a critical success factor for ...	2006	57	1	3		2	1	2	9		66
17	Impact of specific investments, governance mechanisms and be...	2017		3	9	8	15	14	14	63	1	64
18	The role of technology transfer in innovation within small c...	2004	54	1	1	1	3	2	1	9		63
19	Student project collaboration using wikis	2007	47	5	2	2	2		1	12		59
20	A collaborative knowledge management tool for product innova...	2003	43	2	3	2	3	2	3	15		58

Table 1. Top 20 documents with more citations related to the search

Also the h-index graph is obtained and it indicates the authors that has publish at least h number of papers and at least has had h number of citations in each document. In this case, the h number is 31.

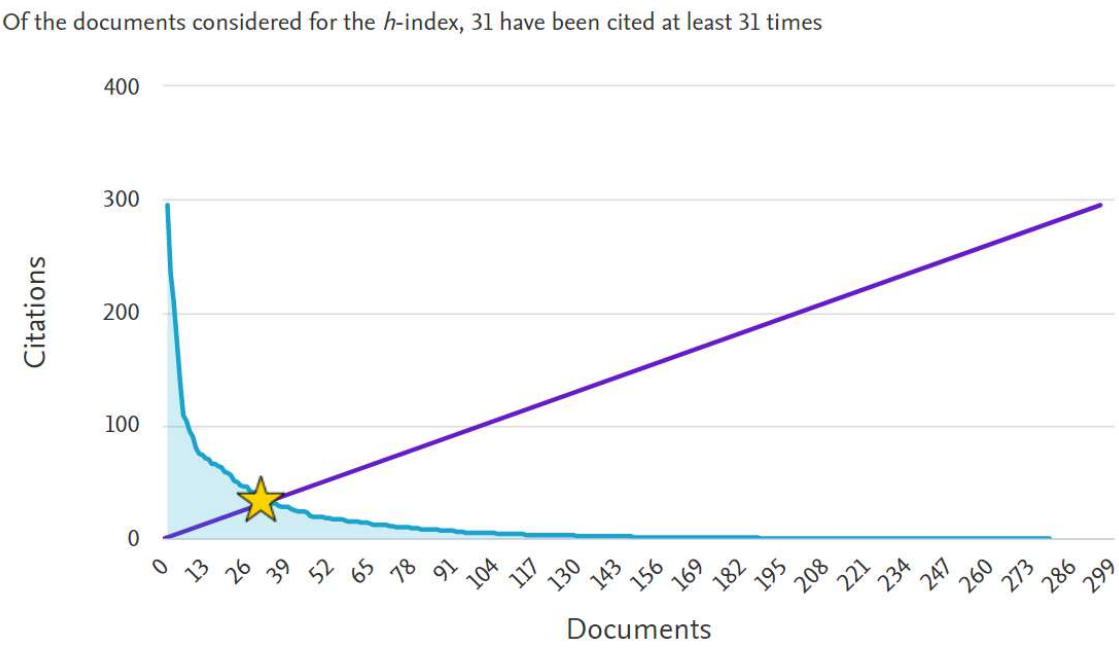


Figure 13. Graph of h-index for the search

Another important point to analyse from the bibliography is to identify new publications that could be relevant to the present research document, for which it is recommended to filter by publication date, with the most recent ones being the first in the search. The documents will be filtered by year (from 2018 to 2022) and then ordered by the number of citations received. The top 10 documents are:

	Documents	Citations	<2018	2018	2019	2020	2021	2022	Subtotal	>2022	Total
		Total	0	4	13	70	107	197	391	6	397
1	Key resources for industry 4.0 adoption and its effect on su...	2021				1	22	78	101	3	104
2	Didactic strategies to promote competencies in sustainabilit...	2019			4	20	27	15	66		66
3	Big size highly customised product manufacturing systems: a ...	2019			3	16	10	18	47		47
4	The roles of a Programme and Project Management Office to su...	2020				5	9	9	23		23
5	Characterizing industry-academia collaborations in software ...	2019				6	4	8	18	1	19
6	Diagnosing institutional logics in partnerships and how they...	2018		1	2	4	3	5	15		15
7	Project management and innovation practices: backgrounds of ...	2020				1	3	10	14		14
8	Opportunities for educational innovations in authentic proje...	2019				4	4	5	13		13
9	Planning benefits realization in a collaborative university-...	2018		2	1	2	3	1	9	1	10
10	A conceptual model for university-society research collabora...	2020				1	4	4	9		9

Table 2. Top 10 document more cited from 2018 to 2020 related to the search

In addition, it could be useful to identify the journals that are more common publishing during the last years documents related to this area of knowledge, in order to clarify in which sources are more accurate information. For this reason, analysing the results, the following journals are the main ones:

- International Journal Of Project Management
- Research Technology Management
- IEEE Transactions on Engineering Management

But apart from the sources obtained, here the important aspect is the documents that allow a better comprehension of the state of the art:

- Mainly the most recent papers are about collaborative projects [10] [11] [12] [13]. That means there is an interest in the last years about managing collaborations in R&D. After that, within the results appear other topics in relation with R&D such as industry 4.0 [14], sustainable developments [15] and industrial research [16].
- Some authors try to analyse the success factor in R&D projects, for example, *Rita Andrade, Gabriela Fernandes and Anabela Tereso* identified that factors in relation with 'inter-relational', 'scientific and technical' and 'strategic' could have an influence on the formation of benefits [17]. This points could be interesting to focus on and search methodologies and tools to improve the management of R&D collaborations.
- Regarding the framework of the innovative projects, it is clear that traditional methodologies do not reach successful results. For instance, this claim is proved in a case of study regarding a smart grid collaborative project [18], where traditional project management tools lead to fail. Authors say that to make rise of collaborative innovation between organizations of different nature, it requires defining a hybrid approach to manage this kind of project. Therefore, during this document it will be interesting to develop a concept of hybrid approach for R&D projects.
- Also for analysing the points and key aspects of R&D projects, there is a research on PM IT tools [19], in which authors overview some functionalities of IT managing software and purpose a battery of functionalities that could be useful to take into account for the purpose of techniques during this investigation.
- One of the most accurate papers with the current R&D management investigation is one made by *Gabriela Fernandes, Sofia Moreira, Madalena Araújo, Eduardo B. Pinto, Ricardo J. Machado* [20]. In this document, the authors state that the best option for managing this kind of projects is an hybrid approach, in which proposes a set of Must Have 24 well-known PM practices that are presented by the PM life cycle, divided into four phases: project initiation, project initial planning, execution, monitoring and control and re-planning, and, lastly, project closure. This 24 practices are taken from an intensive literature review and could be interesting to purpose during this investigation some tools to control them.
- Another research that may be a source of information could be '*Configurations of project management practices to enhance the performance of open innovation R&D projects'* [21], where the authors explain that a certain formal approach is necessary in the management of science-based projects. On the other hand, they review some literature and find aspects that should be taken into account through the life cycle of the project. However, the practices are not clearly defined, they explain what but not how.

6 SOLUTIONS TO AVOID FAILURE IN R&D PROJECTS

As seen in the context and in the analysis of the state of the art, there has been an increasing demand for innovation projects in recent years. In addition, the inherent complexity of these projects poses a management challenge.

That is why, as a contribution of this work, a framework for the correct management of R&D projects will be proposed in this block. In addition, based on research published by other authors, key tools and solutions will be offered to avoid failure and improve management.

6.1 Framework for R&D project management

Throughout this section, a specific methodology focused on the management of research projects is proposed. As it has been observed in the bibliographic review, there are many particularities in the nature of R&D projects, and that is why the traditional management framework is not completely adequate to be able to control the project. In fact, several articles refer to the need for a hybrid framework between traditional and agile management.

First of all, in order to understand the proposed concept, the different stages that a project of this type normally goes through during its life cycle will be briefly defined:

1. Research phase: this is the first phase of the project, mainly arising from the appearance of a problem, technological challenge or improvement. It is usually an informal activity as it seeks the generation of ideas and creativity through collaboration. It tries to find potentially interesting hypotheses or theories to meet the objective of the project. Once a set of proposals is obtained, it is time to give shape to these ideas, trying to find answers to the following questions: How is the idea going to be transformed into reality? How is the idea going to be tested? Is it possible, interesting or can it be developed with the available means?

2. Development phase: second phase preceding the initial phase but which may overlap at some point. It starts when an idea has already been conceived and defined. With this stage, the aim is to design and carry out the tests or prototypes that will mark the final viability of the idea. This part of the life cycle can extend from the pre-production phase to the production phase. This is where R&D resides in the life cycle. Depending on the organisation, the discipline, culture and structure applied to projects in this phase may be strict when there is a tight deadline to deliver a new version. Or it could be applied in a more relaxed way, for example during research for a radical innovation, where time constraints may be non-demanding. In the pre-production phase, all efforts and resources are focused on proving that an idea is good enough to go ahead; in R&D, it is at this point when the prototype has validated the design and production can begin. It is common for activities to move into production before the design is sufficiently mature, which is often a source of unforeseen events, iterations or failures. This part of the life cycle is difficult to manage. Moreover, the quantity of risk which can be tolerated and external pressures to meet deadlines will influence decisions about when to move on.

3. Control phase: as the project progresses, it approaches the control phase, where the number of iterations is reduced, the hypotheses are reduced and the changes disappear. It should be noted that in R&D it is possible for improvements to appear and be developed in this phase as knowledge is greater, however it is clear that the project moves from a more open tendency to something more structured.

