**UNIVERSIDADE FEDERAL DE ITAJUBÁ - UNIFEI**
**PROGRAMA DE PÓS-GRADUAÇÃO EM**
**ENGENHARIA DE PRODUÇÃO**

# Criteria Used in Research & Development Project Selection

**Ernany Daniel de Carvalho Gonçalves**

Itajubá, March 24, 2019

**UNIVERSIDADE FEDERAL DE ITAJUBÁ - UNIFEI**
**PROGRAMA DE PÓS-GRADUAÇÃO EM ENGENHARIA DE PRODUÇÃO**

**Ernany Daniel de Carvalho Gonçalves**

# Criteria Used in Research & Development Project Selection

Dissertation submitted to the post-graduation program in Industrial Engineering as part of the requirements for obtaining a Master's degree in Industrial Engineering.

**Concentration area: Quality and Product**

**Supervisor: DSc. Carlos Eduardo Sanches da Silva**
**Co-supervisor: MSc. Dalton Garcia Borges de Souza**

**March 24, 2019**
**Itajubá**

**UNIVERSIDADE FEDERAL DE ITAJUBÁ - UNIFEI**
**PROGRAMA DE PÓS-GRADUAÇÃO EM ENGENHARIA DE PRODUÇÃO**

# Criteria Used in Research & Development Project Selection

**Ernany Daniel de Carvalho Gonçalves**

Dissertation approved by the examination board in February 28th, 2019, attributing to the author the title of **Master in Industrial Engineering.**

***Examination Board:***
DSc. Mariângela de Oliveira Abans
DSc. Adler Diniz de Souza
DSc. Carlos Eduardo Sanches da Silva (Supervisor)

**Itajubá**
**2019**

# Acknowledgements

First of all I'd like to thank God and my family for making me strong enough to not give up of any challenge that I face.

Also, my friends, colleagues, and teachers that I met during this journey.

My friend Laila and my cousin Vinicius that always sought to motivate me.

My supervisors professor Carlos Eduardo Sanches da Silva and Dalton Garcia Borges de Souza for all the guidance and patience during this 2 years.

Both CERPCH and ICC specialists for receiving me.

And last but not least, I thank UNIFEI, Capes, Fapemig and CNPq for all the structure and financial support.

*"Idle hands are the devil's workshop."*
*(Moira O'Deorain)*

# Resumo

Devido à corrida em busca de inovação, organizações do Brasil e do mundo todo enfrentam desafios constantes para se manterem relevantes no mercado, buscando as melhores formas de gerenciar seus projetos e utilizando dos recursos existentes para maximizar os benefícios e, em alguns casos, minimizar o risco ou custos de seus projetos. De acordo com uma revisão sistemática de 61 artigos, escritos entre 1970 a 2018, que utilizam métodos multi-critérios para tomada de decisões (MCDM) para selecionar projetos de Pesquisa & Desenvolvimento (P&D), apenas 19 deles dão uma explicação adequada dos critérios utilizados. Assim, a fim de contribuir com o processo de seleção de projetos, o objetivo principal deste trabalho é mostrar quais os tipos de critérios que apresentam maior relevância sobre os demais. Todo o processo é feito através de uma revisão sistemática da literatura: desde a seleção dos artigos, o agrupamento dos critérios e sua avaliação por dois especialistas utilizando o método Analytic Hierarchy Process (AHP). Ao final, percebe-se o quão importante é o benefício financeiro para os especialistas, e que a inovação não é considerada tão relevante para eles e para a maioria dos autores dos artigos analisados.

**Palavras-chave**: AHP, seleção de critérios, MCDM, seleção de projetos, P&D, Pesquisa e Desenvolvimento.

# Abstract

Due to the race in search for innovation, organizations from Brazil and around the word face constant challenges to maintain themselves relevant in the market, looking for better ways of managing their projects and using the existing and scarce resources with the objective of maximizing a utility measure or benefit and, in some cases, minimizing the risk or costs of their projects. According to a systematic review of 61 articles, written from 1970 to 2018, which use Multi-Criteria Decision Making (MCDM) methods to select Research  Development (R&D) projects, only 19 of them give a proper explanation of the used criteria. Thus, in order to contribute with the project selection process, the main goal of this work focuses on showing which types of criteria have more importance over the others. The whole process is done thorough a systematic literature review: since the articles selection, the criteria grouping and their evaluation by two specialists using the Analytic Hierarchy Process (AHP) method. By the end, it is noticed how important the financial benefit is to specialists, and that innovation is not considered as relevant to them and to the majority of the analyzed articles.

**Keywords**: AHP, criteria selection, MCDM, project selection, R&D, Research and Development.

# List of Figures

# List of Tables

# List of Abbreviations and Acronyms

| | |
|---|---|
| AHP | Analytic Hierarchy Process |
| ANP | Analytic Network Process |
| ANATEL | Agência Nacional de Telecomunicações |
| ANEEL | Agência Nacional de Energia Elétrica |
| ANPEI | Associação Nacional de Pesquisa e Desenvolvimento das Empresas I-novadoras |
| BFT | Benefit Group |
| CERPCH | Centro Nacional de Referência em Pequenas Centrais Hidrelétricas |
| CI | Consistency Index |
| CMR | Commercial & Market Risk Subgroup |
| COI | Corporate Image Subgroup |
| COM | Competitiveness Subgroup |
| CONFAZ | Conselho Nacional de Política Fazendária |
| CR | Consistency Ratio |
| CUR | Customer Requirements Subgroup |
| DM | Decision maker |
| EEV | External Environment Subgroup |
| ENV | Environmental Subgroup |
| EXT | Extendibility Subgroup |
| FER | Feasibility Requirements Subgroup |
| FIB | Financial Benefit Subgroup |
| FIT | Fitness Subgroup |
| FNI | Financial Income Subgroup |
| GDP | Gross Domestic Product |

| | |
|---|---|
| GII | Global Innovation Index |
| GNR | General Risk Subgroup |
| HMD | Human Development Subgroup |
| ICC | Inatel Competence Center |
| IEV | Internal Environment Subgroup |
| INATEL | Instituto Nacional de Telecomunicações |
| INMETRO | Instituto Nacional de Metrologia, Qualidade e Tecnologia |
| INSEAD | Institut Européen d'Administration des Affaires |
| MKT | Market Subgroup |
| MADM | Multi-Attribute Decision Making |
| MCDA | Multi-Criteria Decision Analysis |
| MCDM | Multi-Criteria Decision Making |
| MODM | Multi-Objective Decision Making |
| MTE | Ministério do Trabalho e Emprego |
| MTR | Material Resources Subgroup |
| M&E | Market & Environment Group |
| NFB | Non-Financial Benefit Subgroup |
| NPV | Net Present Value |
| OGR | Organizational Requirements Subgroup |
| OR | Operational Research |
| PCH | Pequena Central Hidrelétrica |
| PMI | Project Management Institute |
| PMP | Project Management Professional |
| PPP | Purchasing Power Parity |
| QLR | Quality Requirements Subgroup |
| RI | Random Consistency Index |

| | |
|---|---|
| ROV | Real Options Value |
| RSC | Resource Group |
| RSK | Risk Group |
| R&D | Research & Development |
| SCP | Scope Group |
| SCR | Scope Risk Subgroup |
| SEFAZ | Secretaria de Estado da Fazenda |
| SHP | Small Hydro Power Plant |
| SLR | Systematic Literature Review |
| SOC | Social Subgroup |
| STR | Strategic Group |
| S&E | Social & Environment Impact Group |
| S&T | Science & Technology |
| TAR | Technical Attractiveness & Relevance Subgroup |
| TCI | Technical Contribution & Innovativeness Subgroup |
| TCR | Technical Risk Subgroup |
| TEC | Technical Group |
| TIC | Technical Issues & Constraints Subgroup |
| TMR | Timing Requirements Subgroup |
| UIS | UNESCO Institute for Statistics |
| UNESCO | United Nations Educational, Scientific and Cultural Organization |
| UNIFEI | Universidade Federal de Itajubá |
| USP | Universidade de São Paulo |
| WIPO | World Intellectual Property Organization |
| WoS | Web of Science |
| WRR | Work Resources Subgroup |

# Summary

# 1 Introduction

## 1.1 Contextualization

Public policies encouraging research and industrial innovation have become essential for economic development. Consequently, most developed countries and the ones seeking to escape from underdevelopment have understood this formula and are investing in formulating policies meant to encourage and accelerate areas of research, development and innovation. According to the Global Innovation Index (GII) of 2018, an annual ranking published by Cornell University, INSEAD and World Intellectual Property Organization (WIPO), Brazil ranked 64th out of 126 economies evaluated. The most innovative country is Switzerland, followed by the Netherlands and Sweden. The United States ranked 6th and China 17th. According to the study, the improvement in the Brazilian index is mainly due to the outlay on Research  Development (R&D), imports and exports of high technology and the quality of national scientific publications. On the other hand, the country lets down in training scientists and engineers, credit, investment, productivity and new businesses creations (EXAME, 2018; G1, 2018).

Such ranking could be much higher if it was not for the investment cuts by the government in the fields of research, development and innovation. As a result, the country lacks in production capacity and expands the export of a strategic product, of very high added value, that multiplies in billions its own value and should be maintained in national territory at all costs (NEGóCIOS, 2018).

As reported in “Research in Brazil” by Cross, Thomsom and Sinclair (2016), a report revealing the panorama of Brazilian scientific production from 2011 to 2016, by considering the absolute number of publications, not taking into consideration the number of researchers, Brazil is far behind other countries. During this period, Brazil published approximately 250,680 papers, while the United States published 2,521,998 and China 1,402,689, as it can be seen in Figure 1.

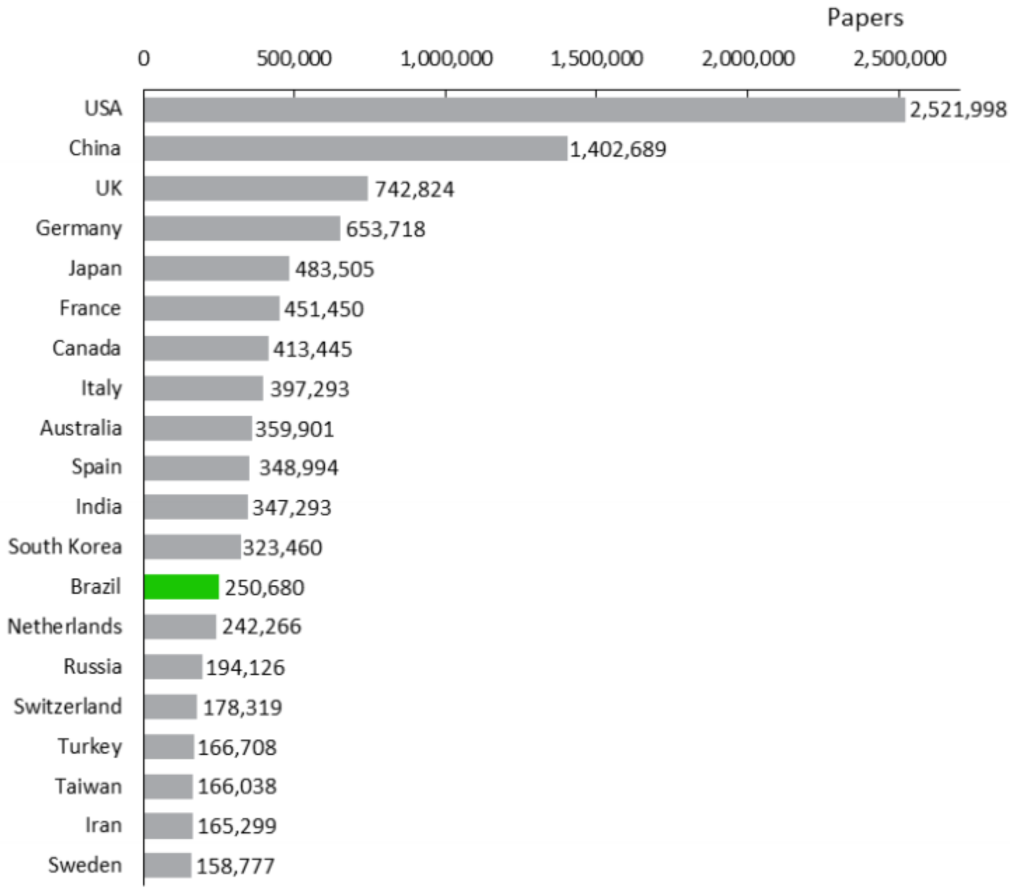


Figure 1 – Number of papers.
Source: (CROSS; THOMSOM; SINCLAIR, 2016).

With few investments provided by the government, educational institutions have been working on their publications' quality in order to keep receiving benefits, increasing their impact along the years little by little coming close to the global average, as shown in Figure 2.

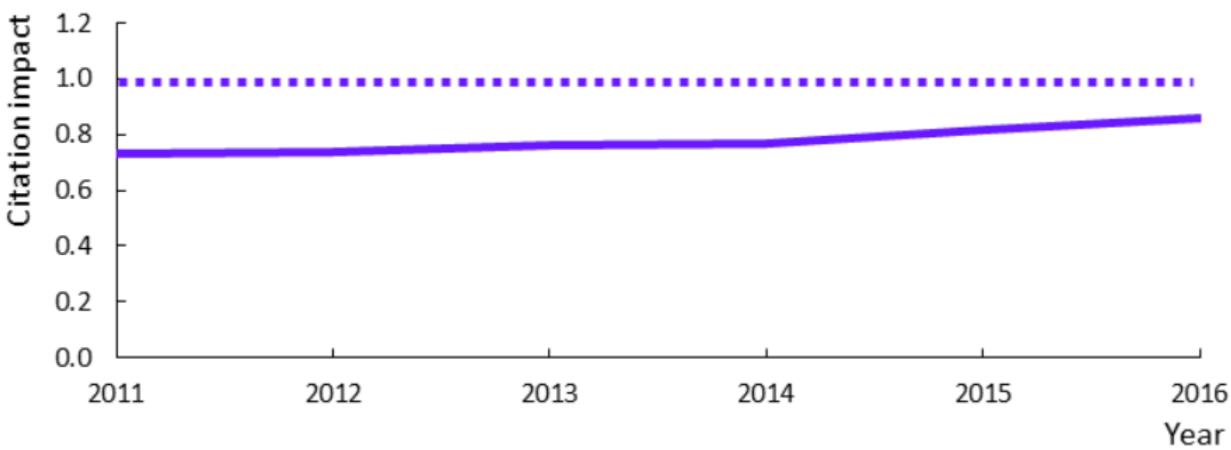


Figure 2 – Brazilian articles impact.
Source: (CROSS; THOMSOM; SINCLAIR, 2016).

To the UNESCO Institute of Statistics (UIS), the global spending on R&D has reached a record high of almost US$ 1,7 trillion. About 10 countries account for 80% of this outlay. Brazil occupies the 9th position with the distinction that it is continually growing more with each position. UNESCO has adjusted the figures to reflect purchasing power parity (PPP$), which makes it possible to compare amounts from country to country. First, there is the United States with a total of PPP$ 170,5 billion. Brazil has been spending around PPP$ 42,1 billion, almost 11 times less than the first place. Many countries try to stimulate greater investments in both the private and public sectors by setting national targets for R&D spending as a share of gross domestic product (GDP). But notice how the rankings change when you switch from total spending in PPP$ to GPD. In the first place is the Republic of Korea with 4,3% of GPD, with 78,2% of investments coming from the business sector. Brazil, on the other hand, appears below the first 20, with 1,3% of GPD and with almost 0% of investments coming from the business sector, eliciting how low the research and development investments have been in the country, resulting in our 64th ranking in innovation (HOWMUCH.NET, 2018; UIS, 2018). All of this information can be better visualized in the table below in the Table 1.

Table 1 – R&D spending by country (PPP$, GDP, Business Sector).

| **#** | **Country** | **PPP$** | **#** | **Country** | **GDP** | **Business Sector** |
|---|---|---|---|---|---|---|
| 1 | United States | 476,5 bi | 1 | Rep. of Korea | 4,3 % | 78,2 % |
| 2 | China | 370,6 bi | 2 | Israel | 4,2 % | 84,6 % |
| 3 | Japan | 170,5 bi | 3 | Japan | 3,4 % | 77,8 % |
| 4 | Germany | 109,8 bi | 4 | Finland | 3,2 % | 67,7% |
| 5 | Rep. of Korea | 73,2 bi | 5 | Switzerland | 3,2 % | 71,5 % |
| 6 | France | 60,8 bi | 6 | Austria | 3,1 % | 71,3 % |
| 7 | India | 48,1 bi | 7 | Sweden | 3,1 % | 67 % |
| 8 | United Kingdom | 44,2 bi | 8 | Denmark | 2,9 % | 63,8 % |
| **9** | **Brazil** | **42,1 bi** | 9 | Germany | 2,9 % | 67,7 % |
| 10 | Russia | 39,8 bi | 10 | United States | 2,7 % | 71,5 % |
| 11 | Italy | 29,6 bi | **<20** | **Brazil** | **1,3 %** | **-** |

Source: Adapted from UIS (2018).

Another aspect that can be seen through the information provided above is the amount of investments coming from the public sector. Disregarding the percentages from the business sector investments out of the total PPP$ of each country, the United States for instance, would have only 135,8 bi PPP$ (out of 476,5 bi PPP$) moved by the government. In Japan's case, the value reaches 37,5 bi PPP$ (out of 170,5 bi PPP$); still less than the amount moved by the Brazilian government (42,1 bi PPP$).

As a representative entity of the segment of innovative companies and institutions, the Associação Nacional de Pesquisa e Desenvolvimento das Empresas Inovadoras (ANPEI) [National Association of Research and Development of Innovative Companies] acts along with the government and productive sectors with the objective of disseminating the importance of technological innovation for the companies' competitiveness and the development of Brazil; with more than 250 associates in different areas (Figure 3), such as USP, Fiat, Petrobras, Samsung among many others, representing R$ 10 billion in investments of research, development and innovation in the country (ANPEI, 2018b; ANPEI, 2018a).

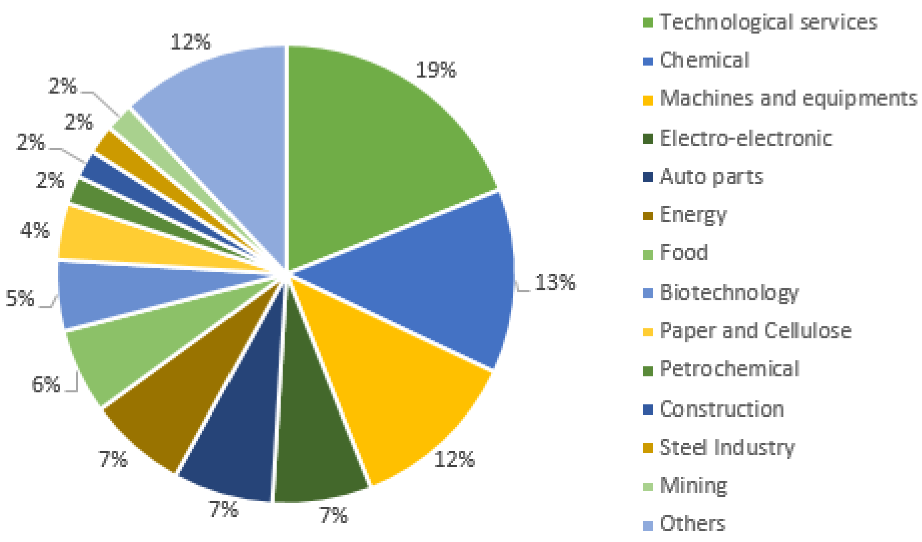


Figure 3 – Associates per area of R&D.
Source: Adapted from Anpei (2018a)
.