Taking into account these points, which are usually common in the development of innovation projects, we can have the following life cycle approach:

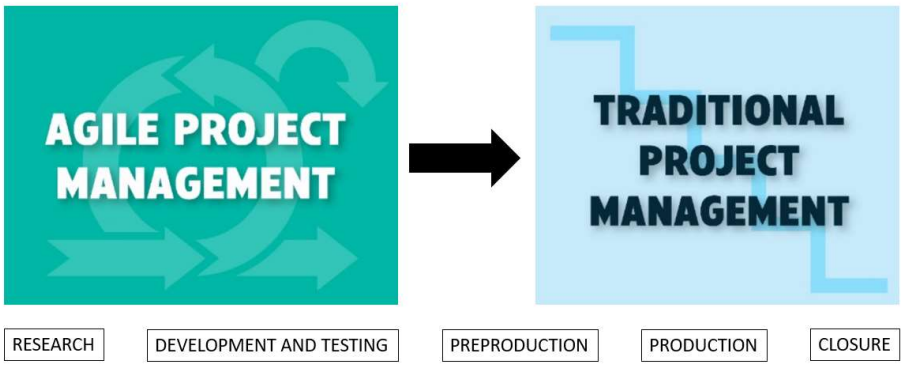


Figure 14. Project life cycle approach

On the other hand, in line with the authors' citations in their publications analysed in the state of the art, R&D project management needs both formal and informal tools and techniques. This will depend on the specific project and the maturity status of the project.

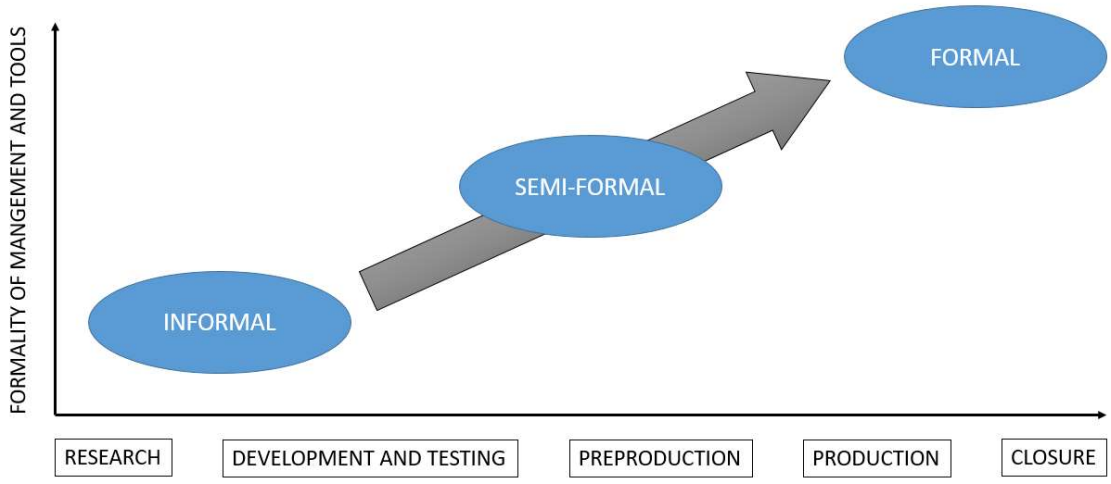


Figure 15. Formality grade along the project life cycle

This does not mean that it is strictly forbidden to use traditional or formal procedures in the early stages of the project. Indeed, they are also necessary for proper project control and management. However, what it is intended is to show that the use of more agile or informal tools is greater during the first stages of creativity and facilitates the progress of the project.

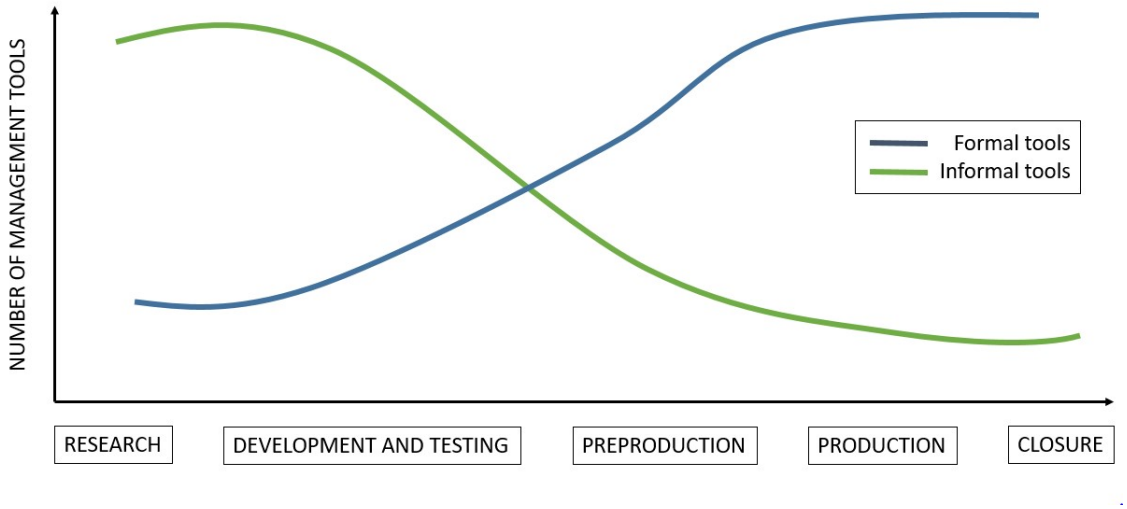


Figure 16. Number of tools during the project life.

For this reason, the next section will show different instruments, some of them with a more traditional nature and others more informal, that will facilitate the management of the different areas common to project steering, taking into account where the problems or failures appear.

6.2 Tools and procedures for improving R&D project management

During this section, different tools and solutions will be proposed to improve the correct management of R&D projects. As it has been previously observed, both traditional and agile techniques are necessary during the management of these projects. Furthermore, in order to make an analytical and coherent approach, the main problems encountered in these research projects will be listed first. Once this overview has been achieved, it will be possible to search for and recommend the use of certain management techniques.

6.2.1 Main problems identified

Thanks to the exhaustive search for information carried out in the state of the art of the project, very useful documents, authors and journals have been found for the development of this activity.

Specifically, different causes of problems and/or factors that cause failure in research projects due to the difficulty and particularities of these projects have been identified. The most common and recurrent ones are listed below:

- Communication between stakeholders, particularly project consortium [22] : In multi-organisational projects, correct communication is essential to be aligned at all times, however, without a well-defined communication strategy, information does not reach the project correctly and difficulties are generated in the project.
- Collaboration [23] [17] [21] : In collaborative research projects, a certain amount of dynamics and attention among the participants is needed to maintain the motivation and involvement of the partners in the project.
- Cultural/Geographic distance [23] [17] [21] : Although with new technologies the geographical gap between societies has narrowed, consideration needs to be

given when managing projects between different cultures to avoid potential socio-cultural problems.

- Objectives clarity [24] [25] [17] [26] [21] [27] : the project objectives are the most important part of the project as they will guide the final result you want to achieve. However, in collaborative research projects, each entity has interests that need to be aligned and negotiated to create common and interesting objectives.
- Necessity of performance and evaluation indicators (monitoring) [23] [28] [25] [21] [29] [30] : As in traditional project management, the evaluation and monitoring of the project to avoid deviations is of paramount importance, which is aggravated in research projects where uncertainty is higher.
- Stakeholder management [23] [28] [25] [31] [27] [30] : in collaborative R&D projects, it is very interesting to participate with different partners as each of them brings their expertise in a different field in order to achieve broader objectives and a wider scope. However, the fact that different stakeholders have so much impact on the project may pose a certain risk if not controlled.
- Dealing with unknowns (risk management) [26] [21]: Planning research and development (R&D) projects can be a challenging task, particularly due to the high level of uncertainty involved. However, rather than using this uncertainty as an excuse to avoid planning altogether, it is important to recognize that planning is even more crucial in such situations.
- Planning [30] [24] [25] [26] [21] [32] [29]: The planning of Research and Development (R&D) projects is frequently insufficient or entirely disregarded due to the considerable amount of uncertainty involved in such projects. However, uncertainty should not be an excuse to avoid planning but rather a reason to plan more thoroughly. Planning enables the management of uncertainty, whereas a lack of planning results in uncertainty managing the project.

6.2.2 Communication

Correct communication within a project is an important factor for its correct development, and in the case of research, it is even more important as the interaction between the different project partners and/or the organisation itself must be constant. Everyone must know where the project stands, if there have been any new developments, deviations or delays.

In terms of communication, the usual types of communication will be briefly discussed:

- Written communication: One of the most commonly used methods, written information can be copied and sent to all staff in the team, and key information such as due dates, company policies and procedures should be sent by written documents.
- Face-to-face communication: it is an interactive communication between two or more people where the participation of all participants is sought. The main objectives of face-to-face communication are:
    - Sharing knowledge
    - To create consensual knowledge
    - To maintain interest and motivation

- Communication via media: It is the most widely used means of communication, which is very important when managing a project with different partners and/or in different locations. Even more important with the rise of "work from home" or remote work. The various forms of electronic media allow managers to save time in sending emails and messages for different purposes: providing updates to project stakeholders, generating reminders, etc. However, media communication cannot replace face-to-face meetings and must be used simultaneously.
    - Virtual meetings:
    - Email
    - Databases
    - Telephone calls

Once the main communication channels have been identified, it is important to have an overview of them with respect to:

- Timing: it could be scheduled dates to unexpected contact.
- Tempo: as needed or one time.
- Formality: from informal contact to formal communication.
- Transmission: one to one communication or interactive/collaborative communications.