Due to the race in search for innovation, organizations from Brazil and around the word face constant challenges to maintain themselves relevant in the market, looking for better ways of managing their projects and using the existing and scarce resources with the objective of maximizing a utility measure or benefit and, in some cases, minimizing the risk or costs of their projects (BHATTACHARYYA, 2015).

The project-driven companies which depend on innovation have the obligation to develop and implement new products and processes frequently to achieve an on-going competitiveness and a strong presence in the market. Therefore, R&D is the main task in their strategic management framework (MEADE; PRESLEY, 2002).

In literature it is possible to find several articles in which the authors focus on studying and/or presenting new multi-criteria decision making (MCDM) methods or proposing improvements to the already existing ones, with the main goal of obtaining the most reliable results for managing their R&D projects, for example (HSU; TZENG; SHYU, 2003; MOHANTY et al., 2005; MEDAGLIA; GRAVES; RINGUEST, 2007; CHENG; LIOU; CHIU, 2017). But to better use these methods it is necessary to determine, along the process, which criteria the decision maker (DM) judges indispensable to evaluate a certain number of projects in a certain situation.

Therefore, the main intent of this work is to aid the DMs in selecting the most relevant criteria for R&D project selection. First of all, a systematic review of 61 articles related to the use of MCDMs in an R&D project selection environment has been done. A hierarchical structure of 8 groups and 27 subgroups for the criteria is presented, and the relevance of each group and subgroup is evaluated by two R&D project managers; one from the energy area and the other from the technology area by using the Analytic Hierarchy Process (AHP) by Saaty (1980), a method widely used by several authors and with a high degree of approval.

## 1.2 Justification

There are several ways to justify the importance of this work. First of all, it has innovative character, since there is no other article with a similar approach. Second, there is the contribution to the area of R&D (BEAUJON; MARIN; MCDONALD, 2001; WANG; HWANG, 2007; IMOTO; YABUUCHI; WATADA, 2008; CONKA; VAYVAY; SENNAROğLU, 2008). It allows project managers to look for new and/or better perspectives in order to evaluate their projects by looking into different criteria. Third, R&D project selection is a common multi-criteria decision making problem because of its high complexity to analyze several criteria of several projects, making it extremely complex to rely solely on human decision making. Therefore, this work gives the DMs different points of view to use the best criteria to select their projects by using these methods (CARLSSON et al., 2007; MONTAJABIHA; KHAMSEH; AFSHAR-NADJAFI, 2017). And lastly, terms like "R&D" or "Research and Development" or "Research & Development"; "MCDM" or "Multicriteria Decision Making" or "Multi-Criteria Decision Making" or "Multi Criteria Decision Making" and "Project Management" or "Project Selection" have an increasing importance along the years. The Figures 4 and 5 exhibit the number of related works in the Scopus and Web of Science databases.

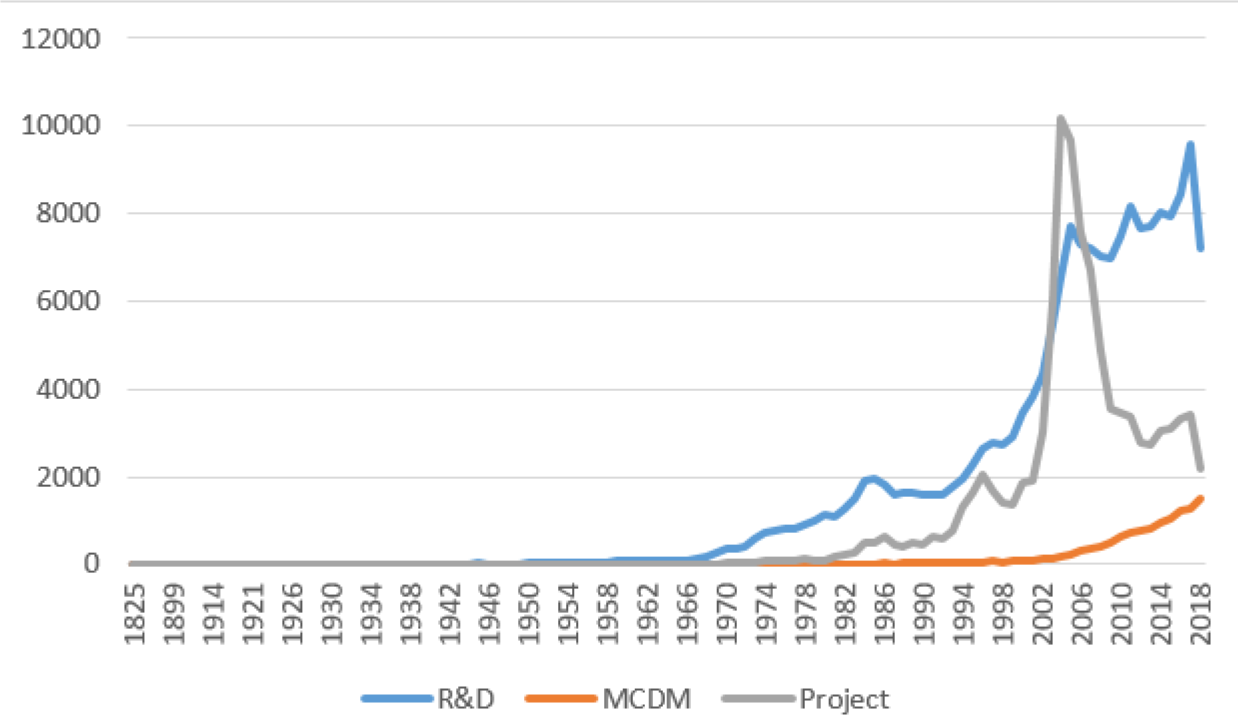


Figure 4 – Number of works along the years.
Source: Scopus.

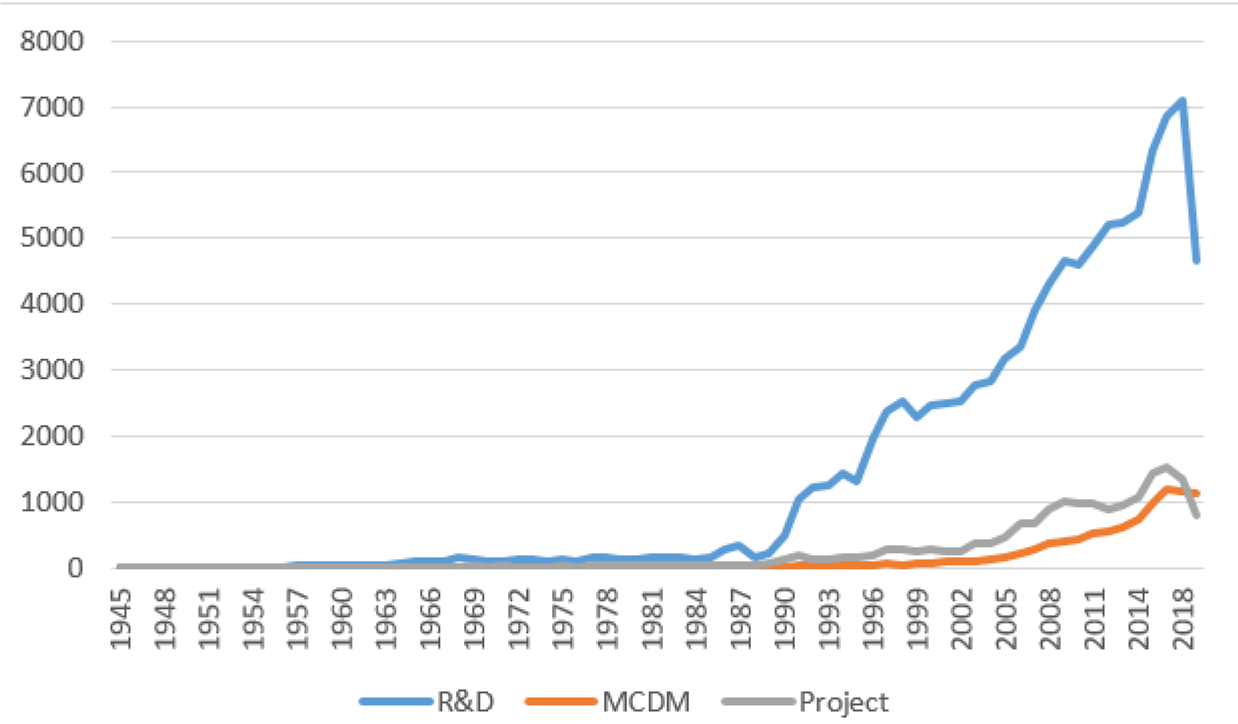


Figure 5 – Number of works along the years.
Source: Web of Science.

## 1.3 Research Questions & Objectives

One way to elucidate the main objective of this work is to present the following research questions that will guide this work:

- Which criteria for R&D project selection are recommended by literature?
- Which ones are the most searched?
- Which ones are the most relevant to organizations?

Thus, in order to answer these questions, the work will conduct a systematic literature review by completing some specific objectives:

- Locating, selecting and evaluating relevant literature;
- The criteria grouping;
- And the groups and subgroups evaluation by specialists using the AHP method.

## 1.4 Research Delimitations

Besides the objectives, it is also necessary to present the delimitations that were established in this work, like:

- The considered research databases were Scopus and Web of Science;
- In relation to the fulfillment of the searches, only articles written in English published in journals in which some kind of MCDM was used to select R&D projects were considered. Besides that, 3 steps of screening would occur, considering the title, abstract and the text;
- This work is not intended to present a validation of the presented criteria, but solely an evaluation made by specialists;
- The chosen AHP method has some limitations as well, like not providing enough guidance to deal with the interdependence of factors (ARROYO; TOMMELEIN; BALLARD, 2014), and the rating scale used in the AHP analysis is conceptual and there are chances of bias while giving relative weights to different factors (SINGH, 2013);
- The criteria were evaluated by two R&D specialists, one from the energy area and the other from the technology area.

## 1.5 Dissertation Structure

This dissertation is divided into 5 chapters. Chapter 1 introduces the theme, brought the justification for conducting the work, some delimitations, showed the research questions, the objectives and its structure. Chapter 2, on the other hand, provides the theoretical background needed to conduct this work. It is subdivided into 5 sections presenting the concepts and explanations about project and portfolio management, Research & Development, the multi-criteria decision making process and the Analytic Hierarchy Process method. More details about the study about R&D criteria can be found in Chapter 3, which focuses on describing in details the main part of this work, from the selection of articles to the criteria evaluation by specialists. Chapter 4 already presents the analysis over the AHP results given by specialists. And in Chapter 5, the last chapter, final commentaries by the author are given, and the possible future works that may rise from this dissertation.

# 2 Theoretical Background

## 2.1 Project Management

In the literature, it is possible to find a great number of project definitions but, in the end, all reach the same conclusion. For example, PMI (2017) defines project as a temporary endeavor undertaken to create a unique product, service, or result. Larson and Gray (2016) increments the idea, stating that all the results must be focused in satisfying the customer's need. Martins et al. (2013), on the other hand, give a more detailed explanation, in which a project can be considered as a set of tasks that need to be planned, executed, controlled and finished, using a certain type of resource in order to accomplish an established goal.

The project itself and how it is managed, are considered the main factors to all organizations that are able to accomplish their objectives, becoming one of the most important topics in the literature (PINTO; PRESCOTT, 1988; AMARAL; MADALENA, 2009; KAISER; ARBI; AHLEMANN, 2015).

After the completion of a project, Wit (1988), Munns and Bjermi (1996) and Belout and Gauvreau (2004) say that its success can be verified by attending their objectives. They also present some factors that project managers must pay attention in order to better conclude it, such as:

- The project must be completed within the schedule and budget stipulated;
- Have used the resources effectively;
- Have met the expected level of quality and performance;
- The project must be completed with the minimum number of changes in the scope;
- And the project must be approved by the client.

To accomplish these objectives, both authors above present some factors that may interfere in the project success and that must attract the manager attention, like:

- Project scope definition;
- Efficiency in assigning tasks;
- The project team satisfaction;
- Budget management;

- Respect to the schedule.

According to PMI (2017), the project manager is responsible for establishing realistic and achievable limits to the project and its achievement within the approved baselines. Pillai, Joshi and Rao (2002), Cleland and Ireland (2012) point out that projects must be continuously monitored and evaluated throughout each phase of their life cycle. Their performance standards should be developed to achieve the desired results.

It is possible to find several project management life cycle models in the literature, Larson and Gray (2016), PMI (2017) are some of them. Pillai, Joshi and Rao (2002), on the other hand, present a typical life cycle to R&D projects, which is the topic of this work (Figure 6):

- **Project proposals based on customer requirements:** project proposals are initiated;
- **Project selection phase:** the proposals are screened, evaluated and selected with the aid of project selection methods;
- **Project execution phase:** the required technologies and products are developed and the product performance is demonstrated through several trials. Concurrently, the designs and technologies developed are transferred to production agencies for the production of systems for development trials and performance demonstration trials;
- **Project implementation phase:** production marketing and sales will commence to recover the investment made and to realize the other intangible benefits envisaged at the time of project selection;
- **Project and services towards customer delight:** a project will become successful only after meeting the objectives and expectations envisaged at the time of selection.

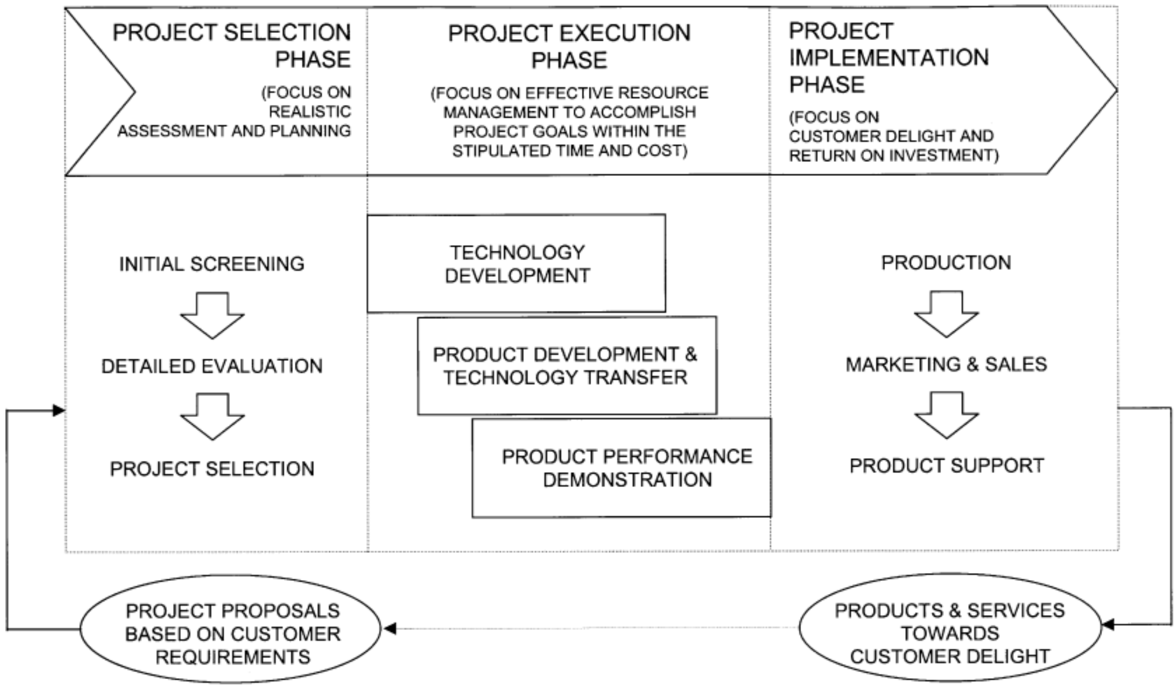


Figure 6 – Typical R&D project life cycle.
Source: Pillai, Joshi and Rao (2002).

To Larson and Gray (2016), most organizations have a portfolio of projects going on side by side and in different project life cycle stages. Careful planning and management by the organization and project management levels are indispensable. In the next section, it will be given the explanation over the portfolio management and which tasks and responsibilities are part of it.

## 2.2 Project Portfolio Management

According to Jonas (2010), a portfolio can be seen as a group of projects that compete for scarce resources and that are conducted under the sponsorship or management of a particular organization. Indeed, a portfolio is not composed with just projects, since it can also be formed by other kind of components such as: other portfolios, programs, projects and/or other works in order to facilitate the management process and to make it possible to meet the organization's objectives (PMI, 2017). The components and their relationships can be seen in Figure 7.

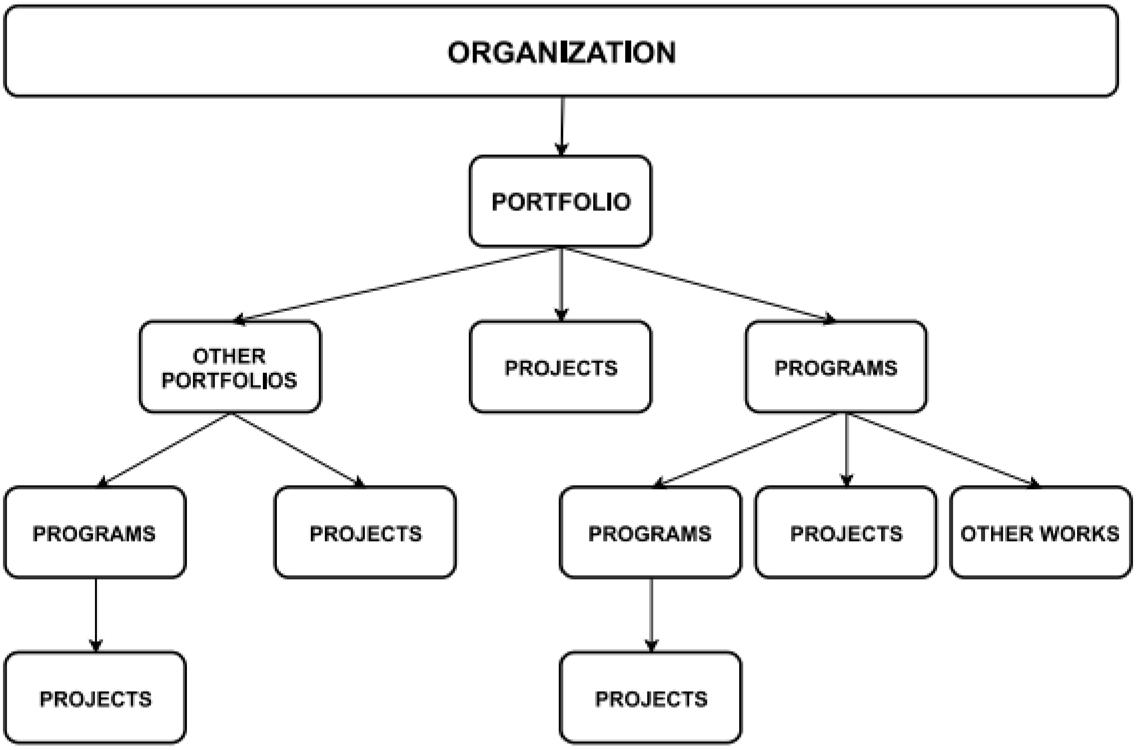


Figure 7 – Portfolio Relationships.
Source: Based on PMI (2017).

The typical activities of the project portfolio management (PPM) scope embrace the gathering of possible projects, their prioritization and selection according to the available resources, and the evaluation of running projects concerning their continuing fit to the portfolio, not forgetting the alignment with the organization goals. These activities usually involve particular optimization algorithms or management techniques that make use of specific project selection criteria (ARCHER; GHASEMZADEH, 1999; ESHLAGHY; RAZI, 2015; KAISER; ARBI; AHLEMANN, 2015). Along the PPM, Amaral and Madalena (2009) and Buys and Stander (2010) present three well-known objectives that need to be satisfied:

- Maximizing the value of a portfolio;
- Linking the portfolio to the organization strategy;
- The continuous monitoring/evaluation of the portfolio.