As shown in the figure below, they can be classified as follows:

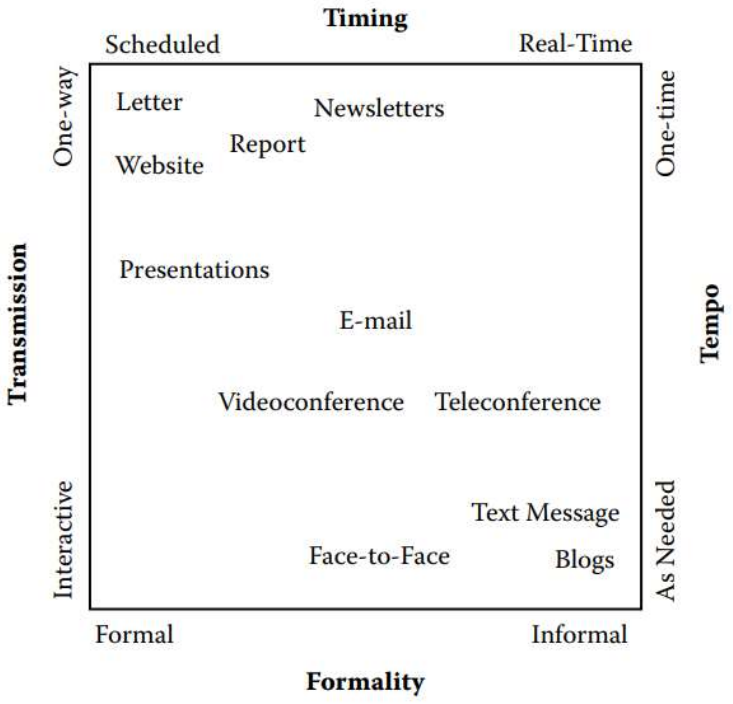


Figure 17. Communication tactics [33]

Once each communication channel has been identified and classified, it is necessary to develop a communication plan, which the project manager is responsible for implementing so that the project can be monitored, reported or stakeholders can be informed or receive information.

6.2.2.1 Communication plan

The main objective of the communication plan is to ensure that stakeholders are updated throughout the project, communicating the status of tasks when necessary, team accomplishments, objectives or milestones achieved, etc. It is the responsibility of the project manager to ensure compliance with this communication plan.

The following identifies the points in the matrix that are recommended for consideration:

- What information will be communicated (level of detail and format)
- How the information will be communicated
- When the information will be communicated (frequency)
- Who is responsible for communicating the project information (owner)
- To whom the information is addressed (audience)

It is also important to identify and break down the stakeholders (especially those at the highest level) and their specific communication needs in a table such as the following:

Name	Title	Contact	Frequency	Format & Channel	Notes
Anna Sánchez Iturregi	Project manager	AnnaSI@gmail.com +34 6xx xxx xxx	Monthly	Project performance status (Budget, Schedule…). Via face to face meeting.	Ask for feedback after meetings. 30 minutes of duration.
Josu Ramón Rodríguez	R&D Engineer	josuramon@gmail.com +34 6xx xxx xxx	Weekly	PowerPoint presentation with status of work. Via video conference	45 minutes of duration
…	…	…	…	…	…

Table 3. Stakeholder register

The following table shows an example of a communication matrix:

Communication Type	Aim	Channel	Frequency	Audience	Owner	Deliverable	Format
Kick-off meeting	Introduce the project team and the project. Review project objectives and management approach.	Team meeting	Once at the beginning of the project	• Project Sponsor • Project Team • Stakeholders	Project Manager	• Agenda • Meeting Minutes	• Soft copy archived on project SharePoint site and project web site
Project Team Meetings	Review status of the project with the team.	Conf. call	Weekly	• Project Team	Project Manager	• Agenda • Meeting Minutes • Project schedule	• Soft copy archived on project SharePoint site and project web site
Technical Design Meetings	Discuss and develop technical design solutions for the project.	In-person meeting	As Needed	• Project Technical Staff	Technical Lead	• Agenda • Meeting Minutes	• Soft copy archived on project SharePoint site and project web site
Monthly Project Status Meetings	Report on the status of the project to management.	Conf. call	Monthly	• PMO	Project Manager	• Slide updates • Project schedule	• Soft copy archived on project SharePoint site and project web site
Project Status Reports	Report the status of the project including activities, progress, costs and issues.	Email	Monthly	• Project Sponsor • Project Team • Stakeholders • PMO	Project Manager	• Project Status Report • Project schedule	• Soft copy archived on project SharePoint site and project web site

Table 4. Communication matrix

Another point that may be of interest is to generate a calendar of meetings that is accessible to everyone involved. This will maintain pre-established communications and oblige staff to respect that date in the calendar.

6.2.3 Tools for collaboration

In addition to establishing a communication plan and ensuring compliance, collaboration is essential, especially in projects involving several national or international partners. There are a number of tools and practices that can be used to improve collaboration in research and development projects. Here are a few options:

- Online collaboration platforms: There are several platforms that allow teams to work together in real time, such as Google Drive, Dropbox, Trello, Asana, Slack, Microsoft Teams, among others. These tools facilitate collaboration by allowing team members to work on shared documents, track project progress, communicate and coordinate tasks.

- Agile methodologies: Agile methodologies, such as Scrum or Kanban, focus on collaboration and communication between team members to achieve project goals. These methodologies encourage teamwork, feedback and continuous adaptation. In order to improve short-term management, Kanban board can be a very useful solution, as it is very easy to implement, visual and understandable for all project collaborators and allows to know what is being done, what has been done and what you want to do.

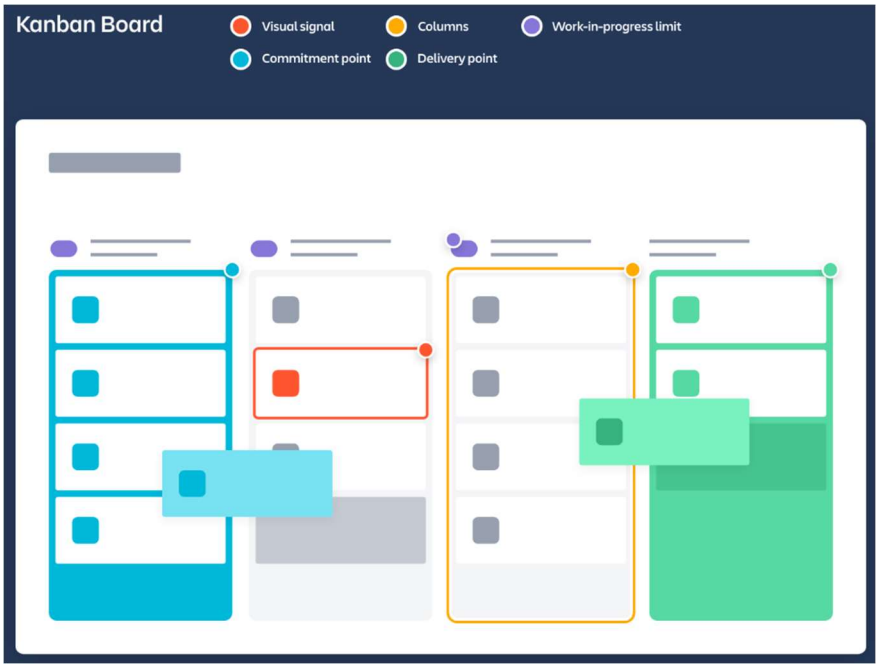


Figure 18. Kanban Board example [34]

- Visual signal: work teams write all their activities and work items on cards, usually one per card.
- Columns: cards/work-items flow through the workflow to completion. Workflows can be as simple as "To do", "In progress", "Testing", "Done" or much more complex.
- Work In Progress (WIP) Limits: WIP limits restrict the maximum number of cards in the stages of the workflow (columns).
- Commitment point: the point at which the team picks up an idea and starts working on the project. Teams often have a backlog for their board. This is where teammates put ideas for projects that the team can pick up when they are ready.
- Delivery point: the end of a Kanban team's workflow. The goal of the teams is to get the cards from the point of commitment to the point of delivery as quickly as possible.

- Regular meetings: It is important to hold regular meetings with the team to maintain communication and ensure that everyone is aware of the progress and challenges of the project. These meetings can be face-to-face or virtual and should have a clear and defined agenda. As mentioned in the previous section, we refer to the project team meetings which should be agreed at the beginning of the project, defining frequency and media.

- Clear roles and responsibilities: It is essential that each team member is clear about his or her role and responsibilities in the project. This will help to avoid confusion and conflict in the collaboration.
  - RACI Matrix: is a tool used to define who is responsible, who is in charge, who is consulted and who is informed in each task or activity of the project. RACI stands for:

- Responsible: the person who is responsible for carrying out the task or activity.
- Accountable: the person who is responsible for the task as a whole and who ensures that it is carried out effectively.
- Consulted: the person who is consulted in the decision-making process or in the execution of the task.
- Informed: the person who is kept informed about the progress of the task or activity.

ROLE / Project Deliverable (or Activity)	Executive Sponsor	Project Sponsor	Steering Committee	Advisory Committee	Role #5	Project Manager	Tech Lead	Functional Lead	SME	Project Team Member	Developer	Administrative Support	Business Analyst	Role #4	Role #5	Consultant	PMO	Role #3	Role #4
	Project Leadership					Project Team Members					Project Sub-Teams					External Resources			
Initiate Phase Activities																			
Request Review by PMO	A/C	R/A				R/A	A/C		C										
Submit Project Request						R											A		
Research Solution	I					R/A	A/C	A/C	C				C			C			
Develop Business Case	I	A/C	I	I		R/A	C	C	C				C			C	C		
Plan Phase Activities																			
Create Project Charter	C	C				R/A	C	C	C				C			C			
Create Schedule	I	I	I	I		R/A	C	C	C	C	C	C	C			C	I		
Create Additional Plans as Required	I	I	I			R/A				I	I	I	I			C	I		
Execute Phase Activities																			
Build Deliverables	C/I	C/I	C/I	C/I			R/A	R/A	R/A	R/A	R/A					A/C			
Create Status Report	I	I	I	I		R/A	R/A	R/A	R/A							C	I		
Control Phase Activities																			
Perform Change Management		C	C	C		R	A	A	A							C	I		
Close Phase Activities																			
Create Lessions Learned	C	C	C	C		R/A	C	C	C	C	C	C	C			C	C		
Create Project Closure Report	I	I	I	I		R/A	I	I	I	I	I	I	I				I		

Figure 19. RACI matrix example [35]

- Project Organisation Chart: is a tool used to visualise the hierarchical structure and roles of the project team. It is presented as a diagram showing the relationship between team members, their roles and responsibilities.

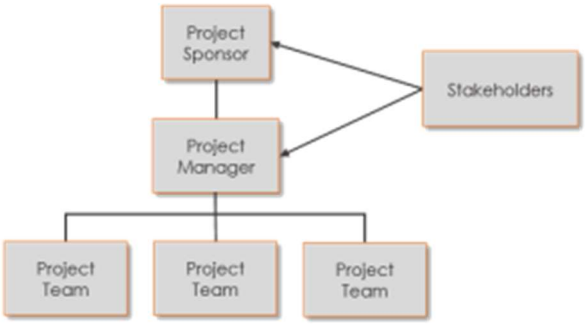


Figure 20. Project organization chart example. [36]

These tools are useful for defining roles and responsibilities in a project and ensuring that all team members are aligned and work together effectively. It is important to choose the tool that best suits the needs of the project and the team.

On the other hand, it is equally important to celebrate the team's achievements and recognise the work of each team member. This helps to keep team members motivated

and engaged in the project. Here are some ideas on how you can celebrate achievements in your project:

- Recognition: Recognition is an effective way to celebrate team achievements. This can be as simple as a verbal congratulations, a thank you email or a handwritten thank you note. Recognition can also be more formal, such as a certificate of appreciation or an award.
- Lunch or meeting: Organise a meeting or lunch with the team to celebrate the achievement. This can be an opportunity for the team to relax, share their experiences and celebrate together.
- Day off: giving team members a day off or extra time off is a way of rewarding them for their hard work. This also allows them time to rest and recharge.
- Recreational activities: Organising a recreational activity with the team, such as a football match, a trip to the cinema or a spa session, is another way to celebrate achievements and encourage team collaboration.
- Personalised gifts: A personalised gift, such as a commemorative T-shirt, a mug with the project logo or a personalised plaque, is a creative way to celebrate the achievements and keep the memory of the project alive.

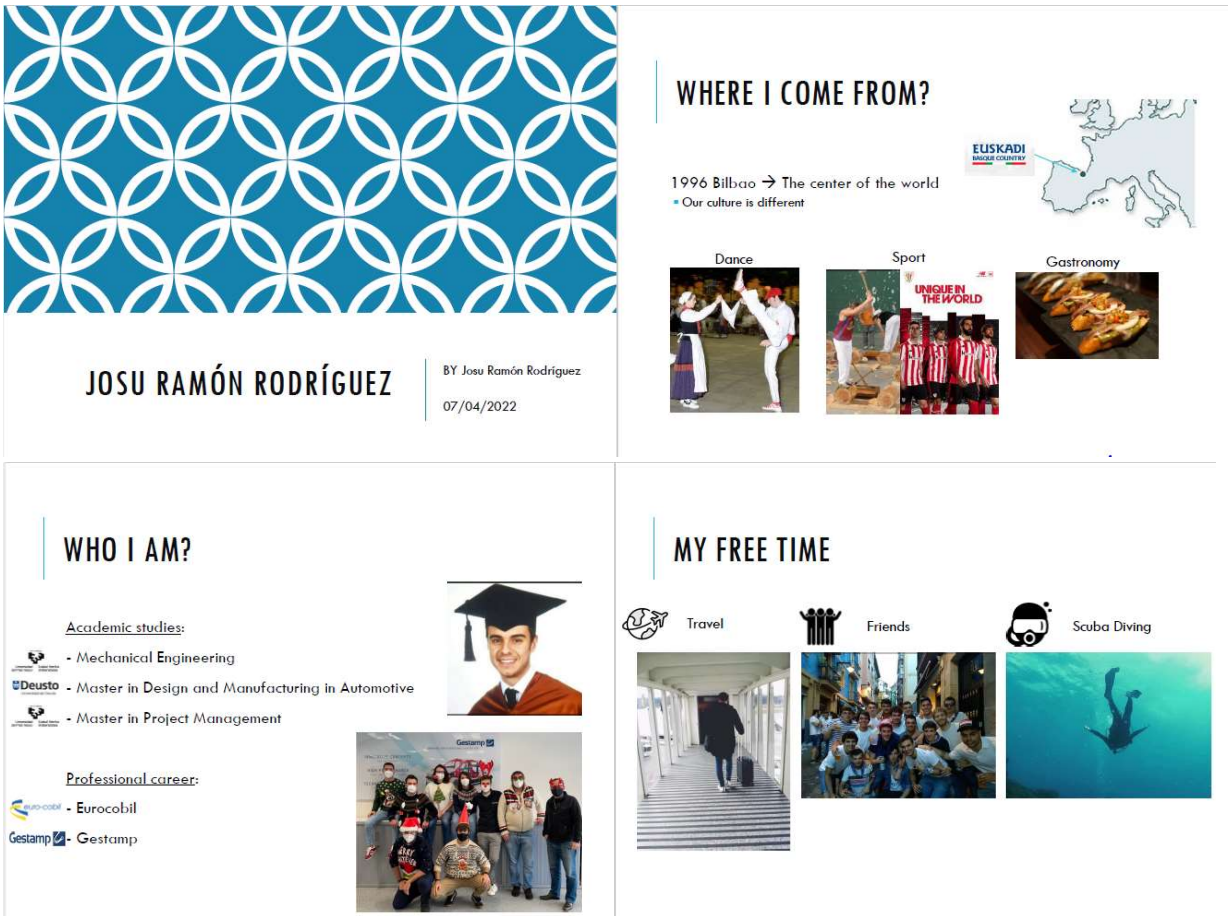
It is important to choose a way of celebrating achievements that is appropriate for the team and the project in question. Each team has its own dynamics and it is important to know the team members well in order to choose the best way to celebrate achievements together.

6.2.4 Cultural/Geographical distance

When managing international collaborative projects, in addition to the already known obstacles, there are others such as geographical distance or cultural differences that can negatively affect the results of the project if they are not properly addressed.

In order to overcome these differences and ensure that they do not affect the project, the following is recommended:

- Letter of introduction: a dynamic way to make yourself known and to establish a relationship with the other participants is to hold a presentation session. The idea is to briefly explain where you are from, your hobbies, your professional portfolio, etc. A short presentation like the following one is enough:



- Comparison between countries: there are websites [37] that help to get an overview of the culture of a country. It is interesting as well as beneficial for project management to learn about other countries to see what their weaknesses are, where they stand out from the rest or from one's own country. In addition, it can be useful for assigning tasks or roles within the project. Below are the results obtained for a comparison between Spain, Sweden and China in the following aspects:
    - Power distance: the degree to which less powerful members of a country's institutions and organisations expect and accept that power is distributed unequally.
    - Individualism: the degree of interdependence a society maintains among its members.
    - Masculinity: a high score means that the values being pursued are success, achievement and power. A low score means that quality of life and care for others are valued more.
    - Uncertainty avoidance: the uncertainty avoidance dimension is about how a society deals with the fact that the future can never be known: should we try to control the future or just let it happen?
    - Long term orientation: this dimension describes how each society has to maintain certain links with its own past while facing the challenges of the present and the future.

- Indulgence: This dimension is defined as the degree to which people try to control their desires and impulses, based on the way they were brought up.