In order satisfy the objectives above, the organizations' managers need to actively employ and manage the following responsibilities (KENDALL; ROLLINS, 2003):

- Determine a viable project mix capable of meeting the strategic goals of the organization;

- Balance the project portfolio;
- Monitor the planning and execution of the chosen projects;
- Analyse the portfolio performance and ways to improve it;
- Evaluate new opportunities against the current portfolio and comparatively to each other,considering the organization's project execution capacity;
- Provide information and recommendations to decision makers at all levels.

However, some authors present several problems faced by companies that may interfere during the process of managing and/or selecting the projects to a portfolio, such as (COOPER; EDGETT; KLEINSCHMIDT, 2000; ELONEN; ARTTO, 2003; AMARAL; MADALENA, 2009):

- Projects that are not linked to the organization's objectives;
- The organizations that do not have proper project selection criteria to form good portfolios;
- Reluctance to end projects;
- Lack of resources;
- Tendency to implement simple projects, losing potential competitive advantages;
- Information overflow and lack of information quality;
- And the decision making based on hierarchy power.

For years, the PPM activities have been considered of great importance by several authors, since it may cause a significant impact on the current and future financial position of an organization, and its ability to compete in the market (LIBERATORE, 1987; MEADE; PRESLEY, 2002; AMARAL; MADALENA, 2009; BHATTACHARYYA; KUMAR; KAR, 2011; ESHLAGHY; RAZI, 2015).

Thus, a lot of research has been made on frameworks, tools, techniques and models for project portfolio selection, resource allocation and overall portfolio management, describing the project choices as a rational decision-making process, which definitely proved to be useful (RINGUEST; GRAVES, 1999; MARTINSUO, 2013). Successful companies have been shown to usually have a systematic approach to better perform these tasks (COOPER; EDGETT; KLEINSCHMIDT, 1997a; COOPER; EDGETT; KLEINSCHMIDT, 1997b; FRICKE; SHENHAR, 2000). Further information about these methods will be given in Section 4 of this chapter.

Amaral and Madalena (2009) explain the project portfolio selection process into five distinct phases:

- **Strategic consideration and orientation:** to better select projects that are in accordance to the organization objectives;
- **Project evaluation:** in which the benefits derived from evaluation methods are determined, as well as the individual contribution of each project to the portfolio objectives;
- **Portfolio selection:** it involves a continuous comparison among projects. In the end they are ranked, making it possible to allow the ones at the top to be included at the organizational portfolio;
- **Organizational resources assignment:** to prevent a complex administrative problem because of the limited resources that are constantly requested for different projects;
- **Monitoring and control:** it is responsible for evaluating, recurrently, the portfolio performance.

Some authors also consider criteria selection a non-trivial task, since they strongly defend the criteria alignment with stakeholders. To Gomes and Gomes (2012), the success of a decision support system depends in large part on how the criteria structure is assembled, taking into account several points of view that "represent the different axes along which the various actors in the decision process, justify, transform and question their preferences" (GHASEMZADEH; ARCHER, 2000; CRISTóBAL, 2011; CHENG; LIOU; CHIU, 2017). When weighting the selected criteria, they would not only be emphasized among the others, but will also make it easier the selection of an optimal R&D portfolio (HUANG; CHU; CHIANG, 2008).

Afshari (2015) says that in the literature the majority of the reviewed studies do not provide a systematic method for criteria selection. And by neglecting the use of an appropriate and systematic criteria selection technique might be the cause of an inaccurate result in the final decision and, consequently, the validity of the MCDM method will be reduced. Bilalis et al. (2002) indicates that certain objective goals and criteria are difficult to measure with distinct values in project selection, making it crucial the establishment of a proper system to identify the criteria and find the relative importance of the for selecting R&D projects. Thus, by adding a systematic method for the criteria selection, would result in more satisfatory results, something that this work looks for (YEH, 2003).

Summing up, project portfolio selection starts with the continuous analysis and judgement of a collection of projects and their criteria, along with the selection process (WANG; XU; LI, 2009; ESHLAGHY; RAZI, 2015).

There are several types of project portfolio selection problems in the literature, such as construction, automotive, chemical, information technology and many others. This dissertation deals with the criteria related to research and development project selection, thus the next section will contextualize this type of project.

## 2.3 Research & Development

According to Thore (2002), towards the end of the 20th century, as a result of the unbridled growth of communication and information technology, a new economy has emerged, known as "Knowledge economy". In this kind of new economy, the currency used is not the money, but the knowledge and how it is used in order to create new forms of technology and knowledge. The new economy driver is the R&D. Their managers frequently need to develop systems and procedures, which will improve the probability of success of their business. The effect of corporate strategy is usually better perceived in the selection of R&D projects (CONKA; VAYVAY; SENNAROğLU, 2008). Mostly, a system is required, by linking the R&D decision making with corporate strategy decision making (TROTT, 1998). Connecting all projects with the strategic direction of the organization is crucial to better utilize the resources. It depends on the knowledge of an administrator and the thinking of the executive in most cases (LIBERATORE, 1986; LIBERATORE, 1988; GRAVES; RINGUEST, 1992; GRAY; LARSON, 2000; IMOTO; YABUUCHI; WATADA, 2008).

To Meade and Presley (2002) and Mohaghar et al. (2012) the key for a continuous competitiveness lies at the organizations ability, mainly the ones that depend totally on innovation, to develop and implement new products and processes. For these organizations R&D becomes an integral function within their strategic management framework. On the other hand, Huang, Chu and Chiang (2008), Beaujon, Marin and McDonald (2001), Wang and Hwang (2007) state that technology and innovation are some of the main factors for these companies to assure their competitiveness.

The associated risks in executing R&D projects has proved to have great impact, since the selection of inadequate projects may result in significant losses of financial and human resources (LIBERATORE, 1986; BARD; BALACHANDRA; KAUFMANN, 1988; JAFARIZADEH; KHORSHID-DOUST, 2008; MONTAJABIHA; KHAMSEH; AFSHAR-NADJAFI, 2017). About that, R&D project selection is considered a complicated multi-criteria decision making process and a major concern to the companies because it features multiple stages, multiple groups of decision-makers, multiple and often-conflicting objectives, limited resources, high risk and uncertainty in predicting the future. Therefore, those factors may become a complicated problem to be handled solely by the human expertise and it it a motivation to develop better ways of selecting projects (BELLMAN; ZADEH, 1970; LIBERATORE, 1988; GRAVES; RINGUEST, 1992; GHASEMZADEH; ARCHER, 2000; MOHANTY et al., 2005; CARLSSON et al., 2007; WANG; HWANG, 2007; MOHAGHAR et al., 2012).

Meade and Presley (2002) summarizes four major topics that abbreviate the whole R&D project selection process and must attract the attention of project managers to evaluate their projects, such as the need to (HUANG; CHU; CHIANG, 2008):

- Relate selection criteria to corporate strategies;
- Consider qualitative benefits and risks of proposed projects;
- Reconcile and integrate the needs and desires of different stakeholders;
- And consider the multi-stage and group decision processes.

In the next section, will be presented the concepts about multi-criteria decision making, the decision making process, and how the method are subdivided.

## 2.4 Multi-Criteria Decision Making

Decision making is one of the most frequent and difficult human tasks. Within the past years, the operational research (OR) has become an important field that supports this scientific management. According to Zopounidis and Doumpos (2002), the OR deals with constructing models and optimizing algorithmic procedures in order to facilitate the analysis of complex real-world problems. According to Neumann and Morgenstern (1947) and Savage (1954), it has become a meaningful aspect in decision analysis. Turban (1988) defines “Decision making” as a process of choosing alternative courses of action to attain a goal or goals. Ribeiro (1996) complements this idea by stating that this process allows the decision makers to choose or select the "sufficiently good" alternative(s) or course(s) of action from a set of possible alternatives. Thus, one of the most important details for a precise decision support is the capacity to handle imprecise and vague information. Bellman and Zadeh (1970) point out that many decision making process in the real world takes place in an environment where the goals, constraints and the consequences of possible actions are not always known correctly.

To better comprehend the process of multi-criteria decision making, there are some basic and important concepts that are needed to be explained, such as (MACCRIMMON, 1973; STARR; ZELENY, 1977; RIBEIRO, 1996):

- **Alternatives:** Is the set of all possible desirable items of choice. For example: objects, products, actions, or even projects;
- **Attributes/Criteria:** It is defined as a set of characteristics related to an alternative and may influence the decision making process;
- **Objectives/Goals:** The objectives are normally reached with the correct selection of alternatives. Usually the collection of attributes evaluated by the decision maker is linked to a specific goal;
- **Preferences/Weights:** Is the relative importance of each attribute determined by the decision makers to be processed by the several multi criteria decision making techniques.

According to Belton and Stewart (2002), the MCDM or multi-criteria decision analysis (MCDA) can be defined as "an umbrella term to describe a collection of formal approaches which looks to take explicit account of multiple criteria in order to help the individuals or groups exploring the decision that matter". This definition outlines three MCDM dimensions, named (MENDOZA; MARTINS, 2006):

- The formal approach;
- The presence of multiple criteria;
- The decisions made individually or in groups.

Because of that, the MCDM has been one of the fastest growing problem in several disciplines. The main problem is how to analyze a collection of alternatives influenced by several conflicting criteria (TRIANTAPHYLLOU, 2010; ZAVADSKAS; TURSKIS; KILDIENE, 2014). This is why the MCDM has grown as a part of operational research, concerning the design of computational and mathematical tools, techniques, models or methods that supports the subjective evaluation of criteria performance made by decision makers (BANAITIENE et al., 2008; BEHZADIAN et al., 2012; ZAVADSKAS; TURSKIS; KILDIENE, 2014; MARDANI; JUSOH; ZAVADSKAS, 2015). These methods help improving the decisions quality by making them more explicit, rational and efficient. The negotiation, quantification and communication of priorities are also facilitated by the use of these methods and allows its use in an interactive decision making or in a decision support system for policy makers (ANANDA; HERATH, 2009; POHEKAR; RAMACHANDRAN, 2004). A decision maker or a group of decision makers are frequently required to choose among multiple quantifiable and/or non-quantifiable criteria to make sure that the selection of alternatives is in accordance with their objectives. Normally, the group of decision makers present different criteria and points of view, which must be resolved within a framework of understanding and mutual compromise for reliable decisions (POHEKAR; RAMACHANDRAN, 2004). Based on the work of Pohekar and Ramachandran (2004) and Wang et al. (2009), it is possible to subdivide the decision making process in four main steps, as shown in Figure 8:

- **Alternatives and criteria selection:** formulation of the sets of alternatives and criteria;
- **Criteria weighting:** the selected criteria weights are determined to show their relative importance in MCDM methods;
- **MCDM method application:** the alternatives are ranked by the MCDM methods from their criteria weights;
- **Result analysis:** the results are analysed by the decision maker. If necessary, the problem is run by other MCDM methods to compare the results.

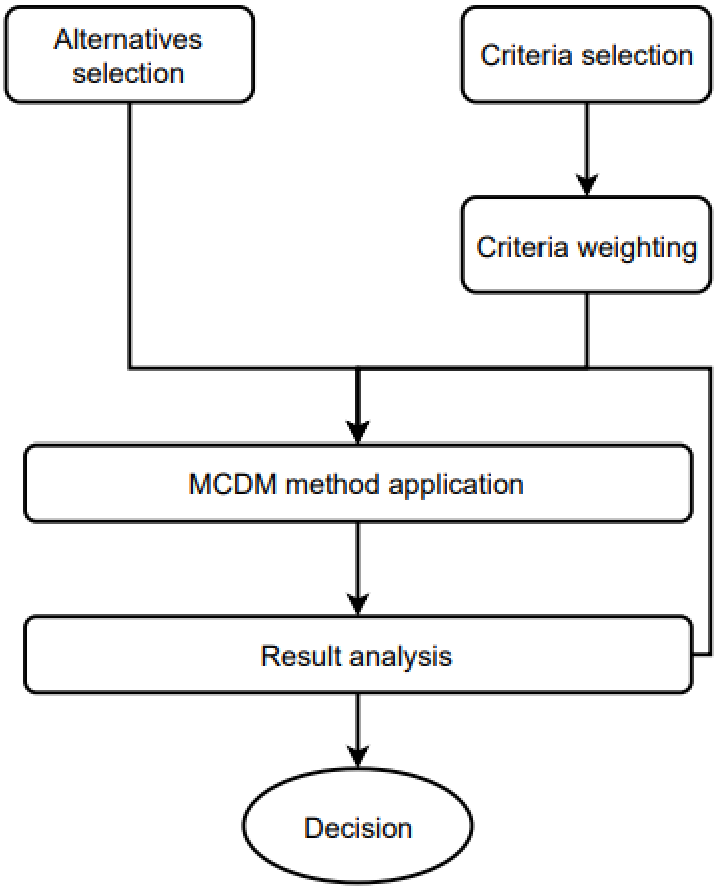


Figure 8 – Decision Making process.
Source: Based on Pohekar and Ramachandran (2004) and Wang et al. (2009).

The MCDM covers a wide range of distinct approaches. One of them can be subdivided in two major categories (MENDOZA; MARTINS, 2006; ZAVADSKAS; TURSKIS; KILDIENE, 2014):

- **MODM (Multi-objective decision making) methods:** are associated with problems in which the alternatives are non-predetermined and the focus of the problem is to design the best alternative considering a set of well-defined constraints and a set of quantifiable objectives. Thus, these methods are more adequate when dealing with multi-objective planning problems, when an infinite (continuous) number of alternatives are defined by the set of constraints;

- **MADM (Multi-attribute decision making) methods:** includes methods that often predicts the human behavior with both objective and subjective information. So, these methods are designed with the objective to select a finite (discrete) number of alternatives.

In order to show the differences between these two categories, Mendoza and Martins (2006) presented a summary made by Malczewski (1999) along with the differences pointed by Hwang and Yoon (1981) and Zeleny (1982) as shown in Table 2.

Table 2 – Comparison of MODM and MADM approaches

| **Criteria for comparison** | **MODM** | **MADM** |
|---|---|---|
| Criteria defined by | Objectives | Attributes |
| Objectives defined | Explicitly | Implicitly |
| Attributes defined | Implicitly | Explicitly |
| Constraints defined | Explicitly | Implicitly |
| Alternatives defined | Implicitly | Explicitly |
| Number of alternatives | Infinite (continuous) | Finite (discrete) |
| Decision maker's control | Significant | Limited |
| Decision modelling paradigm | Process-oriented | Outcome oriented |
| Relevant to | Design/search | Evaluation/choice |

In the next section, the Analytic Hierarchy Process method will be presented. It is a popular and respected MADM method that will be used to evaluate the presented R&D groups and subgroups.

## 2.5 Analytic Hierarchy Process

The AHP, developed by Saaty (1980), is an easy and well-known MADM method that allows the decision makers to deal with complex situations and with different levels of subjectivity. In this work, 13 of the 61 articles analyzed (21%) used the AHP method, either individually, combined or through a proposed variation (LIBERATORE, 1986; LIBERATORE, 1987; LIBERATORE, 1988; HSU; TZENG; SHYU, 2003; KUMAR, 2004; WANG; WANG; HU, 2005; RABBANI et al., 2006; SHIN; YOO; KWAK, 2007; BITMAN; SHARIF, 2008; TOLGA; KAHRAMAN, 2008; IMOTO; YABUUCHI; WATADA, 2008; CONKA; VAYVAY; SENNAROğLU, 2008; KARASAKAL; AKER, 2017).

Harker and Vargas (1987) declares that "AHP is a comprehensive framework which is designed to cope with the intuitive, the rational, and the irrational when we make multi-objective, multi-criteria and multi-actor decisions with and without certainty for any number of alternatives". The main characteristic of this method is structuring the problem, with all the relevant factors, into a hierarchy according to the decision makers judgement. The basic idea is finding the relative importance among the criteria and alternatives through pairwise comparisons (SHIN; YOO; KWAK, 2007). Davis and Williams (1994) highlights that the AHP separates the evaluation decision into hierarchy levels and tries to reduce the inconsistencies from the human judgement (MEADE; PRESLEY, 2002; SHIN; YOO; KWAK, 2007). In the process of evaluation, the required number of pairwise comparisons that an evaluator should provide can be a heavy burden. In any standard AHP application, each evaluation object must be compared to every other object being judged. Therefore, the total number of comparisons that must be made is:

$$T = \frac{n(n-1)}{2} \tag{2.1}$$

where $T$ is the total number of comparisons and $n$ is the number of entities.

The whole AHP calculation process can be understood according to the following steps:

Step 1: Problem definition and determination of its goal;

Step 2: Problem hierarchy structuring from the top (the objective(s) from a decision maker's viewpoint) through the intermediate levels (criteria and/or subcriteria) until the lowest level, which usually contains the set of alternatives;

Step 3: In a decision matrix ($N$), determine the relative importance to each alternative/criterion through the values of Table 3:

$$N = \begin{bmatrix} 1 & w_{12} & \dots & w_{1n} \\ 1/w_{12} & 1 & \dots & w_{2n} \\ \dots & \dots & \dots & \dots \\ 1/w_{1n} & 1/w_{2n} & \dots & 1 \end{bmatrix} \tag{2.2}$$

Step 4: After that, it is necessary to obtain the normalized decision matrix ($|N|$), where each element of $N$ are divided by the sum of its respective column ($S_{ColNn}$):

$$|N| = \begin{bmatrix} 1/S_{ColN1} & w_{12}/S_{ColN2} & ... & w_{1n}/S_{ColNn} \\ (1/w_{12})/S_{ColN1} & 1/S_{ColN2} & ... & w_{2n}/S_{ColNn} \\ ... & ... & ... & ... \\ (1/w_{1n})/S_{ColN1} & (1/w_{2n})/S_{ColN2} & ... & 1/S_{ColNn} \end{bmatrix} \tag{2.3}$$

Step 5: Then, it is possible to calculate the eigenvector or priority vector ($P$), where each vector element $x_n$ are calculated by the sum of its respective row in the normalized decision matrix ($S_{Row|N|n}$) over the number $n$ of entities:

$$P = \begin{bmatrix} S_{Row|N|1}/n \\ S_{Row|N|2}/n \\ ... \\ S_{Row|N|n}/n \end{bmatrix} = \begin{bmatrix} x_1 \\ x_2 \\ ... \\ x_n \end{bmatrix} \tag{2.4}$$

Step 6: After getting the priority vector, it is possible to measure the judgement consistency ratio ($CR$) from the equation:

$$CR = \frac{CI}{RI} \tag{2.5}$$

where the consistency index ($CI$), can be achieved by using the largest eigenvalue ($\lambda_{\max}$). Both variables can be obtained in the next equations:

$$\lambda_{max} = S_{ColN1} * x_1 + S_{ColN2} * x_2 + ...S_{ColNn} * x_n \tag{2.6}$$

$$CI = \frac{(\lambda_{\max} - n)}{(n-1)} \tag{2.7}$$

The other variable from the CR equation is the random consistency index ($RI$), that can be obtained by the number $n$ of entities from Table 4. The CR is only acceptable if it does not exceed 0,10. If it overcomes this value, the judgment matrix is considered inconsistent. In order to obtain a consistent matrix, the judgment must be reviewed and improved (AL-HARBY, 1987);

Step 7: The steps 3, 4, 5 and 6 need to be done to all levels in the hierarchy;

Step 8: After finishing Step 7, AHP gives the possibility to calculate the overall composite weights.

Table 3 – Definition of preference ratings and evaluation scale

| **Numerical Rating** | **Definition** | **Reciprocal Numerical Rating** |
|---|---|---|
| 1 | Equally preferred | 1 |
| 3 | Moderately preferred | 1/3 |
| 5 | Strongly preferred | 1/5 |
| 7 | Very strongly preferred | 1/7 |
| 9 | Extremely preferred | 1/9 |
| 2, 4, 6, 8 | Intermediate levels | 1/2, 1/4, 1/6, 1/8 |

Source: Saaty (1980).