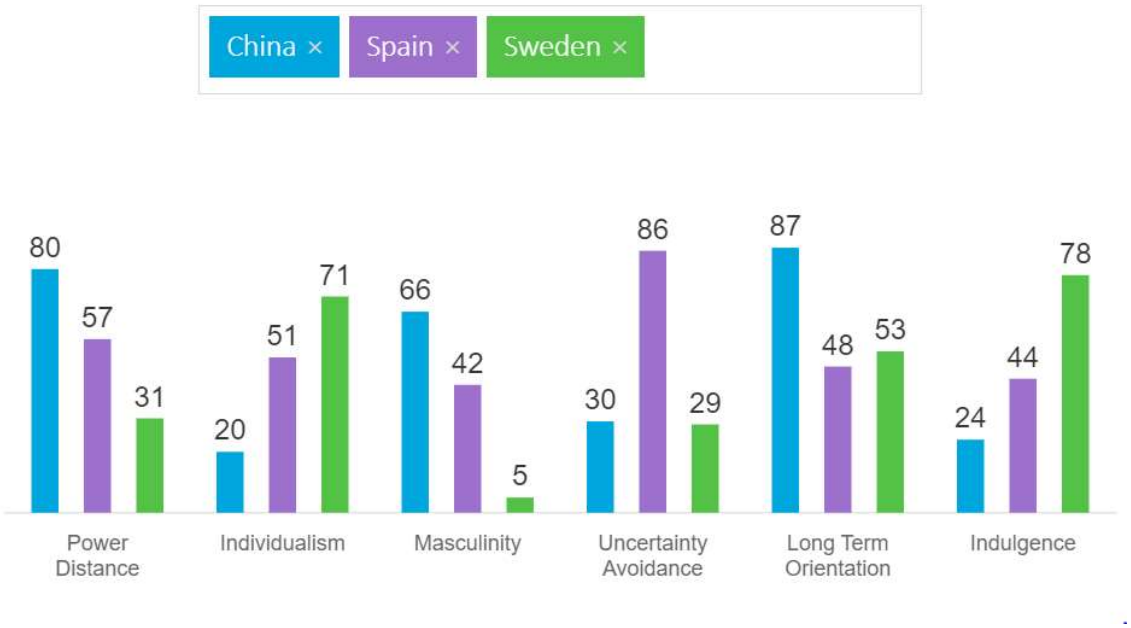
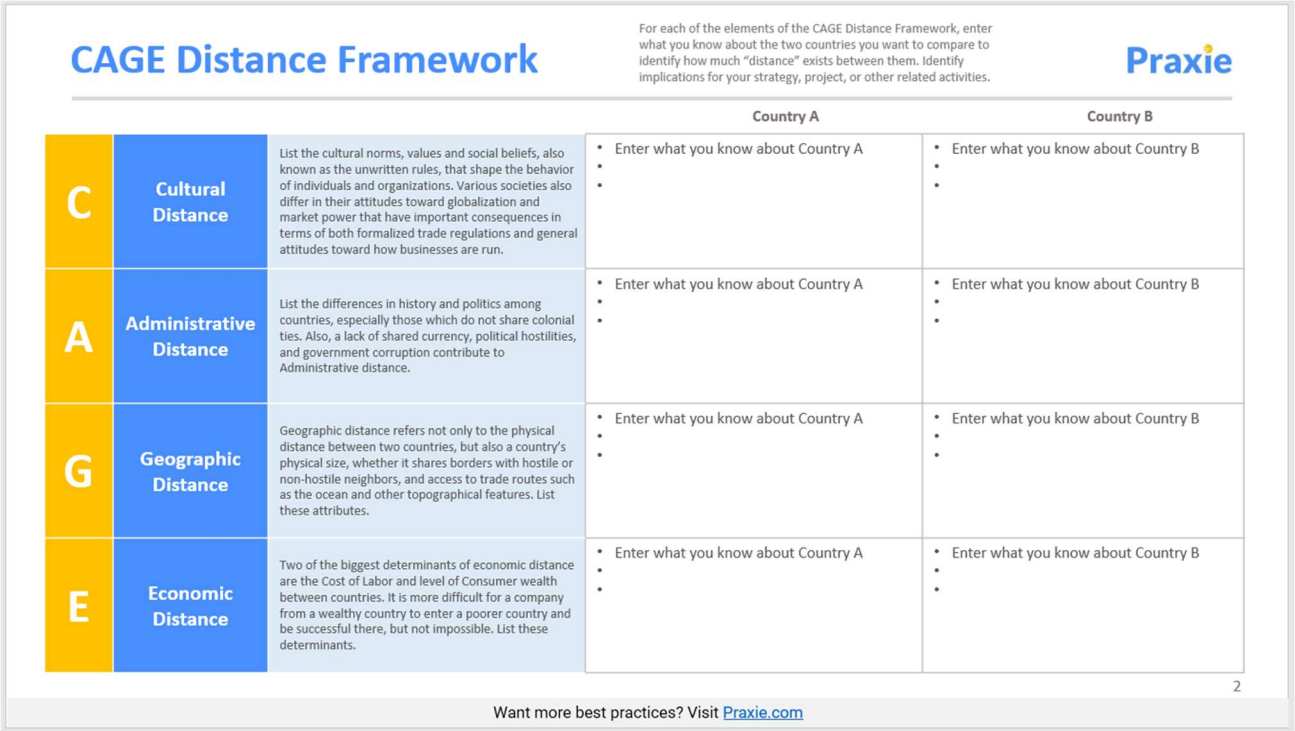


Figure 21. Country cultural comparison [37]

- CAGE Distance Framework: Professor Pankaj Ghemawat developed this tool [38] that identifies the cultural, administrative, geographic and economic differences between the various countries that companies should address and take care of whilst working on and crafting international strategies. The framework can also be used to understand the patterns of capital, trade, the flow of people, and information that work as crucial factors for the organization.
  - **C**ultural distance: what characterizes the culture of the country (language, religions…).
  - **A**dministrative distance: how the administration of the country works (currency, political situation…).
  - **G**eographic distance: what characterizes the geography of the country (timezone, climate…).
  - **E**conomic distance: how is the economy of the country (income levels, infrastructure…).



CAGE Distance Framework

For each of the elements of the CAGE Distance Framework, enter what you know about the two countries you want to compare to identify how much "distance" exists between them. Identify implications for your strategy, project, or other related activities.

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			Country A	Country B
C	Cultural Distance	List the cultural norms, values and social beliefs, also known as the unwritten rules, that shape the behavior of individuals and organizations. Various societies also differ in their attitudes toward globalization and market power that have important consequences in terms of both formalized trade regulations and general attitudes toward how businesses are run.	• Enter what you know about Country A	• Enter what you know about Country B
A	Administrative Distance	List the differences in history and politics among countries, especially those which do not share colonial ties. Also, a lack of shared currency, political hostilities, and government corruption contribute to Administrative distance.	• Enter what you know about Country A	• Enter what you know about Country B
G	Geographic Distance	Geographic distance refers not only to the physical distance between two countries, but also a country's physical size, whether it shares borders with hostile or non-hostile neighbors, and access to trade routes such as the ocean and other topographical features. List these attributes.	• Enter what you know about Country A	• Enter what you know about Country B
E	Economic Distance	Two of the biggest determinants of economic distance are the Cost of Labor and level of Consumer wealth between countries. It is more difficult for a company from a wealthy country to enter a poorer country and be successful there, but not impossible. List these determinants.	• Enter what you know about Country A	• Enter what you know about Country B

2

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Figure 22. CAGE framework template[39]

With this tool, it allows to explore how these factors could affect your organization's collaboration or project to expand the partnership into a foreign market. It can also be used to compare the advantages that different countries present, and to prompt further research into whether expansion is viable.

- Lack of language skills: Another problem that often arises when managing international collaborative projects is language. On the one hand, there is the obstacle of language level, as not all team members have the same level. this makes it difficult to transmit information, especially in meetings. It is often common not to understand all the information received or not to express oneself correctly when sending information. For this reason, the following is proposed:
    - Meetings by videoconference: the fact of seeing the face, the lips when speaking and the expressions or gestures makes communication much easier both for the person receiving the information and for the person sending it, as they can see if the other person is understanding them or not.
    - Slides: it is usually interesting to prepare a small presentation or document that only contains the relevant information so that the person concerned can grasp the main message and understand the basis of the meeting. It is also useful to send this presentation after the end of the meeting in case it requires a second reading.
    - Meeting minutes: this is a document that is prepared during the meeting, noting down the most important points agreed, next steps, participants, etc. In short, it allows us to have control and monitoring through a record. It facilitates communication as all participants must review it and see if they agree with what has been drafted.

6.2.5 Setting goals

The clear and shared definition of project objectives is fundamental to the success of any collaborative research project.

- Kick-off meeting: It is important that stakeholders meet at the beginning of the project to discuss and define the objectives collaboratively. This can help ensure that all perspectives are considered and that all expectations are clear.
- SMART: Defining SMART objectives is good practice in any project, including innovation projects. The acronym SMART refers to objectives that are Specific, Measurable, Achievable, Relevant and Time-bound.
    - **S**pecific: The objective should be clear and specific, avoiding generic and vague objectives.
    - **M**easurable: The objective should be measurable, in order to be able to assess whether or not it has been achieved. There should be a clear way to measure progress towards the objective.
    - **A**chievable: The objective should be realistic and achievable, taking into account the resources available and the limitations of the team.
    - **R**elevant: The objective should be relevant to the project and the overall objectives of the organisation. It should make sense in the context of the project and be important to the overall success.
    - **T**ime-bound: The objective must be time-bound, which means that a deadline must be set for achieving it.

  With time, the definition of the SMART acronym has been updated, reflecting the importance of the efficiency and feedback. Some authors have extended it, including some focus areas: for example, SMARTER notion includes Evaluated and Revised. Sometimes SMART can be expressed with two A's as SMAART. In this case, the first A means Achievable and the second is Action-oriented [40].

- SWOT analysis: is a useful tool for assessing the current situation of a project or company and provides valuable information for decision-making. The acronym SWOT stands for Strengths, Weaknesses, Opportunities, Opportunities and Threats, and is used to analyse both internal and external factors that can affect the success of a project. SWOT analysis can assist in defining collaborative objectives in a number of ways:
    - By identifying internal strengths, the team can set realistic objectives that capitalise on these strengths and are in line with available resources and skills.
    - By identifying external opportunities, the team can set objectives that take advantage of market trends, customer demand and other external factors.
    - By identifying internal weaknesses, the team can set objectives that address these weaknesses and enable the team to improve its performance.
    - By identifying external threats, the team can set objectives that address these challenges and reduce the risks associated with the project.

In the end, in projects where different entities are involved, it is interesting to perform this exercise to better understand the situation of our partner and to see where it can contribute more to the project. Ultimately, collaboration should reduce the weaknesses of each partner, compensating with the strengths of the others and thus reducing the threats.

6.2.6 Tools for monitoring

Balanced Scorecard (BSC) is a strategic management technique that can be used in research projects to set and measure strategic objectives in several key areas. The BSC focuses on four main perspectives: Financial, Customer, Internal Processes and Learning and Growth.