Table 4 – Random consistency index (RI)

| **n** | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|
| **RI** | 0 | 0.58 | 0.9 | 1.12 | 1.24 | 1.32 | 1.41 |

Source: (SAATY, 1980).

The step-by-step guide to achieve the main objective of this research will be presented in the next chapter.

# 3 R&D Criteria

## 3.1 Method Definition: Systematic Literature Review

To Tranfield, Denyer and Smart (2003), a systematic literature review (SLR) is a method that adopts a precise, transparent and explicit approach that includes a series of phases to ensure that an appropriate rigor and transparency is brought to the literature review process. This type of research provides a summary of the evidence related to a specific intervention strategy through the application of explicit and systematized methods of research, critical appraisal and synthesis of selected information (SAMPAIO; MANCINI, 2007; MALHOTRA, 2015). It is particularly useful for integrating information from a set of studies conducted separately that may show conflicting and/or overlapping results, as well as identify issues that require evidence and assist in guiding future researches (LINDE; WILLICH, 2003; KHAN; KEUNG, 2016).

According to Turrioni and Mello (2012), this research can be classified as to its:

- **Applied Nature:** since it is characterized by its practical interest, the results are applied or used immediately in the solution of problems that occur in reality;
- **Objective - Descriptive research:** since it "delineates what it is" and aims to describe the characteristics of a given population or phenomenon or the establishment of relations between variables;
- **Combined Approach:** since it considers that the researcher can combine aspects of both qualitative and quantitative researches in all or some of the stages of the research process.

The characteristics presented above were one of the reasons for which SLR seems fit to help conduct the rest of this work.

To Garza-Reyes (2015), the SLR consists of 5 consecutive phases: formulating the question, locating the studies, evaluating and selecting the studies, analyzing and synthesizing, and reporting and using the results. In this dissertation, adapting these 5 phases to the 4 that will compose the rest of this work was preferred, as it can be seen in the following Figure 9.

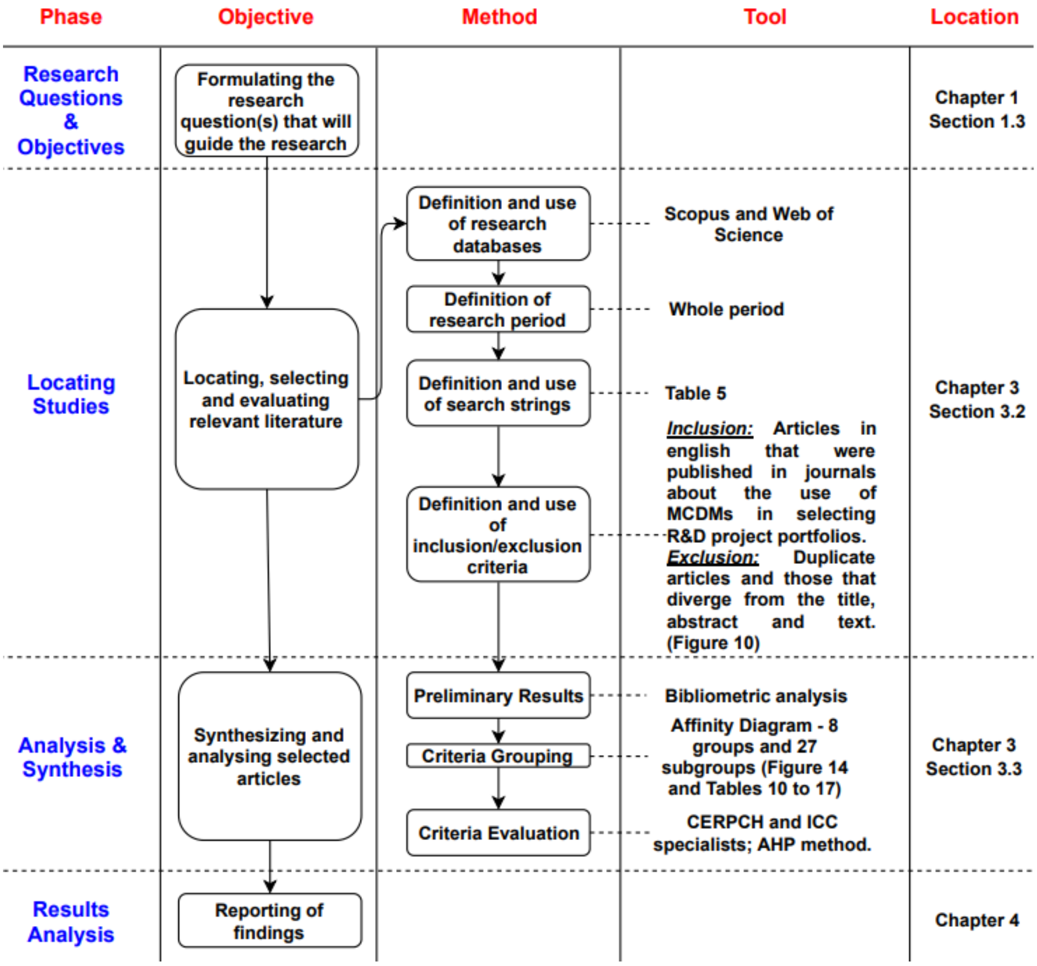


Figure 9 – SLR process.
Source: Based on Garza-Reyes (2015).

## 3.2 Locating Studies

In order to obtain the most published papers and to avoid an unwanted amount of noise, the collected keywords related to MCDM methods were obtained through the analysis of the most cited papers about MCDM reviews in different fields of study (STEWART, 1992; RIBEIRO, 1996; POHEKAR; RAMACHANDRAN, 2004; MENDOZA; MARTINS, 2006; ANANDA; HERATH, 2009; WANG et al., 2009; HO; XU; DEY, 2010; ZAVADSKAS; TURSKIS; KILDIENE, 2014; GOVINDAN et al., 2015; MARDANI; JUSOH; ZAVADSKAS, 2015; MARDANI et al., 2015). With all the obtained keywords, it was possible to build the Table 5, which presents acronyms, synonyms and correspondent words to MCDM, their most cited methods, besides the keywords related to R&D and project management resulting in 2604 keyword combinations

Table 5 – Keyword Groups and Keywords

| **Keyword Group** | **Keywords** |
|---|---|
| MCDM | "MCDM" **OR** "multicriteria decision making" **OR** "multi-criteria decision making" **OR** "multi criteria decision making" **OR** "multiplecriteria decision making" **OR** "multiple-criteria decision making" **OR** "multiple criteria decision making" **OR** "MCDA" **OR** "multicriteria decision analysis" **OR** "multi-criteria decision analysis" **OR** "multi criteria decision analysis" **OR** "multiplecriteria decision analysis" **OR** "multiple-criteria decision analysis" **OR** "multiple criteria decision analysis" **OR** "multicriteria decision aiding" **OR** "multi-criteria decision aiding" **OR** "multi criteria decision aiding" **OR** "multiplecriteria decision aiding" **OR** "multiple-criteria decision aiding" **OR** "multiple criteria decision aiding" |
| **OR** | |
| MADM | "MADM" **OR** "multiattribute decision making" **OR** "multi-attribute decision making" **OR** "multi attribute decision making" **OR** "multipleattribute decision making" **OR** "multiple-attribute decision making" **OR** "multiple attribute decision making" **OR** "MADA" **OR** "multiattribute decision analysis" **OR** "multi-attribute decision analysis" **OR** "multi attribute decision analysis" **OR** "multipleattribute decision analysis" **OR** "multiple-attribute decision analysis" **OR** "multiple attribute decision analysis" **OR** "multiattribute decision aiding" **OR** "multi-attribute decision aiding" **OR** "multi attribute decision aiding" **OR** "multipleattribute decision aiding" **OR** "multiple-attribute decision aiding" **OR** "multiple attribute decision aiding" |
| **OR** | |
| MODM | "MODM" **OR** "multiobjective decision making" **OR** "multi-objective decision making" **OR** "multi objective decision making" **OR** "multipleobjective decision making" **OR** "multiple-objective decision making" **OR** "multiple objective decision making" **OR** "MODA" **OR** "multiobjective decision analysis" **OR** "multi-objective decision analysis" **OR** "multi objective decision analysis" **OR** "multipleobjective decision analysis" **OR** "multiple-objective decision analysis" **OR** "multiple objective decision analysis" **OR** "multiobjective decision aiding" **OR** "multi-objective decision aiding" **OR** "multi objective decision aiding" **OR** "multipleobjective decision aiding" **OR** "multiple-objective decision aiding" **OR** "multiple objective decision aiding" |
| **OR** | |

| | |
|---|---|
| Methods | "Simple Additive Weighting" **OR** "Additive Ration Assessment" **OR** "SWARA" **OR** "Step-wise Weight Assessment Ration Analysis" **OR** "TOPSIS" **OR** "Technique for Order of Preference by Similarity to Ideal Solution" **OR** "ELECTRE" **OR** "Elimination et Choix Traduisant la Réalité" **OR** "Elimination and Choice Expressing REality" **OR** "LINMAP" **OR** "Linear Programming Technique for Multidimensional Analysis and Preference" **OR** "AHP" **OR** "Analytic Hierarchy Process" **OR** "ANP" **OR** "Analytic Network Process" **OR** "PROMETHEE" **OR** "The Preference Ranking Organization Method for Enrichment of Evaluations" **OR** "MOORA" **OR** "Multi-Objective Optimization on the basis of Ration Analysis" **OR** "MULTIMOORA" **OR** "Multiplicative form with Multi-Objective Optimization on the basis of Ration Analysis" **OR** "DEA" **OR** "Data Envelopment Analysis" **OR** "VIKOR" **OR** "Visekriterijumska optimizacija i Kompromisno Resenje" **OR** "Multicriteria Optimization and Compromise Solution" **OR** "COPRAS" **OR** "Complex Proportional Assessment" **OR** "EVAMIX" **OR** "Evaluation of Mixed Data" **OR** "DEMATEL" **OR** "Decision-Making trial and Evaluation Laboratory" **OR** "WASPAS" **OR** "Weighted Aggregated Sum Product Assessment" **OR** "WSM" **OR** "Weighted Sum Method" **OR** "WPM" **OR** "Weighted Product Method" **OR** "Compromise Programming" **OR** "MAUT" **OR** "Multi-Attribute Utility Theory" **OR** "CBR" **OR** "Case Based Reasoning" **OR** "Genetic Algorithm" **OR** "SMART" **OR** "Simple Multi-Attribute Rating Technique" **OR** "MAVT" **OR** "Multi-Attribute Value Theory" **OR** "REMBRANDT" **OR** "Ratio Estimation in Magnitudes" **OR** "Decibels to Rate Alternatives which are Non-Dominated" **OR** "NAIADE" **OR** "Novel Approach to Imprecise Assessment and Decision Environments" **OR** "Linear Programming" **OR** "Non-Linear Programming" **OR** "Non Linear Programming" **OR** "Multi-Objective Programming" **OR** "Multi Objective Programming" **OR** "Multiobjective programming" **OR** "Goal Programming" **OR** "Integer Linear Programming" **OR** "Integer Non-Linear Programming" **OR** "Integer Non Linear Programming" **OR** "Integer Programming" |
| **AND** | |
| Projects | "Project Selection" **OR** "Project Evaluation" **OR** "Project Portfolio Selection" **OR** "Project Portfolio Evaluation" **OR** "Project Portfolio" OR "Project Portfolio Management" |
| **AND** | |
| R&D | "Research and Development" **OR** "Research & Development" **OR** "R&D" **OR** "R and D" **OR** "RnD" **OR** "R n D" **OR** "R & D" |

The search was carried out in February, 16th 2018 (updated in November, 3rd 2018) using the documents from the two main widespread databases available, Scopus and Web of Science (WoS). This choice is justified as Scopus is the largest multidisciplinary database, including approximately 15,000 peer-reviewed journals and more than 4,000 publishers (JAHANGIRIAN et al., 2010). On the other hand, Web of Science includes 10,000 peer-reviewed journals and was the only citation database and publication Covering all domains of science for many years (CHADEGANI et al., 2013). Yet, both databases give to researchers the possibility of exporting metadata, which helps in building the process of a literature review and, specially, bibliometric analyses.

From the obtained documents, a series of filters to reduce all the noise that could disturb the articles analysis was made. First it was intended to use only articles in English that had been published in journals. Later,3 screening rounds were made, in each one the title, the abstract and text focusing only on articles related to the use of MCDM's in selecting the R&D projects were analyzed, Figure 10 shows a summary of all the documents filtering process. In the end, the obtained articles will be analyzed to make possible the creation of a list of criteria.

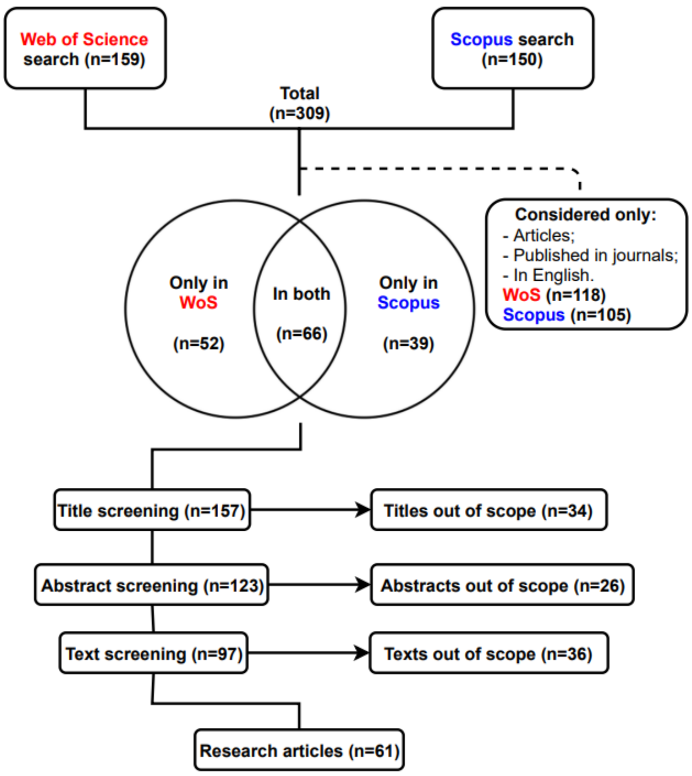


Figure 10 – Filters applied

## 3.3 Analysis & Synthesis

### 3.3.1 Preliminary Results

The end of all the articles screening allows the opportunity to make some primary analysis over them. The first one is about the number of articles per year, as shown in

Figure 11. It can be seen that this subject started being explored in 1970 and that from 2005 until 2017 there was a large increase of the volume of articles.

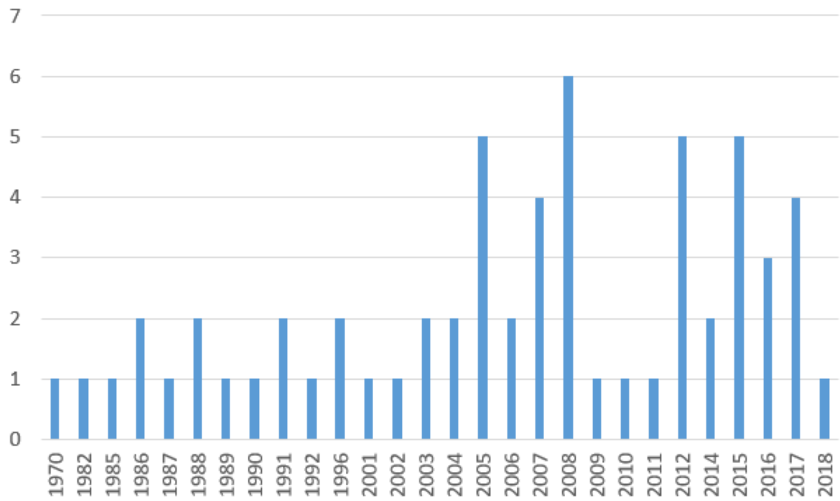


Figure 11 – Articles analyzed by year

Another type of possible analysis is to look over the authors that have the greater number of articles about the subject. From the 61 analyzed articles, it was possible to list a total of 128 authors, the Table 6 shows the first 5 of them.

Table 6 – Principal R&D authors

| Author | Number of Articles |
|---|---|
| Samuel B. GRAVES | 6 |
| Jeffrey L. RINGUEST | 6 |
| Mikael COLLAN | 4 |
| Farhad HASSANZADEH | 3 |
| Matthew J. LIBERATORE | 3 |

Graves and Ringuest are the authors who have most articles published and worked together over the years with a total of 6 articles. At the beginning, Ringuest and Graves (1989) described a multi-objective model of the R&D project selection problem. The model initiated from an earlier goal programming formulation of the problem, which suggested Delphic methods for selection of priorities and aspiration levels. Ringuest and Graves (1990) developed a multi-objective linear programming model as an alternative to maximize the net present value (NPV) illustrated in a project selection problem. Some project selection models have been based on linear programming, leaving the decision maker with the requirement to optimize based on a single objective, when the practicing manager is normally dealing with multiple objectives. Graves and Ringuest (1992) recommended multiple objective linear programming, a technique which overcomes this objection but generates a problem of its own, multiple non-dominated solutions from which the decision maker must now choose. In order to solve the problem of making this choice, it was suggested that the manager considers the probabilities of what each of these solutions will attain desired levels on each objective. At the beginning of the 21st century, Ringuest, Graves and Case (2004) developed a practical and simple model for R&D project selection through the use of mean-gini analysis. One year later, Ringuest and Graves (2005) used linear programming in a method that searches for optimal portfolios that minimize the risk of a given expected return. And in the last article at the moment, Medaglia, Graves and Ringuest (2007) proposed an evolutionary algorithm method, as an alternative to the PSI method, for project selection problems with partially funded projects, multiple (stochastic) objectives, project interdependencies (in the objectives), and a linear structure for resource constraints.

Next, there is Collan with 4 articles published. Collan and Luukka (2014) showed how profitability results of R&D project evaluation with the fuzzy pay-off method can be ranked with four new variants of fuzzy TOPSIS, each using a different fuzzy similarity measure. Collan, Fedrizzi and Luukka (2015) introduced new closeness coefficients for fuzzy similarity based on TOPSIS. The new closeness coefficients were based on multi-distance or fuzzy entropy, and were able to take into consideration the level of similarity between analyzed criteria, and can be used to account for the consistency or homogeneity of, for example, performance measuring criteria.

The other 2 articles were written along the forth place Hassanzadeh, who had 3 articles published. Hassanzadeh, Collan and Modarres (2012a), Hassanzadeh, Collan and Modarres (2012b) employed a Fuzzy pay-off, formulated as a fuzzy 0-1 integer programming model, considering the existing uncertainty, to evaluate R&D projects. The other article published by Hassanzadeh was written in 2014, in which Hassanzadeh, Nemati and Sun (2014) have developed a multi-objective binary integer programming model for R&D project portfolio selection with competing objectives when problem coefficients in both objective functions and constraints are uncertain.

And lastly, Liberatore, with 3 articles published can be considered among the other 4, the only one who has published his articles alone. Liberatore (1986) explored several methods, such as scoring models, goal programming, multi-attribute utility theory (MAU) and AHP for prioritizing projects and allocation of resources. Liberatore (1987) and Liberatore (1988) proposed an extension of the method AHP for industrial R&D project selection linking it to a spreadsheet model, and later used cost-benefit analysis and 0-1 linear integer programming, along with an AHP-spreadsheet model, for resource allocation.

Another possible analysis is checking the number of articles per country (of the main author), as shown in Figure 13. It can be seen that the greater number of articles related to R&D project selection comes from the United States, with a total of 18, followed by Iran with 6 and Turkey with 5. In the filtered articles, only one is from Brazil.

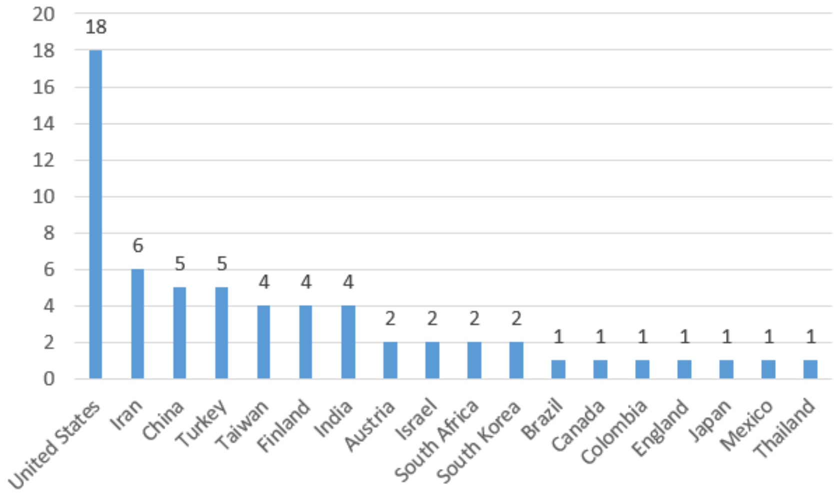


Figure 12 – Articles analyzed by origin country

Another option of analysis is observing the impact of each group of keywords (“MCDM”, “MADM”, “MODM” and “Methods”) over the possible keywords of “Projects”, already considering the “R&D” environment and also that the filters weren’t applied. The Tables 8 and 7 show the results of both runs, in Scopus and Web of Science, respectively. After combining the Boolean operators and keywords, it is noted that “Project Selection” brought the greatest number of documents (with 114 for Scopus and 130 for Web of Science) and “Project Portfolio Evaluation” has proved that it is not a possible keyword variant in this work, with 0 documents for both. Beyond that, it was also possible to see that using the group of keywords from the group “Methods” by itself, proved to be more effective by bringing the greatest number of related documents (with 128 for Scopus and 147 for Web of Science) than the generalized keyword groups, and the “MCDM” proved to be the most efficient group among the generalized keyword groups (with 34 for Scopus and 27 for Web of Science).

Table 7 – Keywords strength (Scopus)

| **R&D - Scopus** | | | | | | | |
|---|---|---|---|---|---|---|---|
| AND | Project Selection | Project Evaluation | Project Portfolio Selection | Project Portfolio Evaluation | Project Portfolio | Project Portfolio Management | OR |
| MCDM | 21 | 4 | 1 | 0 | 7 | 1 | 34 |
| MADM | 2 | 1 | 1 | 0 | 1 | 0 | 5 |
| MODM | 2 | 0 | 0 | 0 | 1 | 0 | 3 |
| Methods | 89 | 30 | 19 | 0 | 36 | 3 | 177 |
| OR | 114 | 35 | 21 | 0 | 45 | 4 | |

Table 8 – Keywords strength (Web of Science)

| R&D - Web of Science | | | | | | | |
|---|---|---|---|---|---|---|---|
| AND | Project Selection | Project Evaluation | Project Portfolio Selection | Project Portfolio Evaluation | Project Portfolio | Project Portfolio Management | OR |
| MCDM | 18 | 3 | 1 | 0 | 4 | 1 | 27 |
| MADM | 4 | 2 | 1 | 0 | 1 | 0 | 8 |
| MODM | 2 | 0 | 1 | 0 | 2 | 0 | 5 |
| Methods | 106 | 32 | 19 | 0 | 32 | 3 | 192 |
| OR | 130 | 37 | 22 | 0 | 39 | 4 | |

And lastly, it was also possible to verify which journals were more interested in this subject. The Figure 13 shows the first 10 journals out of 40. IEEE Transactions on Engineering Management is a good option for related publications with 11 articles, nearly one sixth of the total, followed by the European Journal of Operational Research with 5, and Omega with 3 articles.

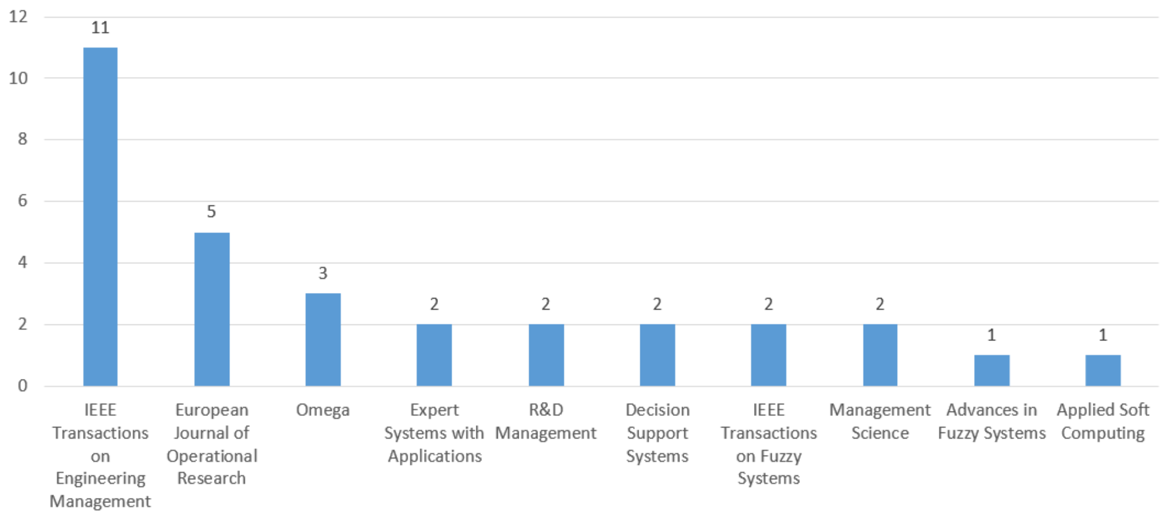


Figure 13 – Articles published by journals.

### 3.3.2 Criteria Grouping

During the analysis of the 61 filtered articles, a list with all the identified criteria in the articles was made. However, as shown in C.E. (Criteria Explained) in Table 9, 69% of them don't give a satisfactory explanation of each criteria used in their project selections, or simply do not explicit their use, the other 31% gave a better explanation of them, allowing their grouping into groups and subgroups.

Table 9 – List of articles

| # | Authors | Title | C.E. [1] |
|---|---|---|---|
| 1 | Bell and Read (1970) | The application of a research project selection method | No |
| 2 | Taylor, Moore and Clayton (1982) | R and D Project Selection and Manpower Allocation with Integer Non-Linear Goal Programming | Yes |
| 3 | Madey and Dean (1985) | Strategic Planning for Investment in R&D using decision analysis and mathematical programming | No |
| 4 | Czajkowski and Jones (1986) | Selecting Interrelated R&D projects in Space Technology Planning | No |
| 5 | Liberatore (1986) | R&D project selection | No |
| 6 | Liberatore (1987) | Extension of the Analytic Hierarchy Process for Industrial R&D Project Selection and Resource Allocation | No |
| 7 | Bard, Balachandra and Kaufmann (1988) | An Interactive Approach to R&D Project Selection and Termination | Yes |
| 8 | Liberatore (1988) | An expert support system for R&D project selection | No |
| 9 | Ringuest and Graves (1989) | The Linear Multi-Objective R&D Project Selection Problem | No |
| 10 | Ringuest and Graves (1990) | The Linear R&D Project Selection Problem: An Alternative to Net Present Value | No |
| 11 | Stewart (1991) | A multi-criteria decision support system for R&D project selection | Yes |
| 12 | Oral, Kettani and Lang (1991) | A Methodology for Collective Evaluation and Selection of Industrial Research and Development projects | Yes |
| 13 | Graves and Ringuest (1992) | Choosing the best solution in an R&D project selection problem with multiple objectives | No |
| 14 | Heidenberger (1996) | Dynamic project selection and funding under risk: A decision tree based MILP approach | No |
| 15 | Henig and Katz (1996) | R&D project selection: A decision process approach | Yes |
| 16 | Beaujon, Marin and McDonald (2001) | Balancing and optimizing a portfolio of R&D projects | No |
| 17 | Meade and Presley (2002) | R&D project selection using the analytic network process | Yes |
| 18 | Stummer and Heidenberger (2003) | Interactive R&D portfolio analysis with project interdependencies and time profiles of multiple objectives | No |
| 19 | Hsu, Tzeng and Shyu (2003) | Fuzzy multiple criteria selection of government-sponsored frontier technology R&D projects | Yes |
| 20 | Ringuest, Graves and Case (2004) | Mean-Gini analysis in R&D portfolio selection | Yes |
| 21 | Kumar (2004) | AHP-based formal system for R&D project evaluation | Yes |
| 22 | Wang, Wang and Hu (2005) | Analytic hierarchy process with fuzzy scoring in evaluating multidisciplinary R&D projects in China | Yes |
| 23 | Gustafsson and Salo (2005) | Contingent portfolio programming for the management of risky projects | No |
| 24 | Ringuest and Graves (2005) | Formulating optimal R&D portfolios | No |
| 25 | Sun and Ma (2005) | A packing-multiple-boxes model for R&D project selection and scheduling | No |
| 26 | Mohanty et al. (2005) | A fuzzy ANP-based approach to R&D project selection: a case study | Yes |

[1] Criteria Explained.

| | | | |
|---|---|---|---|
| 27 | Karsak (2006) | A generalized fuzzy optimization framework for R&D project selection using real options valuation | No |
| 28 | Rabbani et al. (2006) | A comprehensive model for R and D project portfolio selection with zero-one linear goal-programming | No |
| 29 | Medaglia, Graves and Ringuest (2007) | A multiobjective evolutionary approach for linearly constrained project selection under uncertainty | No |
| 30 | Carlsson et al. (2007) | A fuzzy approach to R&D project portfolio selection | No |
| 31 | Wang and Hwang (2007) | A fuzzy set approach for R&D portfolio selection using a real options valuation model | No |
| 32 | Shin, Yoo and Kwak (2007) | Applying the analytic hierarchy process to evaluation of the national nuclear R&D projects: The case of Korea | No |
| 33 | Imoto, Yabuuchi and Watada (2008) | Fuzzy regression model of R&D project evaluation | Yes |
| 34 | Fang, Chen and Fukushima (2008) | A mixed R&D projects and securities portfolio selection model | No |
| 35 | Bitman and Sharif (2008) | A conceptual framework for ranking R&D projects | Yes |
| 36 | Conka, Vayvay and Sennaroğlu (2008) | A combined decision model for R&D project portfolio selection | No |
| 37 | Tolga and Kahraman (2008) | Fuzzy multiattribute evaluation of R&D projects using a real options valuation model | Yes |
| 38 | Eilat, Golany and Shtub (2008) | R&D project evaluation: An integrated DEA and balanced scorecard approach | No |
| 39 | Wu et al. (2009) | Bargaining game model in the evaluation of decision making units | No |
| 40 | Jung and Seo (2010) | An ANP approach for R&D project evaluation based on interdependencies between research objectives and evaluation criteria | Yes |
| 41 | Bhattacharyya, Kumar and Kar (2011) | Fuzzy R&D portfolio selection of interdependent projects | No |
| 42 | Hassanzadeh, Collan and Modarres (2012a) | A Practical Approach to R&D Portfolio Selection Using the Fuzzy Pay-Off Method | No |
| 43 | Hassanzadeh, Collan and Modarres (2012b) | A practical R&D selection model using fuzzy pay-off method | No |
| 44 | Mohaghar et al. (2012) | An integrated approach of Fuzzy ANP and Fuzzy TOPSIS for R&D project selection: A case study | No |
| 45 | Oral (2012) | Action research contextualizes DEA in a multi-organizational decision-making process | No |
| 46 | Eckhause, Gabriel and Hughes (2012) | An Integer Programming Approach for Evaluating R&D Funding Decisions With Optimal Budget Allocations | No |
| 47 | Hassanzadeh, Nemati and Sun (2014) | Robust optimization for interactive multiobjective programming with imprecise information applied to R&D project portfolio selection | No |
| 48 | Collan and Luukka (2014) | Evaluating R&D Projects as Investments by Using an Overall Ranking From Four New Fuzzy Similarity Measure-Based TOPSIS Variants | No |
| 49 | Collan, Fedrizzi and Luukka (2015) | New Closeness Coefficients for Fuzzy Similarity Based Fuzzy TOPSIS: An Approach Combining Fuzzy Entropy and Multidistance | No |

| | | | |
|---|---|---|---|
| 50 | Karaveg, Thawesaengskulthai and Chandrachai (2015) | A combined technique using SEM and TOPSIS for the commercialization capability of R&D project evaluation | Yes |
| 51 | Bhattacharyya (2015) | A Grey Theory Based Multiple Attribute Approach for R&D Project Portfolio Selection | Yes |
| 52 | Eshlaghy and Razi (2015) | A hybrid grey-based k-means and genetic algorithm for project selection | No |
| 53 | Jeng and Huang (2015) | Strategic project portfolio selection for national research institutes | Yes |
| 54 | Arratia et al. (2016) | Static R&D project portfolio selection in public organizations | No |
| 55 | Heydari, Hosseini and Makui (2016) | Developing and solving an one-zero non-linear goal programming model to R and D portfolio project selection with interactions between projects | No |
| 56 | Stewart (2016) | Multiple objective project portfolio selection based on reference points | No |
| 57 | Marcondes et al. (2017) | Using mean-Gini and stochastic dominance to choose project portfolios with parameter uncertainty | No |
| 58 | Montajabiha, Khamseh and Afshar-Nadjafi (2017) | A robust algorithm for project portfolio selection problem using real options valuation | No |
| 59 | Karasakal and Aker (2017) | A multicriteria sorting approach based on data envelopment analysis for R&D project selection problem | Yes |
| 60 | Cheng, Liou and Chiu (2017) | A Consistent Fuzzy Preference Relations Based ANP Model for R&D Project Selection | No |
| 61 | Liang et al. (2018) | Method for three-way decisions using ideal TOPSIS solutions at Pythagorean fuzzy information | No |

Through the systematic reading of 61 articles that presented and/or described the criteria for R&D project portfolio selection, the author used the affinity diagram (MIZUNO, 1993) to gather them into 27 subgroups. With the affinity grouping it was also possible to assign these subgroups to one of the 8 groups. If necessary, the nominations of both groups and subgroups would be adapted by the author to a more adequate word. The results were synthesized through the Figure 14.

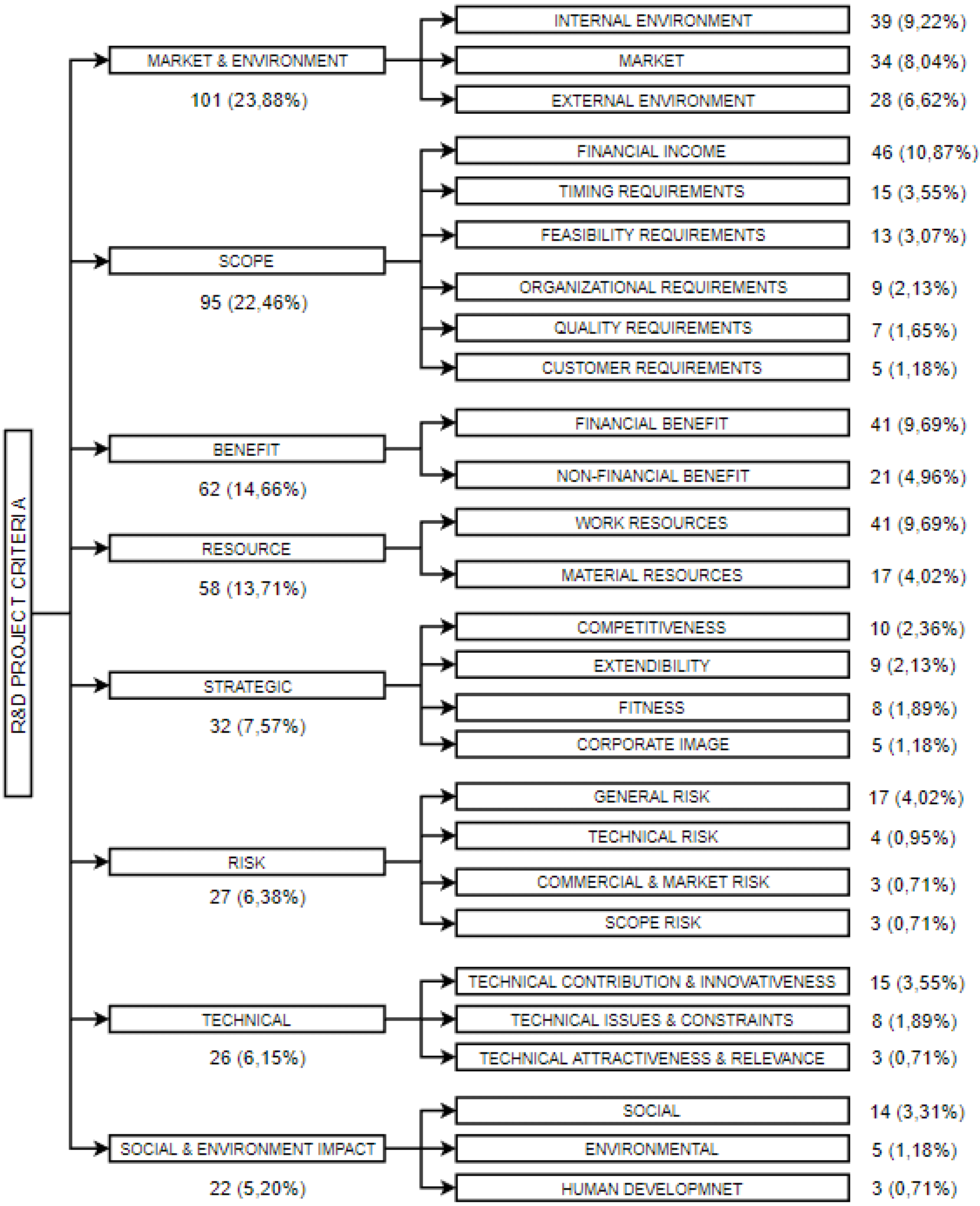


Figure 14 – Criteria hierarchy

A more detailed explanation over each group and subgroup will be given in the following sections:

#### 3.3.2.1 Market & Environment

The Market & Environment (M&E) group includes all the criteria related exclusively to the market and the relationship between the organization with their internal and external environments (LIBERATORE, 1988; TOLGA; KAHRAMAN, 2008; CHENG;

LIOU; CHIU, 2017). The M&E criteria can be subdivided into three subgroups which will be explained at the following topics:

- **Internal Environment (IEV):** comprehends the criteria related to factors inside an organization, like workplace safety and manufacturing capability (MEADE; PRESLEY, 2002; CHENG; LIOU; CHIU, 2017).
- **Market (MKT):** includes criteria exclusively related to the market, such as sales, market acceptance, interactions, trends, potential and possible market share (MADEY; DEAN, 1985; MOHANTY et al., 2005).
- **External Environment (EEV):** considers all factors and criteria that are not within the company and out of its control, such as the existence of competitors (MOHANTY et al., 2005), unexpected volatilities (MONTAJABIHA; KHAMSEH; AFSHAR-NADJAFI, 2017) and regulations (MOHANTY et al., 2005; MOHAGHAR et al., 2012).

More examples of each Market & Environment subgroup criteria along with their referenced article can be seen at Table 10.