In the context of a research project, one possible way of applying the BSC could be as follows:

- Financial perspective: This perspective focuses on the financial and economic objectives of the project. For example, financial objectives may include securing funding, reducing costs, increasing revenues, and generating value for sponsors and investors. Financial indicators may include, for example, project budget, return on investment (ROI), cost per discovery and project profitability.
- Customer perspective: This perspective focuses on customer-related objectives and end-user satisfaction. In a research project, objectives may include generating new knowledge, solving specific scientific or technical problems, improving people's quality of life, or creating value for society. Indicators can be, for example, the success rate in obtaining relevant results, end-user satisfaction, improved problem solving and the social impact of the project.
- Internal Processes Perspective: This perspective focuses on objectives related to the efficiency and quality of project processes. In a research project, objectives may include optimisation of the research methodology, improvement of resource management, reduction of response times and quality of results. Indicators can be, for example, the number of relevant discoveries, the turnaround time for obtaining results, the number of publications and patents, and the quality of publications and patents.
- Learning and Growth Perspective: This perspective focuses on objectives related to the development and growth of the research team. In a research project, objectives may include the improvement of the team's skills and competences, the promotion of teamwork and innovation in research methodology. Indicators can be, for example, training and development of the team, collaboration with other teams, and development of new products and services.

Once the perspectives and objectives of the BSC have been defined, specific and measurable targets should be set for each indicator. This will allow you to track the progress of the project and make data-driven decisions. It is important to regularly review the BSC indicators and make adjustments based on the results obtained. Here is presented a simple template for BSC:

Figure 23. Template for Balanced Scored C. [41]

6.2.7 Tools for stakeholder management

Having all stakeholders on board is the best way to lay a solid foundation for the design, development, and implementation of local strategies. But bringing the right people together and maintaining their support in a multi-stakeholder group can be a challenging task. It is also one of the potential realising factors that projects need to manage.

1. Identify who the stakeholders are. They may be important to the organisation but that does not necessarily mean they are important to the project.
2. Determine what power they have and what their intentions are with regard to the project. Basically, it is a question of assessing their capacity to influence the project, whether they have power and how much power they have over the project.
3. Identify the relationship between the stakeholders. The aim is to see if it is possible to improve the chances of the project by working with your supporters to improve the views of those who oppose it.

The figure below shows the options based on an assessment of the potential for cooperation and stakeholder threat:

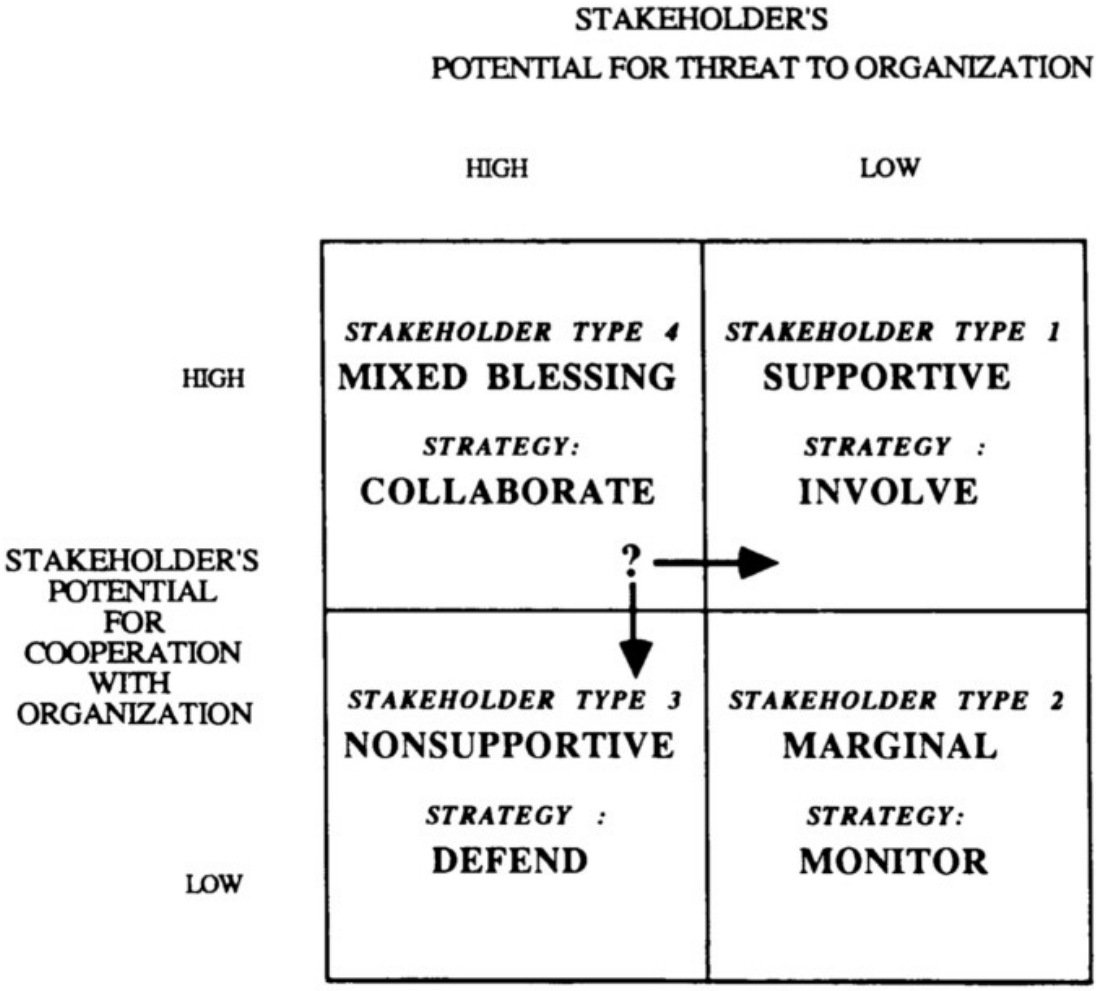

Figure 24. Types of stakeholders and how to manage them.[42]

Thus, stakeholders in the upper right quadrant (1) have a high potential to support the project, but a low potential to influence. Therefore, project managers need to involve these stakeholders to increase support. In the lower right quadrant (2) are those with low potential for support and low influence. They are marginal to the project, but must be monitored and informed to keep them up to date. In the lower left quadrant (3) are those who have little capacity for support, but potentially a lot of influence on the project. Managers should be wary of these stakeholders and defend the project from them, as they could become a major threat to the project if they are ignored. Finally, in the upper left quadrant (4) are those who have a strong supportive capacity and a great deal of influence. They are active partners and should be treated as such.

In addition to influence and interest in the project, it is important to take into account in a collaborative project the relationships that stakeholders may have with each other. In other words, a project in which the different partners do not have good relationships or have had previous conflicts may pose a risk. The diagram below shows an example of such an approach to mapping stakeholders and their relationships. With this information you can draw an ideal map and define strategies to help you get there.

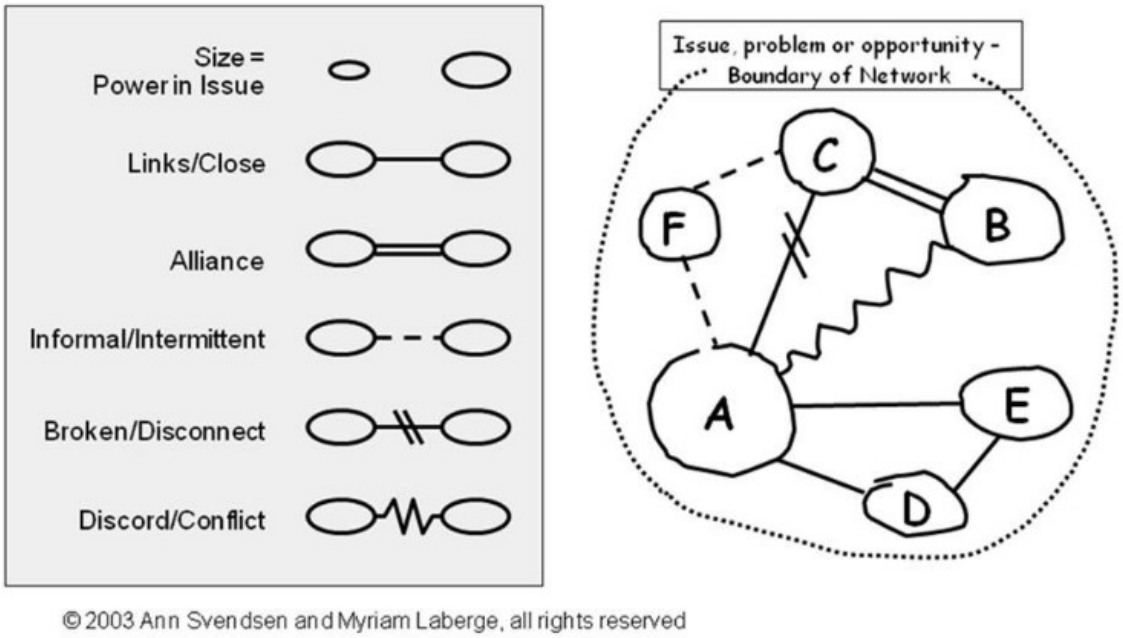

Figure 25. Map of stakeholder relationships.[43]

Now with this information and stakeholder overview, a stakeholder analysis template can be completed that will help define those strategies to improve your support:

Stakeholder Names and Roles	How Important ? (Low – Med – High)	Current Level of Support? (Low – Med – High)	What do you want from stakeholders ?	What's important to stakeholders?	How could stakeholders block your efforts?	What is your strategy for enhancing stakeholder support?

Figure 26. Stakeholder analysis template. [43]

6.2.8 Tools for dealing with unkowns

Through careful planning, you can effectively manage uncertainty and minimize its impact on the project's outcome. On the other hand, failing to plan can result in uncertainty controlling the project instead of the other way around. So, when it comes to inventing something, it is essential to embrace the challenge and put in the effort to plan your project effectively. Remember, planning is not a hindrance, but rather a powerful tool for success.

When it comes to planning R&D projects, it's important to start with a detailed plan for the near-term part of the project. For the rest of the project, even if you can only come

up with a rough plan that lists major milestones, it's better than no plan at all. As the project progresses, keep adding details to your plans as soon as possible. This means that your level of planning detail will gradually deepen over time, like a wave moving forward.

Planning the unknowns: There are two major types of unknowns: known unknowns and unknown unknowns. Known unknowns are the things that you know you don't know. For example, you might be aware that you don't know whether a new technology will be useful for an untested application. Or, you might know that you don't know whether it will rain or snow on the day you planned to conduct an outdoor experiment in the future. In such cases, it's important to plan for the known unknowns as best you can, while also being prepared to adapt and adjust as the project progresses and new information becomes available. Unknown unknowns are the things that we are not aware of, and that we have no way of reasonably predicting. These events can occur unexpectedly and without warning, making them particularly difficult to plan for. For instance, a project manager who is doing an excellent job may suddenly become incapacitated due to a heart attack and be unable to work for several months. Such unforeseeable events are a prime example of unknown unknowns, which can happen at any time during the course of a project. While it's impossible to anticipate every possible unknown unknown, it's important to remain flexible and be ready to adapt as needed to overcome unexpected challenges.

- Planning known unkowns: One useful tool for identifying potential problems is a "Fatal Flaw Analysis," which involves two steps.

  The first step is to hold a brainstorming session with key project personnel and perhaps other creative individuals not directly involved in the project. During this session, you should ask questions such as, "What could possibly go wrong with this project?" or "What might happen that could have a negative impact on this project?" It's important to list all ideas without judgment or evaluation at this stage, as the goal is simply to generate a comprehensive list of potential flaws.

  In the second step, you should evaluate and prioritize the brainstormed ideas with a qualified group of people. Each idea should be placed into one of several categories in following figure, based on its likelihood of occurrence and its potential impact on the project. This step will help you to identify the most critical issues and develop a plan to address them before they become major obstacles.

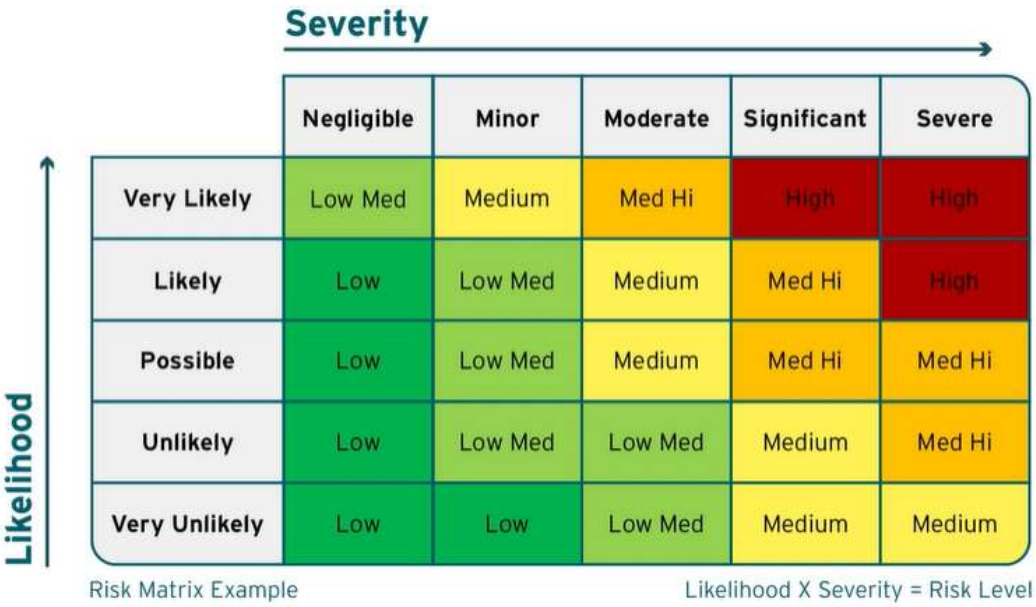

Figure 27. Fatal Flaw Analysis [44]

By going through a structured approach to determine potential problems in the project, many of the known unknowns and their solutions have been identified. Additionally, the analysis considers the risk or probability of these events occurring. Since the likelihood or risk of the events happening has been established, any resulting additional budget and duration could be labelled as "Risk Fund" and "Risk Time" respectively when estimating project costs and duration. The "Risk Fund" would be added to the original project cost estimate, and the "Risk Time" would be added to the original project duration estimate.

A different kind of known unknown exists in project planning when there are tasks for which the outcome is uncertain. For instance, a task involving the reaction of chemical A with chemical B may result in the production of chemical C, but it is also possible that chemicals D or E could be produced in large amounts. In such cases, it may not be feasible to plan beyond the reaction step, and one may have to wait and see what happens. However, this approach of delayed planning is not recommended as it can leave one unprepared for the worst-case scenario. To avoid potential crises, it is advisable to adopt a different approach for activities in the project plan with uncertain outcomes. First, one should identify the three most-probable outcomes and seek expert advice if necessary. Second, assume that all three outcomes will occur and plan accordingly. A Network Diagram, also known as a PERT chart, can be used to illustrate this approach.

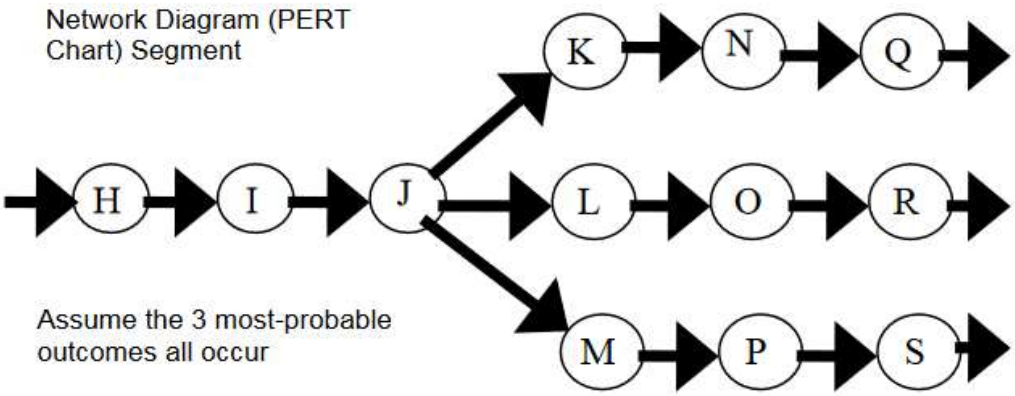

Figure 28. Planning when a task has an uncertain outcome [26]

- Planning unknown unknowns: in project planning, it is common to include a contingency in the project cost estimate that takes into account corporate policy as well as the uncertain nature of the project. These contingencies can be as high as 30% or more of the total R&D project cost for very uncertain projects. Additionally, a time contingency should be factored into the project duration estimate to account for unknown unknowns. Performance contingencies are also necessary and their size will depend on the project at hand. Although there are various approaches to calculating these contingencies, they often rely on good judgment and experience.

6.2.9 Tools for planning

When choosing a specialized technical tool for planning and scheduling an R&D project, it is important for a manager to understand that traditional project management tools are only effective when combined with soft managerial tools for team management. While the project management literature often emphasizes rational techniques, it is crucial to also consider and use other methods in conjunction with these techniques.

- Network techniques: In the realm of network techniques, the Critical Path Method (CPM) and the Program Evaluation and Review Technique (PERT) are commonly used. Despite their similar approach and recommendations for method application, CPM relies on a deterministic approach for estimating activity completion time, whereas PERT is based on a probabilistic approach, which is better suited for handling uncertainties in R&D projects. While CPM is widely used in the construction industry, PERT is more applicable in R&D project management.
  The Graphical Evaluation and Review Technique (GERT) is a network chart that is particularly useful for R&D projects that are highly uncertain and have many alternative paths and loops. It is especially effective for poorly defined projects where the probability of success is uncertain. Unlike other network charts like CPM and PERT, GERT can model probabilistic events and decision points, allowing for a more accurate analysis of the project's risk and uncertainty. GERT can also handle loops and feedback, making it a valuable tool for complex R&D projects with many interdependencies. In GERT, each activity is represented as

an arrow, and each arrow is associated with two parameters: the duration of the activity and the probability of its occurrence. The duration is the expected time it will take to complete the activity, while the probability of occurrence represents the likelihood of the activity being completed. These parameters are essential for determining the critical path and for calculating the overall project schedule and budget.
The three logical operators in GERT concern activities incoming to the node and they are:

1. XOR - alternative (only one path possible)
2. OR - alternative (one or more paths can be performed)
3. AND - all paths have to be performed.

In GERT, the activities that follow a node can be of two types of relations. The first type is deterministic, which means that there is a 100% chance that every activity will be completed. The second type is probabilistic, which means that each activity has a chance of occurrence, and its probability of occurrence is less than 100%.