Table 10 – Market & Environment criteria per subgroup

| Market & Environment | |
|---|---|
| Internal Environment | Manufacturing facility and equipment requirements (Adequacy) (5, 7, 8, 21, 37, 60); Manufacturing Capability (5, 7, 8, 37, 60); Capability to market product (5, 7, 8, 37); Competence and experience on similar project (26, 44); Degree of competence (26, 44); Manufacturing safety (5, 37); Computer capacity utilization (2); Complete product line and quality improvement (5); Environmental considerations (17); Existence of project champion (17); Existence of required competence (17); Workplace safety (17); Capability of research team (19); Influencing actors (35); Compatibility with the existing system (36); Manufacturing Environmental considerations (37); Learning and growth (Platform for growth) (38); Synergy with other operations (38); Intellectual property valuation (50); Technology capability (50); Technology compatibility (50); Compatibility of the Expenses to the Market (59); Existence of required competence and degree of internal commitment (59); R&D Infrastructure and Culture of the Company (59). |
| Market | Market Potential (5, 7, 8, 17, 26, 37, 44, 50, 53, 60); Expected market share (5, 9, 13, 26, 29, 44); Market trend and growth (5, 7, 8, 37); Potential market iterations with the previous product (26, 44); Sales (3, 18); Unit price (5, 60); Customer acceptance (5); Market scope of application (19); Expected sales volume (33); Market analysis (50); Market strategy (50); Aid an organization in competing in the market (53); Opportunity for market success (53); Conducting Market Research (59). |
| External Environment | Competitors effort in similar areas (26, 44, 60); Environmental Economic regulations (26, 44); Environmental policy (26, 44); Environmental Safety considerations (26, 44); Environmental Social ambience (26, 44); Government policy (26, 44); Pricing trend, proprietary problem, geographical extent, and effect on existing products (5); Relationship with existing markets (5); Environment Compatibility (15); Environmental considerations (17); External regulations (17); Number and strength of competitors (17); Intensity of competition (19); Relatedness of industry (19); Influencing actors (35); Regulatory constraints (35); Regulatory impact (38); Ability to meet likely future regulamentations (53); Annual market volatility (58); Collaboration with University/Industry (59). |

#### 3.3.2.2 Scope

The Scope (SCP) group includes all the criteria related to the necessary requirements for performing the project according to its scope (LIBERATORE, 1986; EILAT; GOLANY; SHTUB, 2008; JENG; HUANG, 2015). The SCP criteria can be subdivided into six subgroups which will be explained at the following topics:

- **Financial Income (FNI):** is related to all financial resources needed to perform the project being able to be measured in terms of cost, budget, cash flow, total investment and other metrics (LIBERATORE, 1988; RINGUEST; GRAVES, 1990; KARSAK, 2006; BHATTACHARYYA; KUMAR; KAR, 2011; CHENG; LIOU; CHIU, 2017).

- **Timing Requirements (TMR):** is related to all criteria belonging to a time dimension, such as timing, project completion time and time to market (LIBERATORE, 1986; MEADE; PRESLEY, 2002; HEYDARI; HOSSEINI; MAKUI, 2016).

- **Feasibility Requirements (FER):** includes the criteria that are mandatory to successfully perform the project, for example, the product life cycle (MOHANTY et al., 2005) and the financial feasibility (KUMAR, 2004).

- **Organizational Requirements (OGR):** comprehends the criteria imposed by the organization, like the objective of R&D, priority, congruence and importance (SUN; MA, 2005; IMOTO; YABUUCHI; WATADA, 2008; EILAT; GOLANY; SHTUB, 2008).

- **Quality Requirements (QLR):** put together all the criteria that may interfere on the overall quality of the project, such as customer feedback, customer satisfaction and the quality proposal (HSU; TZENG; SHYU, 2003; EILAT; GOLANY; SHTUB, 2008).

- **Customer Requirements (CUR):** includes the criteria that are imposed by the customer, such as expected utility (MOHANTY et al., 2005) and clarity of definition (KUMAR, 2004).

More examples of each Scope subgroup criteria along with their referenced article can be seen at Table 12.

Table 11 – Scope criteria per subgroup

| Scope | |
|---|---|
| Financial Income | Cost (2, 4, 5, 7, 8, 16, 25, 31, 33, 36, 41, 42, 43, 47, 49, 51, 58); Cash flow (9, 10, 11, 14, 18, 23, 27, 38); Budget (1, 7, 10, 29, 34, 39, 45); Total Investment (5, 7, 8, 28, 38, 60); Utilization of assets, cost trend, cost reduction, and cash flow (5); R&D funds (18); Aids or collaboration from outside agencies (21); Commercial sponsorship (21); Initial expenditures (27); Fund (41); Financial resources (59). |
| Timing Requirements | Timing (5, 7, 8, 19, 37); Project completion time (2, 51, 55); Time to market (17, 53); Development time (5); Payout period (5); Anticipated completion time (21); Period (33); Starting time (58). |
| Feasibility Requirements | Product life cycle (17, 26, 44, 60); Fits in overall objectives and strategy (5); Soundness of scientific principles (19); Financial feasibility (21); Necessity (33); Research life cycle phase (35); Market need (38); Financial analysis (50); Content of a technical plan (53); Necessary funding (55). |
| Organizational Requirements | Urgency of the project to maintain power generation capacity of the corporation (11); Priority (25); Objective of R&D (33); Methods to perform and manage this project (35); Congruence (38); Importance (38); Methodology of the project (59); Project management planning (59); Work packages and project schedule (59). |
| Quality Requirements | Quality of proposal (19); Customer Complaints (38); Customer delivery statistics (38); Customer focus feedback(38); Customer Performance improvement (38); Customer satisfaction (38); Team/supplier satisfaction (38). |
| Customer Requirements | Expected utility (26, 44); Clarity of definition (21); Facts needed to perform this project (35); Urgent customer requirement (53). |

#### 3.3.2.3 Benefit

The Benefit (BFT) group includes all the criteria related to the possible rewards that a project can bring to the organization like a high monetary return or a good number of patents (RINGUEST; GRAVES; CASE, 2004; JUNG; SEO, 2010; BHATTACHARYYA; KUMAR; KAR, 2011). The BFT criteria can be subdivided into two subgroups in which will be explained at the following topics:

- **Financial Benefit (FIB):** expresses the financial return of the project to an organizational and can be measured by different indicators, such as net present value (NPV) (RABBANI et al., 2006), present value of return (BARD; BALACHANDRA; KAUFMANN, 1988) and real options value (ROV) (TOLGA; KAHRAMAN, 2008).
- **Non-Financial Benefit (NFB):** expresses the non-financial gains of the project to an organizational, such as patents (JUNG; SEO, 2010) and academic papers (CONKA; VAYVAY; SENNAROğLU, 2008).

More examples of each Benefit subgroup criteria along with their referenced article can be seen at Table 12.

Table 12 – Benefit criteria per subgroup

| Benefit | |
|---|---|
| Financial Benefit | Expected return (2, 3, 5, 14, 15, 20, 24, 30, 34, 50, 52, 53, 60); Economic (12, 22, 36, 39, 45); Net present value (NPV) (17, 28, 29, 44); Profit (3, 13, 15, 55); Real options value (ROV) (37, 42, 43, 48); Profitability (5, 7, 8); Benefit or pay-off interaction (4); Present value of return (7); Expected net benefit (16); Growth potential of product (19); Value-added of target products (19); Expected savings resulting modernising system instead of replacement (36); Earned value (38); Potential of Profitability, Improvements in Productivity and Cost (59). |
| Non-Financial Benefit | Patents (5, 33, 36, 40, 53); Academic papers (36, 40, 52); Scientific contribution (12, 39, 45); Benefit/Cost (1, 49); Outcome (41, 51); Outcome or technology interaction (4); Dissemination ability (22); Theoretical of technical contribution (22); Research (26); Track record of submitter of this project (35); Expected degree of the facts and the knowledge which will be gained during the project (36). |

#### 3.3.2.4 Resource

The Resource (RSC) group includes all the criteria related to the resources used on a project, such as manpower, materials and equipment (HEIDENBERGER, 1996; WANG; WANG; HU, 2005; CHENG; LIOU; CHIU, 2017). The RSC criteria can be subdivided into two subgroups which will be explained at the following topics:

- **Work Resources (WRR):** comprehends the criteria related to resources that will be used, such as manpower and the knowledge necessary (WANG; HWANG, 2007; MOHAGHAR et al., 2012).
- **Material Resources (MTR):** includes the criteria related to resources that till be consumed, like raw material and energy (WANG; WANG; HU, 2005; CHENG; LIOU; CHIU, 2017).

More examples of each Resource subgroup criteria along with their referenced article can be seen at Table 13.

Table 13 – Resource criteria per subgroup

| Resource | |
|---|---|
| Work Resources | Manpower (2, 14, 16, 18, 27, 28, 31, 36, 38, 40, 41, 50, 52, 55); Technical resources (5, 7, 8, 37); Knowledge/skills availability (5, 26, 44); Availability of R&D resources (5, 60); Labor available to staff (42, 43); Labor required for implementation (42, 43); Research staff availability (26, 44); Resource requirements (12); Availability of resources (17); Availability of complementary assets (19); Availability of human expertise (21); Skills needed for the tools needed for this project (35); Subcontracting needed to perform this project (35); Tools needed to perform this project (35); Availability of people and facilities (38); Resource interdependency (51); Technical resource availability (53); Other resources (55); Resources other than manpower (59). |
| Material Resources | Availability of raw material (5, 26, 44, 60); Facilities available (5, 26, 44); Availability of R&D resources (5, 60); Resource requirements (12); Availability of resources (17); Availability of material resources and consumables (21); In-house availability of technology (21); Energy and material saved (22); Resource interdependency (51); Other resources (55); Resources other than manpower (59). |

#### 3.3.2.5 Strategic

The Strategic (STR) group is related to an exclusive benefit to the organization, in which includes all the criteria that provides a strategical aspect from the project to the organization (STEWART, 1991; HSU; TZENG; SHYU, 2003; CONKA; VAYVAY; SENNAROğLU, 2008). The STR criteria can be subdivided into four subgroups which will be explained at the following topics:

- **Competitiveness (COM):** measures the potential of a project to enhance its participation on the market more than its competitors. It can be achieved, for example, by the concatenation with Science & Technology (S&T) policy or with the development and use of proprietary technology (HSU; TZENG; SHYU, 2003).
- **Extendibility (EXT):** is related to the capacity of a project to grow or enhance its company's growing by the addition of new components. It can be measured, for example, by the applicability of a project results in other products and process (MEADE; PRESLEY, 2002), the potential technical interaction with existing products (MOHANTY et al., 2005) and the compatibility with other projects (LIBERATORE, 1986).
- **Fitness (FIT):** measures the ability of a project to be within the organization's strategic alignment. It can be also described as strategic fit (CARLSSON et al.,

2007) and strategic need (MOHANTY et al., 2005), for example.

- **Corporate Image (COI):** describes the potential of a project to enhance the company's visibility before the society or a specific company or an economic segment. Some authors like Liberatore (1986) used corporate image as a criteria and others indirectly achieved this by pursuing other goals, such as the contribution of a project to the national economy (WANG; WANG; HU, 2005) or employing a reputable leader (KUMAR, 2004).

More examples of each Strategic subgroup criteria along with their referenced article can be seen at Table 14.

Table 14 – Strategic criteria per subgroup

| Strategic | |
|---|---|
| Competitiveness | Competitiveness (11, 35); Importance of the client organization to the engineering investigations division, and of the project to the client (11); Concatenation with S&T policy (19); Proprietary technology (19); Anticipated change of commercial success (21); Utility of regional resources (21); R&D project efficiency and commercialization potential (22); Degree of the ownership (36); Learning and growth (Propriety position) (38). |
| Extendibility | Applicability to other products and processes (17, 19, 60); Potential technical interaction with existing products (26, 44); Compatibility with other projects (5); Potential for long-term gains to the division, such as in generating future contracts (11); Extent of tie-in with existing projects (21); Technical interdependency (51). |
| Fitness | Strategic fit (17, 30, 35); Strategic need (26, 44); Idea source (35); Strategic (36); Program complexity (38). |
| Corporate Image | Corporate Image (5); Contribution to national strategic technological independence (11); Leader Reputation (21); Contribution to national economy (22); Decreasing Inter-Regional Differences in Terms of Development (59). |

#### 3.3.2.6 Risk

The Risk (RSK) group includes all the criteria related to the uncertainty of the project's future like the probability of success or the possibility of appearing different issues (MEADE; PRESLEY, 2002; CARLSSON et al., 2007; EILAT; GOLANY; SHTUB, 2008). The RSK criteria can be subdivided into four subgroups which will be explained at the following topics:

- **General Risk (GNR):** comprehends the criteria related to the overall uncertainty associated to a project and can be represented by, for example, the probability of success (CHENG; LIOU; CHIU, 2017).

- **Technical Risk (TCR):** is related, in a general manner, to the uncertainty associated to the technology or the probability of technical issues to occur (MEADE; PRESLEY, 2002; KUMAR, 2004).
- **Commercial & Market Risk (CMR):** is related, in a general manner, to the uncertainty of a project to induce the commercial success (LIBERATORE, 1986; MOHANTY et al., 2005; EILAT; GOLANY; SHTUB, 2008).
- **Scope Risk (SCR):** measures the probability of project's results staying outside of its scope after conclusion. Therefore, it can be associated to the risk of delay (ESHLAGHY; RAZI, 2015), additional costs (MOHANTY et al., 2005) or unexpected interdependencies (BHATTACHARYYA, 2015).

More examples of each Risk subgroup criteria along with their referenced article can be seen at Table 15.

Table 15 – Risk criteria per subgroup

| Risk | |
|---|---|
| General Risk | Probability of Success (2, 3, 5, 6, 7, 8, 12, 17, 37, 60); Risk (23, 28, 41, 47, 51, 55); Uncertainty (30). |
| Technical Risk | Probability of technical issues (17, 21); Probability of commercial and technical success (38); Technical (52). |
| Commercial & Market (5); Market Risk | Commercial (26); Probability of commercial and technical success (38). |
| Scope Risk | Economic and technical (26); Interdependency (51); Delay (52). |

#### 3.3.2.7 Technical

The Technical (TEC) group includes all the technical or technological criteria related to the innovativeness, impact and relevance of the project under development (HSU; TZENG; SHYU, 2003; KUMAR, 2004; WANG; WANG; HU, 2005). The TEC criteria can be subdivided into three subgroups which will be explained at the following topics:

- **Technical Contribution & Innovativeness (TCI):** indicates the potential of a project to introduce new approaches to achieve new technologies (ORAL; KETTANI; LANG, 1991; JENG; HUANG, 2015). It can also be measured by terms of advancement of technology (HSU; TZENG; SHYU, 2003) and creativity (WANG; WANG; HU, 2005).
- **Technical Issues & Constraints (TIC):** is related to the main technologies used in the project and their impact or possible associated problems. The criteria

can be exemplified as the technological connections (HSU; TZENG; SHYU, 2003), the technological difficulty (IMOTO; YABUUCHI; WATADA, 2008) and type of technology (HSU; TZENG; SHYU, 2003).

- **Technical Attractiveness & Relevance (TAR):** indicates the receptivity by the market with the relevance of a developed technology (KUMAR, 2004; CONKA; VAYVAY; SENNAROğLU, 2008).

More examples of each Technical subgroup criteria along with their referenced article can be seen at Table 16.

Table 16 – Technical criteria per subgroup

| Technical | |
|---|---|
| Technical Contribution & Innovativeness | Innovativeness (19, 21, 35, 36, 50, 53, 59); Technical Contribution (12, 37, 39); Advancement of technology (19, 53); Creativity and level of advancement (22); Technique improvement (22); This projectś improvement to technological dimensions (35). |
| Technical Issues & Constraints | Likelihood of technical success (5, 53); Generics or specific (19); Technological connections (19); Technological difficulty (33); Technology skill base (38); Key of technology (53); Technology used in the project (59). |
| Technical Attractiveness & Relevance | Attractiveness of technological route (21); Technological relevance of the project (21); Technological (36). |

#### 3.3.2.8 Social & Environment Impact

The Social & Environment Impact (S&E) group includes all the criteria related to society, the environment and to the company's workers (ORAL; KETTANI; LANG, 1991; EILAT; GOLANY; SHTUB, 2008; KARASAKAL; AKER, 2017). The S&E Impact criteria can be subdivided into three subgroups which will be explained at the following topics:

- **Social (SOC):** measures the capacity of the project to generate social benefit (RINGUEST; GRAVES, 1989; ORAL; KETTANI; LANG, 1991). It can also be associated to job creation opportunities (KARASAKAL; AKER, 2017) and the ethics or morality of the project (BITMAN; SHARIF, 2008).

- **Environmental (ENV):** measures the capacity of a project to generate any environmental benefit (STEWART, 1991; KARASAKAL; AKER, 2017). Besides the internal environment, it can also be associated to the external environment, such as the project ecological implications (BITMAN; SHARIF, 2008) or its sustainability (KARAVEG; THAWESAENGSKULTHAI; CHANDRACHAI, 2015).

- **Human Development (HMD):** associates to any criteria related to the improvement and training of human resources (STEWART, 1991; EILAT; GOLANY; SHTUB, 2008).

More examples of each Social & Environment Impact subgroup criteria along with their referenced article can be seen at Table 17.

Table 17 – Social & Environment Impact criteria per subgroup

| Social & Environment Impact | |
|---|---|
| Social | Social benefit (12, 19, 22, 36, 39, 45, 59); Benefit to Environment & Life (11, 59); Improvement on the QESIS (19, 53); Social relevance (21); Ethics/Morality of this project (35); Job Creation Opportunity (59). |
| Environmental | Benefit to Environment & Life (11, 59); Safety and pollution concerns (19); Ecological implications of performing this project (35); Sustainability (50). |
| Human Development | Contribution to staff training and development, and to general job satisfaction (11); Learning and growth (Durability [technical and market]) (38); Learning and growth (Team members trained) (38). |

### 3.3.3 Criteria Evaluation

#### 3.3.3.1 Centro Nacional de Referência em Pequenas Centrais Hidrelétricas

The Brazilian Centro Nacional de Referência em Pequenas Centrais Hidrelétricas (CERPCH) is an institution created in 1998 and it is located in the Universidade Federal de Itajubá (UNIFEI) with focus on Small Hydro Power Plant (SHP) technology diffusion, through agreement among several governmental institutions, universities and energy centred organizations.

This institution aims the promotion of the popularization of small hydro power plants through information network, projects, researches, scientific and technological development and also the encouragement of the instruction and training in this field of performance, besides the accomplishment of events, having great part of your partnerships (80%) coming from the public sector.

The CERPCH also performs in areas such as:

- **Communication:** CERPCH has the objective to spread of information through the periodical Revista PCH Noticias & SHP News, the gateway <https://cerpch.org.br> and the accomplishment of scientific technical events such as the SHP Market and Environment Conference. Besides, it is responsible for the production of books and guidelines as well as the accomplishment of specialization courses.

- **Projects:** It operates in the development of Basic Projects, Inventory Studies, Retrofitting Projects and Re-powering of Hydro Power Plants. It was responsible for the largest rising of the state of conservation of the small hydro power plants accomplished for ANEEL in 1999.

- **Social and Environmental Responsibility:** Understanding the complexity and relevance of the process of generation of energy, CERPCH looks for alternatives sustainable development through projects such as the "Agroenergy" Course.

Their specialist is graduated in public relations, master in energy engineering with a work related to renewable energies and the environment and, currently, act as a doctoral student. She is also professor of environmental management and environmental impact assessment at UNIFEI and CERPCH's project coordinator. She has experience in the area of energy engineering, working mainly with SHP, environment, renewable energy, energy market, communication and project management. She has experience in renewable energy, generation and energy planning, working mainly with SHP, environment, environmental licensing, environmental management and project management. And since 2010, she has been working at CERPCH with the management of research projects.

As explained in the AHP section, the specialist had to determine the relative importance from each pairwise comparison among groups and their subgroups. All the specialist values and results can be seen in Appendix A.

#### 3.3.3.2 Inatel Competence Center

The Inatel Competence Center (ICC) is an institution founded in 1985 and it is located in the Instituto Nacional de Telecomunicações (INATEL) with focus in providing services and technical solutions (Internet of Things, Cloud Computing, telecommunications...) to the national and international market.