For calculating probability and duration of activities, the next example is presented:

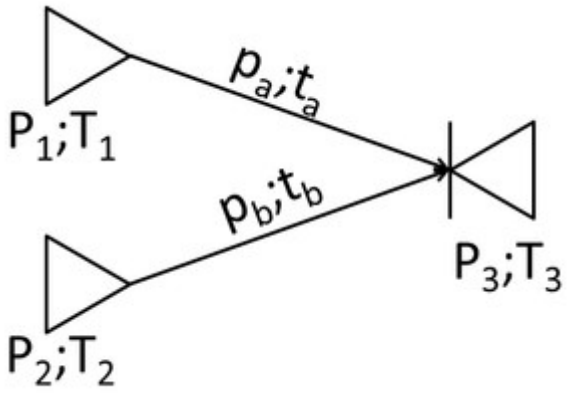

Figure 29. Basic GERT network example.[45]

The equations below show how to calculate probability and duration of arriving at node 3 from nodes 1 and 2, which are alternative.

$$P_3 = P_1 p_a + P_2 p_b$$

$$\overline{T}_3 = \frac{P_1 p_a (\overline{T}_1 + t_a) + P_2 p_b (\overline{T}_2 + t_b)}{P_1 p_a + P_2 p_b}$$

- Non network techniques: Non-network techniques such as the Work Breakdown Structure (WBS) and the Gantt chart are widely used in project management. The WBS involves breaking down project activities into smaller sub-activities or tasks. This helps in creating an overview of the project and enables better planning and control. On the other hand, the Gantt chart provides a static visual representation of tasks, giving a snapshot of the project's progress at a given point in time.

A Work Breakdown Structure is a useful tool for breaking down a project into smaller, manageable tasks and assigning responsibility to organizational sections. However, in R&D, it can be difficult to break down projects without knowing all the components and having an existing organizational structure in place. This can limit creativity and hinder innovation. To address this, a modified tool called the Creativity Breakdown Structure (CBS) has been proposed. The Creativity Breakdown Structure allows us to visually deconstruct each problem we need to solve into its fundamental problem areas, such as theory, knowledge, energy source, timing, cost, equipment, materials, components, and mechanical design. This helps us identify the necessary properties that any potential solution must possess, allowing us to reverse-engineer it. Breaking down tasks into packages is a natural way of conducting research, but the CBS documentation has the additional benefit of aiding project communication, control, and monitoring for both researchers and managers. To effectively implement a Creativity Breakdown Structure, it is recommended to follow a well-organized and documented approach:

1. Firstly, create a traditional Work Breakdown Structure (WBS) or Product Breakdown Structure (PBS) by designing a research plan and dividing the problem into smaller, measurable tasks.
2. Next, create a sequence or order of tasks and group them into packages.
3. Analyse the dependencies between packages and develop relationships between each task.
4. Break down the tasks into specific problems.
5. Finally, assign resources for the implementation of each task.

Another useful tool could be the Design Breakdown Structure (DBS) that breaks down areas and components into fundamental problem areas that must be addressed to achieve specific goals. Like the WBS, it is a graphical representation that displays all the problems that need to be resolved, potential solutions to those problems, and their interrelationships. The DBS may also include multiple CBSs to address individual problems that require resolution. As each problem area is identified, alternative solutions can be listed underneath their respective problem areas. While a WBS focuses on the project's 'WHAT' outputs, the DBS emphasizes the project's 'HOW' questions.

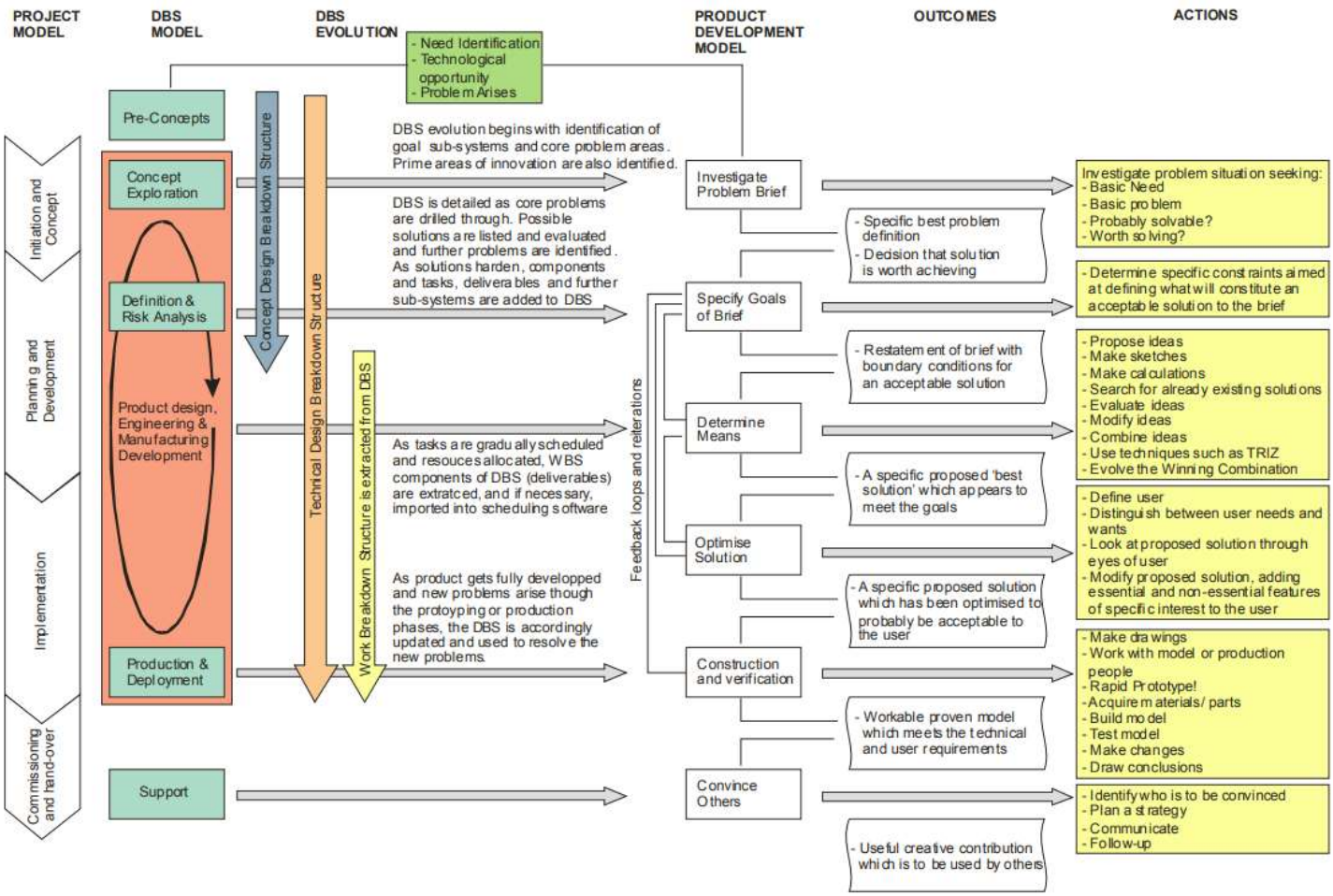

Figure 30. Design Breakdown Structure example. [46]

Another commonly used tool for planning and monitoring is the Gantt chart. It is simple to create and easy to read, making it a popular choice among managers. However, if changes are made during the implementation phase, it may be difficult to track delays. To create a Gantt chart, the following steps are recommended: first, define all the activities with their unique identification number. Then, sequence the activities to create a task sequence. Finally, estimate the starting and completion times for each activity, and calculate slack time. The resulting data is presented in a two-dimensional graph.

ID	Task Name	Start	Finish
1	Project outlining	2014-01-06	2014-02-06
2	Supplay and purchace of equipment	2014-02-06	2014-06-06
3	Theoreticl appraoch	2014-02-06	2014-08-06
4	Empirical research	2014-06-09	2015-06-08
5	Model testing and conclusions	2015-06-08	2015-12-08

Figure 31. Simple Gantt Chart example.[47]

7 CONCLUSIONS

As described during the course of this study, the number of new research and development projects and investments at national and European level are clearly growing year by year. However, these types of projects present particularities that make their management an obstacle for project managers. Uncertainty, extensive collaboration with stakeholders and the difficulty of planning are some of the aspects that differentiate these projects from traditional or structured projects, which are easier to manage as they are more predictable and repetitive.

In order to address the correct management of these projects, firstly through a literature review, the factors that contribute to failure or negatively affect the management of innovation projects have been identified, the most common of which are as follows:

- Poor communication between participants
- Need for collaboration,
- Cultural and geographical differences
- Clarity of objectives
- The need for performance indicators and evaluation
- Stakeholder management
- Risk management
- The importance of good planning

Once the most common factors have been identified, a framework of action for the management of R&D projects is proposed, in which the use of traditional and agile tools stands out, creating a hybrid methodology. During the beginning of the project (basic research), uncertainty is greater and therefore the tools to be used should be more agile. On the other hand, as the project progresses, the objectives are more clearly defined and the tendency is to use more traditional tools.

On the other hand, from the factors identified, solutions are proposed to help the management of the innovation project. The solutions proposed, given the framework presented, have a more traditional or structured nature:

- Comunication
    - Comunication plan
    - Stakeholder register
- Collaboration
    - Online collaboration platforms
    - Kanban/Scrum
    - Meetings
    - RACI Matrix
    - Project Organization Chart
- Cultural/Geographical distance
    - Letter of introduction
    - Country anlisys/comparison
    - CAGE Distance Framework
    - Language skills
- Setting goals
    - Kick off meeting

    - SMART
    - SWOT analisys
- Monitoring
    - Balanced ScoreCard (BSC)
- Stakeholder management
    - Assessment of the potential for cooperation – threat
    - Map of relationships
    - Stakeholder anlisys template

Finally, it should be noted that the nature of each project may vary and it will be the responsibility of the project manager to know how to choose the best tools to suit each project.

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