At the beginning, there were only 3 employees working in a few projects and with few companies partnerships. Nowadays, these numbers have increased with more than 270 employees working in more than 200 projects per year and more than 50 partnerships where a great part of these partnerships (85%), also come from the private sector.

The ICC also performs in areas such as:

- **Calibration and Testing:** With a laboratory accredited by INMETRO and evaluated by ANATEL, it calibrates equipments for voltage, current, frequency and power quantities. It also provides pre-tests and equipments approval (accredited MTE, CONFAZ and SEFAZ).

- **Continuing Education:** It provides custom services at the area of technological and management, providing assistance in launching teams, supporting strategical decisions, dissemination of technologies, among others.
- **Project Management:** It has a project management office in order to ensure that the scope, schedule and quality of the project be attended. The projects are managed by a multidisciplinary team, with professionals certified by PMI (Project Management Institute) and SCRUM.

Their specialist is the manager at the development of hardware and software with 25 years of experience at project developments, acting in tasks such as sales, management and project selection. It is also certified PMP (Project Management Professional) and Doctor in Industrial Engineering.

As explained in the AHP section, the specialist had to determine the relative importance from each pairwise comparison among groups of criteria and their subgroups. All the specialist values and results can be seen in Appendix B.

Further comments and comparisons between both specialists results will be given in the next chapter.

# 4 Results Analysis

## 4.1 Groups/Subgroups Data Analysis

With all pairwise comparisons completed and respecting the consistency ratio, it is possible to make some analysis between both specialists' results. All decision matrices and their respective priority vectors to each specialist can be seen in Appendices A and B. In order to keep the analysis organized, each one will be made in separate topics, as it follows:

- **R&D Groups:** As shown in Figure 15 (or Tables 20 and 30), it is possible to see that both specialists consider BFT the main factor to be analyzed at project selection (33,02% to CERPCH's and 26,30% to ICC's). To CERPCH's, RSC is considered the second most important factor (18,93%). On the other hand, to ICC's this type of criteria is considered the least important (2,64%). A possible justification to this result may be by the way their businesses are managed, the kind of resources used or the experience of each specialist in managing them. To ICC's specialist, the second factor with highest priority would be RSK (23,40%) and to CERPCH's, the third (15,50%). It is important to note that this group's importance is close to CERPCH's RSC and ICC's BFT being overall a factor of great relevance.

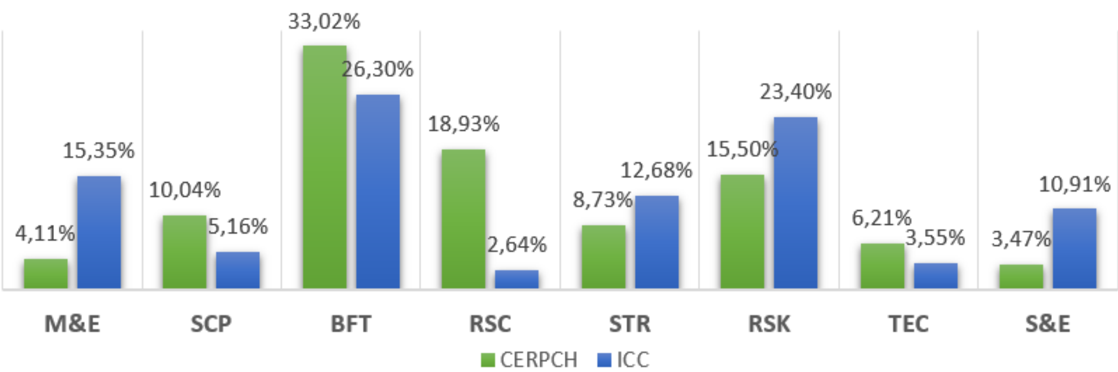


Figure 15 – Groups' Relative Importance.

- **Market & Environment Subgroups:** Looking to the M&E subgroups at Figure 16 (or Tables 21 and 31), it is seen that both specialists deem that the highest factor which may affect the progress of the project comes from the EEV subgroup (68,06% to CERPCH's and 66,89% to ICC's). As CERPCH is a unique institution at the sector of energy with this kind of business, it justifies their specialist judgement in considering MKT as the least important factor at their projects evaluation (11,79%).

On the other hand, ICC's specialist judges MKT as the second factor (26,47%), since they have competitors with similar business as them.

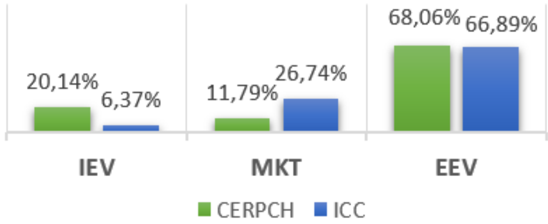


Figure 16 – Market & Environment Subgroups' Relative Importance.

- **Scope Subgroups:** Once more the same consensus occurs between both specialists, in which the highest factor that may be evaluated, is the criteria from the FNI subgroup (48,40% to CERPCH's and 37,55% to ICC's), as it is shown in Figure 17 (or Tables 22 and 32). An odd observation that can be made of SCP subgroups, is that CERPCH's specialist considers TMR as the second factor in selecting a project (15,48%), while the ICC's considers it the least (5,35%). A justification that may come from this, is the time of experience from both. Although the ICC's has been working for a longer period with project management, this may be one of the reasons why TMR doesn't present such relevance. Another observation that is possible to make around ICC's, is the equal importance their specialist gives to QLR and CUR, something comprehensible for they must provide excellent services to stand out over their competitors.

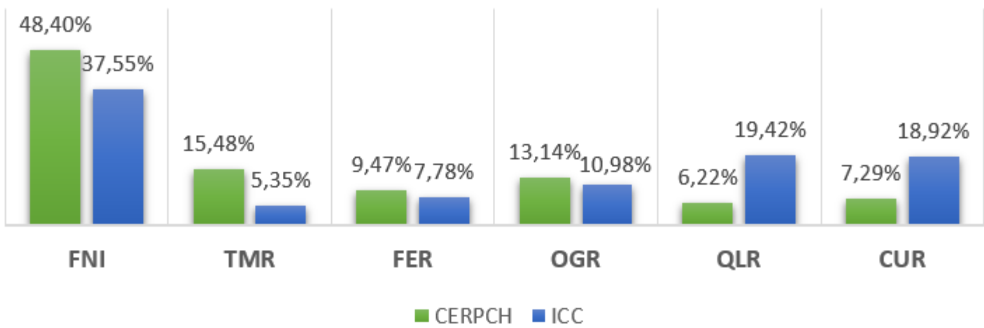


Figure 17 – Scope Subgroups' Relative Importance.

- **Benefit Subgroups:** At BFT subgroups, as shown in Figure 18 (or Tables 23 and 33), both specialists clearly judge that FIB is undoubtedly the most relevant subgroup (88,89% to CERPCH's and 83,33% to ICC's).

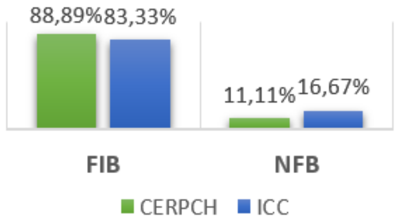


Figure 18 – Benefit Subgroups' Relative Importance.

- **Resource Subgroups:** By looking at Figure 19 (or Tables 24 and 34), it is possible to better visualize the reason RSC doesn't have a similar importance in the groups evaluation. To CERPCH specialist, the WRR subgroup criteria (88,89%) has a bigger importance to the project requirements than the MTR (11,11%). On the other hand, ICC's judges that both kinds of resources must have the same importance in evaluating a project (50%). Something that may justify such judgement is how their projects must be executed, as ICC's depends totally on machines, energy, internet and, mainly, their staff.

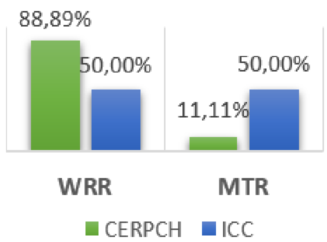


Figure 19 – Resource Subgroups' Relative Importance.

- **Strategic Subgroups:** The STR subgroups may be the first ones in which their results highly diverge. As noted in Figure 20 (or Tables 25 and 35), COM subgroup is presented as the least important factor to CERPCH (6,00%) while to ICC's it is the top priority (50,62%). The reasonable justification comes through their possible competitors, since CERPCH works with an exclusive kind of work having no competition, unlike the ICC's case. The second factor that was evaluated by ICC's specialist is the criteria from EXT subgroup (21,37%). To CERPCH the bigger relevance comes from this subgroup (47,39%), the second most relevant factor is the criteria from COI subgroup (28,82%), making it possible to earn investments by the government or attracting new clients. Besides that, a similar relevance is given from both to the criteria from FIT subgroup (17,80% to CERPCH's and 16,53% to ICC's).

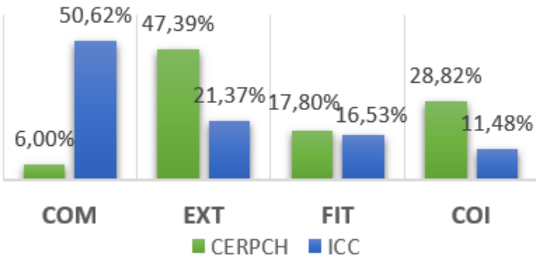


Figure 20 – Strategic Subgroups' Relative Importance.

- **Risk Subgroups:** According to Figure 21 (or Tables 26 and 36) in RSK subgroups a great presence of each specialist profile is there since the CERPCH specialist considers SCR (52,31%) far more relevant than GNR (7,49%). The opposite occurs with ICC's (42,31% to GNR and 12,25% to SCR). Besides that, it can be seen that to ICC's the criteria related to TCR and CMR subgroups are equally relevant (22,72%). To CERPCH the TCR may be the second factor (34,61%) when analyzing a project. The GNR (7,49%) and CMR (5,60%) may be the last concern to them.

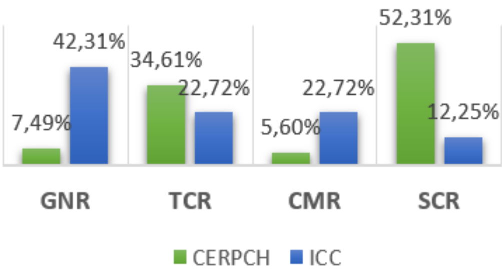


Figure 21 – Risk Subgroups' Relative Importance.

- **Technical Subgroups:** When looking to TEC subgroups at Figure 22 (or Tables 27 and 37), it is possible to see that the CERPCH specialist showed they value more the TCI subgroup criteria (63,93%) to maintain their competitor profile. To ICC's, on the other hand, higher importance is given to criteria related to TIC subgroup (65,51%).

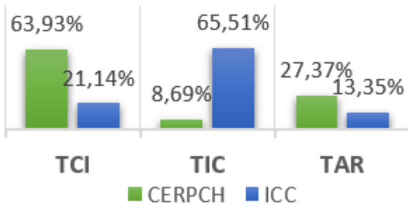


Figure 22 – Technical Subgroups' Relative Importance.

- **Social & Environment Subgroups:** In this last subgroup, it is possible to see at Figure 23 (or Table 28 and 38) that, to the CERPCH specialist, because great part of their staff is composed by researchers, great importance was given to criteria of HMD (68,53%). And as an institution of the sector of energy, the worry over the ENV criteria (22,13%) must not be the least important. To ICC's, it is shown that SOC (40,55%) and ENV (47,69%) subgroups' criteria are of close relevance when evaluating a project. As ICC aims to provide great services to their clients, it is already necessary to have a staff highly prepared for that, being one of the reasons that HMD (11,50%) criteria are the least relevant.

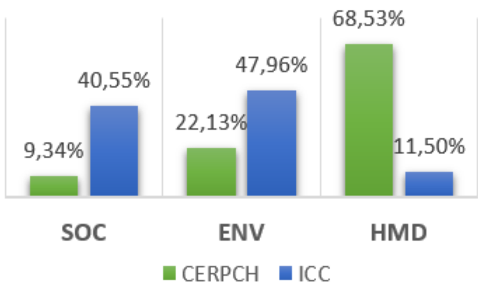


Figure 23 – Social & Environment Impact Subgroups' Relative Importance.

## 4.2 Overall Composite Weights Analysis

By the end of AHP calculations, it was possible to calculate groups/subgroups overall composite weights resulting, lastly, in Table 18 (or Tables 29 and 39).

To the CERPCH specialist, the criteria related to FIB (29,35%) has the highest importance in evaluating the project over other criteria. Next, the WRR (16,83%) is the second subgroup criteria with great importance. The overall composite weights also show that criteria related to SCR (8,11%) and TCR (5,36%) are also important to their specialist followed by FNI criteria (4,86%). At the bottom of the table it is possible to see that the criteria related to COM (0,47%) and MKT (0,40%) are one of the subgroups with lower importance, these results ended up translating correctly the organization's reality. To ICC's, the FIB (21,92%) also resulted with the highest importance over the others. Different from CERPCH, it is possible to see the presence at the top of the table of criteria related to EEV (10,27%) and GNR (9,90%). As it was said about the institution, criteria related to COM (6,42%) are also highly relevant over the others. At the bottom of the table, according to the overall composite weights, criteria related to TAR (0,47%), FER (0,40%) and TMR (0,28%) are not as relevant as the other criteria at the top.

Table 18 – Specialists criteria comparison

| CERPCH | | ICC | |
|---|---|---|---|
| BFT - FIB | 29,35% | BFT - FIB | 21,92% |
| RSC - WRR | 16,83% | M&E - EEV | 10,27% |
| RSK - SCR | 8,11% | RSK - GNR | 9,90% |
| RSK - TCR | 5,36% | STR - COM | 6,42% |
| SCP - FNI | 4,86% | RSK - TCR | 5,32% |
| STR - EXT | 4,14% | RSK - CMR | 5,32% |
| TEC - TCI | 3,97% | S&E - ENV | 5,23% |
| BFT - NFB | 3,67% | S&E - SOC | 4,42% |
| M&E - EEV | 2,80% | BFT - NFB | 4,38% |
| STR - COI | 2,52% | M&E - MKT | 4,10% |
| S%E - HMD | 2,38% | RSK - SCR | 2,87% |
| RSC - MTR | 2,10% | STR - EXT | 2,71% |
| TEC - TAR | 1,70% | TEC - TIC | 2,33% |
| SCP - TMR | 1,55% | STR - FIT | 2,10% |
| STR - FIT | 1,55% | SCP - FNI | 1,94% |
| SCP - OGR | 1,32% | STR - COI | 1,46% |
| RSK - GNR | 1,16% | RSC - WRR | 1,32% |
| SCP - FER | 0,95% | RSC - MTR | 1,32% |
| RSK - CMR | 0,87% | S&E - HMD | 1,25% |
| M&E - IEV | 0,83% | SCP - QLR | 1,00% |
| S&E - ENV | 0,77% | M&E - IEV | 0,98% |
| SCP - CUR | 0,73% | SCP - CUR | 0,98% |
| SCP - QLR | 0,62% | TEC - TCI | 0,75% |
| TEC - TIC | 0,54% | SCP - OGR | 0,57% |
| STR - COM | 0,52% | TEC - TAR | 0,47% |
| M&E - MKT | 0,49% | SCP - FER | 0,40% |
| S&E - SOC | 0,32% | SCP - TMR | 0,28% |

## 4.3 Specialists Analysis

After calculating the overall composite weights of both judgements, as shown at Table 18 above (or Tables 29 and 39), each one was sent back to its respective specialist along with 3 questions in order to see their opinions on the results:

- **What explanation would you give over the first 5 prioritized criteria?**

  To CERPCH's, these results translated the current reality of their organization. To ICC's, criteria related to the financial viability are in the core of their evaluation process (FIB, EEV, FNI, WRR and COM). Besides that, a very common approach in project management is the risk-oriented management that could justify the other criteria (GNR, TCR and CMR).

Beyond the specialists' commentaries, when comparing the first 5 criteria from both, side-by-side, it is seen at Table 18 how important the FIB criteria (29,35% to CERPCH and 21,92% to ICC) are to these organizations for maintaining themselves alive. Another point is the similar importance given to TCR (5,36% to CERPCH and 5,32% to ICC) in both evaluations, since it is a factor that may influence their projects execution.

- **Some criteria with low importance would still have a chance of being used on projects evaluation?**

  Both specialists are open to the possibility. To ICC's, some possible ones would be from NFB, TIC and QLR subgroups.

- **Which benefits this list of criteria could bring to your organization?**

  To CERPCH's, some criteria that were applied empirically are now highlighted. To ICC's, this could result in their formalization and draw attention to the most relevant ones.

## 4.4 Group Decision Making Analysis

Saaty (2008) says that by using the geometric mean, it is possible to combine the decision makers final outcomes without having to hear them at the same time. Its calculation through the values from Tables 29 and 39, it resulted the Table 19.

According to the table, it is possible to see that FIB (30,36%) is the criteria proved to be most relevant over the others. It can also be seen that the criteria related to EEV (6,42%) have an importance in evaluating projects followed by TCR (6,39%) and SCR (6,39%). From the RSC group, it is possible to see that WRR (5,64%) has a greater importance over the MTR subgroup (1,99%). Looking to the SCP subgroups, it is seen that almost all of them are at the bottom of the table except for FNI (3,67%). On the STR group, something similar happens in which a great part of their subgroups is concentrated at the center of the table apart from the criteria related to EXT (4,01%) closer to the top. And for the TEC subgroups it is possible to see that TCI (2,07%) criteria have a greater importance over the other related subgroups.

Table 19 – Group Decision Making - General Results

| **Group** | **Subgroup** | **%** |
|---|---|---|
| Benefit | Financial Benefit | 30,36% |
| Market & Environment | External Environment | 6,42% |
| Risk | Technical Risk | 6,39% |
| Risk | Scope Risk | 5,77% |
| Resource | Work Resources | 5,64% |
| Benefit | Non-Financial Benefit | 4,80% |
| Risk | General Risk | 4,06% |
| Strategic | Extendibility | 4,01% |
| Scope | Financial Income | 3,67% |
| Risk | Commercial & Market Risk | 2,57% |
| Social & Environment Impact | Environment | 2,40% |
| Strategic | Corporate Image | 2,29% |
| Strategic | Competitiveness | 2,19% |
| Strategic | Fitness | 2,16% |
| Social & Environment Impact | Human Development | 2,07% |
| Technical | Technical Contribution & Innovativeness | 2,07% |
| Resource | Material Resources | 1,99% |
| Market & Environment | Market | 1,69% |
| Social & Environment Impact | Social | 1,43% |
| Technical | Technical Issues & Constraints | 1,34% |
| Market & Environment | Internal Environment | 1,08% |
| Technical | Technical Attractiveness & Relevance | 1,07% |
| Scope | Organizational Requirements | 1,04% |
| Scope | Customer Requirements | 1,01% |
| Scope | Quality Requirements | 0,95% |
| Scope | Timing Requirements | 0,78% |
| Scope | Feasibility Requirements | 0,74% |

In the next, and final, chapter, the conclusion of this work will be presented.

# 5
# Conclusion

Considering how important R&D is to countries around the world and their organizations, this work aimed to contribute to the project selection process by presenting which criteria may be more relevant above the others, in order to provide the most satisfactory results when the MCDM's are used. The process was presented during Chapter 3, from the need to look for the correct keywords to obtain the necessary articles for the analysis, the criteria grouping and their definitions, and their evaluation by two specialists using the AHP method.

Despite the satisfactory results, at the end, there is still room for improvement. During the reading of the 61 articles selected considering the use of MCDM's to select R&D projects, only 19 of them (31%) gave a satisfactory explanation of the criteria used, the other 42 (69%), not only did many of them did not give a good explanation, some still did not present the criteria used explicitly. Something else that could have affected the articles filtering was the three screening phases; in which the title was firstly considered, then solely the abstract and, lastly, only the text. This could have excluded possible articles that still could be considered fit to the theme but presented an unsatisfactory title or abstract. On the other hand, the title and abstract filters could have also allowed the articles, that didn't fit their criteria, to pass. Nonetheless, all the resulting articles that were read led to the presented groups and subgroups.

Since chapter 1 and 2, some authors highlighted how important innovation and technology may contribute to the organization's competitiveness and the country's economy. However, there were some authors who did not share the same idea, since the number of used criteria related to market, project requirements, benefits and many others were far greater than the ones defended by them. One lesson that could be learned by specialists and authors, is to always give a little more importance to the innovativeness of their projects, since it was shown this could enhance their position in the market and the economy of its country.

Still in the theoretical background chapter, the importance of the linkage between both project portfolio management and the organization's objectives was very highlighted. During the analysis it was possible to see how organizations influence the project evaluation process, being one of the reasons that some values obtained by the AHP differ between the specialists. For example, the relevance given to some subgroups like WRR, MTR, TCI, TIC and HMD.

Through the specialists' results, it is possible to see that the current economic crisis in Brazil may be one of the factors influencing the obtained results by the objects of study, since they prioritized the FNI significantly. It should be noted that in Brazil the public policies of innovation are centered mainly in financing R&D projects through government contribution, which undergoes strong budget reductions. Thus, the groups and subgroups of criteria identified in this work could be used by these governmental development agencies to select the most relevant ones.

During this research, it was possible to propose the criteria evaluation to organizations in the energy and technology area and to compare the obtained results with CERPCH's and ICC's, not preventing that in the future these criteria may be evaluated by organizations from different areas of research and development, such as chemical industry, food, construction and many others, or even verifying the contribution of the identified criteria for the selection of R&D projects to the Brazilian governmental organisms or in technology-based incubators. This evaluation process can grow to the point where it is possible to create a scale of criteria for different R&D segments, besides the possible validation of these groups and subgroups.

As PMBOK is one of the several guides of project management, the present work also opens the possibility to evolve into the development of a R&D project management guide, in which would include the chapter about the determination of projects criteria.

Another alternative is to check the liability among the criteria by applying the Analytic Network Process (ANP) method, also developed by Saaty, and to compare the results between both methods.

Shifting the focus on the study of criteria being solely about the criteria themselves, another option of future work would be the study about the profile of decision makers and how this may influence the decision making process, if they would prefer using only criteria or if would be more relevant to use subcriteria in selecting projects, or even if they are in favor or against the use of formalized criteria.

# APPENDIX A – CERPCH Evaluation

Table 20 – CERPCH - R&D groups evaluation

| | **M&E** | **SCP** | **BFT** | **RSC** | **STR** | **RSK** | **TEC** | **S&E** | **Priority Vector** |
|---|---|---|---|---|---|---|---|---|---|
| **M&E** | 1 | 1/3 | 1/6 | 1/3 | 1/3 | 1/4 | 1 | 1 | **4,11% (7)** |
| **SCP** | 3 | 1 | 1/3 | 1 | 1 | 1/2 | 2 | 2 | **10,04% (4)** |
| **BFT** | 6 | 3 | 1 | 5 | 4 | 3 | 4 | 6 | **33,02% (1)** |
| **RSC** | 3 | 1 | 1/5 | 1 | 4 | 3 | 4 | 6 | **18,93% (2)** |
| **STR** | 3 | 1 | 1/4 | 1/4 | 1 | 1/3 | 2 | 3 | **8,73% (5)** |
| **RSK** | 4 | 2 | 1/3 | 1/3 | 3 | 1 | 3 | 5 | **15,50% (3)** |
| **TEC** | 1 | 1/2 | 1/4 | 1/4 | 1/2 | 1/3 | 1 | 4 | **6,21% (6)** |
| **S&E** | 1 | 1/2 | 1/6 | 1/6 | 1/3 | 1/5 | 1/4 | 1 | **3,47% (8)** |

Table 21 – CERPCH - Market & Environment subgroups evaluation

| | **IEV** | **MKT** | **EEV** | **Priority Vector** |
|---|---|---|---|---|
| **IEV** | 1 | 2 | 1/4 | **20,14% (2)** |
| **MKT** | 1/2 | 1 | 1/5 | **11,79% (3)** |
| **EEV** | 4 | 5 | 1 | **68,06% (1)** |

Table 22 – CERPCH - Scope subgroups evaluation

| | **FNI** | **TMR** | **FER** | **OGR** | **QLR** | **CUR** | **Priority Vector** |
|---|---|---|---|---|---|---|---|
| **FNI** | 1 | 5 | 6 | 5 | 4 | 6 | **48,40% (1)** |
| **TMR** | 1/5 | 1 | 2 | 1 | 3 | 3 | **15,48% (2)** |
| **FER** | 1/6 | 1/2 | 1 | 1/2 | 2 | 2 | **9,47% (4)** |
| **OGR** | 1/5 | 1 | 2 | 1 | 2 | 2 | **13,14% (3)** |
| **QLR** | 1/4 | 1/3 | 1/2 | 1/2 | 1 | 1/2 | **6,22% (6)** |
| **CUR** | 1/6 | 1/3 | 1/2 | 1/2 | 2 | 1 | **7,29% (5)** |

Table 23 – CERPCH - Benefit subgroups evaluation

| | **FIB** | **NFB** | **Priority Vector** |
|---|---|---|---|
| **FIB** | 1 | 8 | **88,89% (1)** |
| **NFB** | 1/8 | 1 | **11,11% (2)** |

Table 24 – CERPCH - Resource subgroups evaluation

| | **WRR** | **MTR** | **Priority Vector** |
|---|---|---|---|
| **WRR** | 1 | 8 | **88,89% (1)** |
| **MTR** | 1/8 | 1 | **11,11% (2)** |

Table 25 – CERPCH - Strategic subgroups evaluation

| | **COM** | **EXT** | **FIT** | **COI** | **Priority Vector** |
|---|---|---|---|---|---|
| **COM** | 1 | 1/6 | 1/4 | 1/5 | **6,00% (4)** |
| **EXT** | 6 | 1 | 3 | 2 | **47,39% (1)** |
| **FIT** | 4 | 1/3 | 1 | 1/2 | **17,80% (3)** |
| **COI** | 5 | 1/2 | 2 | 1 | **28,82% (2)** |

Table 26 – CERPCH - Risk subgroups evaluation

| | **GNR** | **TCR** | **CMR** | **SCR** | **Priority Vector** |
|---|---|---|---|---|---|
| **GNR** | 1 | 1/7 | 2 | 1/8 | **7,49% (3)** |
| **TCR** | 7 | 1 | 6 | 1/2 | **34,61% (2)** |
| **CMR** | 1/2 | 1/6 | 1 | 1/7 | **5,60% (4)** |
| **SCR** | 8 | 2 | 7 | 1 | **52,31% (1)** |

Table 27 – CERPCH - Technical subgroups evaluation

| | **TCI** | **TIC** | **TAR** | **Priority Vector** |
|---|---|---|---|---|
| **TCI** | 1 | 6 | 3 | **63,93% (1)** |
| **TIC** | 1/6 | 1 | 1/4 | **8,69% (3)** |
| **TAR** | 1/3 | 4 | 1 | **27,37% (2)** |

Table 28 – CERPCH - Social & Environment Impact subgroups evaluation

| | **SOC** | **ENV** | **HMD** | **Priority Vector** |
|---|---|---|---|---|
| **SOC** | 1 | 1/3 | 1/6 | **9,34% (3)** |
| **ENV** | 3 | 1 | 1/4 | **22,13% (2)** |
| **HMD** | 6 | 4 | 1 | **68,53% (1)** |

Table 29 – CERPCH - Overall composite weights

| **Group** | **Sub-group** | **%** |
|---|---|---|
| Benefit | Financial Benefit | 29,35% |
| Resource | Work Resources | 16,83% |
| Risk | Scope Risk | 8,11% |
| Risk | Technical Risk | 5,36% |
| Scope | Financial Income | 4,86% |
| Strategic | Extendibility | 4,14% |
| Technical | Technical Contribution & Innovativeness | 3,97% |
| Benefit | Non-Financial Benefit | 3,67% |
| Market & Environment | External Environment | 2,80% |
| Strategic | Corporate Image | 2,52% |
| Social & Environment Impact | Human Development | 2,38% |
| Resource | Material Resources | 2,10% |
| Technical | Technical Attractiveness & Relevance | 1,70% |
| Scope | Timing Requirements | 1,55% |
| Strategic | Fitness | 1,55% |
| Scope | Organizational Requirements | 1,32% |
| Risk | General Risk | 1,16% |
| Scope | Feasibility Requirements | 0,95% |
| Risk | Commercial & Market Risk | 0,87% |
| Market & Environment | Internal Environment | 0,83% |
| Social & Environment Impact | Environment | 0,77% |
| Scope | Customer Requirements | 0,73% |
| Scope | Quality Requirements | 0,62% |
| Technical | Technical Issues & Constraints | 0,54% |
| Strategic | Competitiveness | 0,52% |
| Market & Environment | Market | 0,49% |
| Social & Environment Impact | Social | 0,32% |

# APPENDIX B – ICC Evaluation

Table 30 – ICC - R&D groups evaluation

| | **M&E** | **SCP** | **BFT** | **RSC** | **STR** | **RSK** | **TEC** | **S&E** | **Priority Vector** |
|---|---|---|---|---|---|---|---|---|---|
| **M&E** | 1 | 3 | 1/4 | 6 | 2 | 1 | 4 | 2 | **15,35% (3)** |
| **SCP** | 1/3 | 1 | 1/5 | 3 | 1/5 | 1/3 | 2 | 1/4 | **5,16% (6)** |
| **BFT** | 4 | 5 | 1 | 7 | 2 | 1 | 9 | 2 | **26,30% (1)** |
| **RSC** | 1/6 | 1/3 | 1/7 | 1 | 1/5 | 1/9 | 1 | 1/3 | **2,64% (8)** |
| **STR** | 1/2 | 5 | 1/2 | 5 | 1 | 1/5 | 1 | 3 | **12,68% (4)** |
| **RSK** | 1 | 3 | 1 | 9 | 5 | 1 | 7 | 2 | **23,40% (2)** |
| **TEC** | 1/4 | 1/2 | 1/9 | 1 | 1 | 1/7 | 1 | 1/5 | **3,55% (7)** |
| **S&E** | 1/2 | 4 | 1/2 | 3 | 1/3 | 1/2 | 5 | 1 | **10,91% (5)** |

Table 31 – ICC - Market & Environment subgroups evaluation

| | **IEV** | **M** | **EEV** | **Priority Vector** |
|---|---|---|---|---|
| **IEV** | 1 | 1/5 | 1/9 | **6,37% (3)** |
| **MKT** | 5 | 1 | 1/3 | **26,74% (2)** |
| **EEV** | 9 | 3 | 1 | **66,89% (1)** |

Table 32 – ICC - Scope subgroups evaluation

| | **FI** | **TMR** | **FER** | **OGR** | **QLR** | **CUR** | **Priority Vector** |
|---|---|---|---|---|---|---|---|
| **FI** | 1 | 9 | 3 | 4 | 2 | 3 | **37,55% (1)** |
| **TMR** | 1/9 | 1 | 1 | 1/2 | 1/3 | 1/4 | **5,35% (6)** |
| **FER** | 1/3 | 1 | 1 | 1/3 | 1/2 | 1/2 | **7,78% (5)** |
| **OGR** | 1/4 | 2 | 3 | 1 | 1/2 | 1/5 | **10,98% (4)** |
| **QLR** | 1/2 | 3 | 2 | 2 | 1 | 2 | **19,42% (2)** |
| **CUR** | 1/3 | 4 | 2 | 5 | 1/2 | 1 | **18,92% (2)** |

Table 33 – ICC - Benefit subgroups evaluation

| | **FIB** | **NFB** | **Priority Vector** |
|---|---|---|---|
| **FIB** | 1 | 5 | **83,33% (1)** |
| **NFB** | 1/5 | 1 | **16,67% (2)** |

Table 34 – ICC - Resource subgroups evaluation

| | **WRR** | **MTR** | **Priority Vector** |
|---|---|---|---|
| **WRR** | 1 | 1 | **50,00% (1)** |
| **MTR** | 1 | 1 | **50,00% (1)** |

Table 35 – ICC - Strategic subgroups evaluation

| | **COM** | **EXT** | **FIT** | **COI** | **Priority Vector** |
|---|---|---|---|---|---|
| **COM** | 1 | 4 | 3 | 3 | **50,62% (1)** |
| **EXT** | 1/4 | 1 | 2 | 2 | **21,37% (2)** |
| **FIT** | 1/3 | 1/2 | 1 | 2 | **16,53% (3)** |
| **COI** | 1/3 | 1/2 | 1/2 | 1 | **11,48% (4)** |

Table 36 – ICC - Risk subgroups evaluation

| | **GNR** | **TCR** | **CMR** | **SCR** | **Priority Vector** |
|---|---|---|---|---|---|
| **GNR** | 1 | 2 | 2 | 3 | **42,31% (1)** |
| **TCR** | 1/2 | 1 | 1 | 2 | **22,72% (2)** |
| **CMR** | 1/2 | 1 | 1 | 2 | **22,72% (2)** |
| **SCR** | 1/3 | 1/2 | 1/2 | 1 | **12,25% (4)** |

Table 37 – ICC - Technical subgroups evaluation

| | **TCI** | **TIC** | **TAR** | **Priority Vector** |
|---|---|---|---|---|
| **TCI** | 1 | 1/4 | 2 | **21,14% (2)** |
| **TIC** | 4 | 1 | 4 | **65,51% (1)** |
| **TAR** | 1/2 | 1/4 | 1 | **13,35% (3)** |

Table 38 – ICC - Social & Environment Impact subgroups evaluation

| | **SOC** | **ENV** | **HMD** | **Priority Vector** |
|---|---|---|---|---|
| **SOC** | 1 | 1 | 3 | **40,55% (2)** |
| **ENV** | 1 | 1 | 5 | **47,96% (1)** |
| **HMD** | 1/3 | 1/5 | 1 | **11,50% (3)** |

Table 39 – ICC - Overall composite weights

| **Group** | **Subgroup** | **%** |
|---|---|---|
| Benefit | Financial Benefit | 21,92% |
| Market & Environment | External Environment | 10,27% |
| Risk | General Risk | 9,90% |
| Strategic | Competitiveness | 6,42% |
| Risk | Technical Risk | 5,32% |
| Risk | Commercial & Market Risk | 5,32% |
| Social & Environment Impact | Environment | 5,23% |
| Social & Environment Impact | Social | 4,42% |
| Benefit | Non-Financial Benefit | 4,38% |
| Market & Environment | Market | 4,10% |
| Risk | Scope Risk | 2,87% |
| Strategic | Extendibility | 2,71% |
| Technical | Technical Issues & Constraints | 2,33% |
| Strategic | Fitness | 2,10% |
| Scope | Financial Income | 1,94% |
| Strategic | Corporate Image | 1,46% |
| Resource | Work Resources | 1,32% |
| Resource | Material Resources | 1,32% |
| Social & Environment Impact | Human Development | 1,25% |
| Scope | Quality Requirements | 1,00% |
| Market & Environment | Internal Environment | 0,98% |
| Scope | Customer Requirements | 0,98% |
| Technical | Technical Contribution & Innovativeness | 0,75% |
| Scope | Organizational Requirements | 0,57% |
| Technical | Technical Attractiveness & Relevance | 0,47% |
| Scope | Feasibility Requirements | 0,40% |
| Scope | Timing Requirements | 0,28% |

# Bibliography

AFSHARI, A. Selection of construction project manager by using delphi and fuzzy linguistic decision making. **Journal of Intelligent Fuzzy Systems**, v. 28, n. 6, p. 2827–2838, 2015.

AL-HARBY, K. Application of the ahp in project management. **International Journal of Project Management**, v. 19, n. 1, p. 19–27, 1987.

AMARAL, A.; MADALENA, A. Project portfolio management phases: A technique for strategy alignment. **World academy of science, Engeneering and Technology**, v. 3, n. 10, p. 1919–1927, 2009.

ANANDA, J.; HERATH, G. A critical review of multi-criteria decision making methods with special reference to forest management and planning. **Ecological economics**, v. 68, n. 10, p. 2535–2548, 2009.

ANPEI. **Estatísticas**. 2018. Disponível em: <http://anpei.org.br/estatisticas/>.

ANPEI. **Sobre**. 2018. Disponível em: <http://anpei.org.br/sobre/>.

ARCHER, N.; GHASEMZADEH, F. An integrated framework for project portfolio selection. **International Journal of Project Management**, v. 17, n. 4, p. 207–216, 1999.

ARRATIA, M. et al. Static r&d project portfolio selection in public organizations. **Decision Support Systems**, v. 84, p. 53–63, 2016.

ARROYO, P.; TOMMELEIN, I.; BALLARD, G. Comparing ahp and cba as decision methods to resolve the choosing problem in detailed design. **Journal of construction engineering and management**, v. 141, n. 1, 2014.

BANAITIENE, N. et al. Evaluating the life cycle of a building: A multivariant and multiple criteria approach. **Omega**, v. 36, n. 3, p. 429–441, 2008.

BARD, J.; BALACHANDRA, R.; KAUFMANN, P. An interactive approach to r&d project selection and termination. **IEEE Transactions on Engineering Management**, v. 35, n. 3, p. 139–146, 1988.

BEAUJON, G.; MARIN, S.; MCDONALD, G. Balancing and optimizing a portfolio of r&d projects. **Naval Research Logistics**, v. 48, n. 1, p. 18–40, 2001.

BEHZADIAN, M. et al. A state-of the-art survey of topsis applications. **Expert Systems with Applications**, v. 39, n. 17, p. 13051–13069, 2012.

BELL, D.; READ, A. The application of a research project selection method. **R&D Management**, v. 1, n. 1, p. 35–42, 1970.

BELLMAN, R.; ZADEH, L. Decision-making in a fuzzy environment. **Management Sci**, v. 17, n. 4, p. 141–164, 1970.

BELOUT, A.; GAUVREAU, C. Factors influencing project success: the impact of human resource management. **International journal of project management**, v. 22, n. 1, p. 1–11, 2004.

BELTON, S.; STEWART, T. **Multiple Criteria Decision Analysis. An Integrated Approach**. [S.l.]: Kluwer Academic Publishers, 2002.

BHATTACHARYYA, R. A grey theory based multiple attribute approach for r&d project portfolio selection. **Fuzzy Information and Engineering**, v. 7, n. 2, p. 211–225, 2015.

BHATTACHARYYA, R.; KUMAR, P.; KAR, S. Fuzzy r&d portfolio selection of interdependent projects. **Computers and Mathematics with Applications**, v. 62, n. 10, p. 3857–3870, 2011.

BILALIS, N. et al. A fuzzy sets approach to new product portfolio management. **IEEE International Engineering Management Conference**, p. 485–490, 2002.

BITMAN, W.; SHARIF, N. A conceptual framework for ranking r&d projects. **IEEE Transactions on Engineering Management**, v. 55, n. 2, p. 267–278, 2008.

BUYS, A.; STANDER, M. Linking projects to business strategy through project portfolio management. **South African Journal of Industrial Engineering**, v. 21, n. 1, p. 59–68, 2010.

CARLSSON, C. et al. A fuzzy approach to r&d project portfolio selection. **International Journal of Approximate Reasoning**, v. 44, n. 2, p. 93–105, 2007.

CHADEGANI, A. A. et al. A comparison between two main academic literature collections: Web of science and scopus databases. **Asian Social Science**, v. 9, n. 5, p. 18–26, 2013.

CHENG, C.-H.; LIOU, J.; CHIU, C.-Y. A consistent fuzzy preference relations based anp model for r&d project selection. **Sustainability (Switzerland)**, v. 9, n. 8, 2017.

CLELAND, D.; IRELAND, D. **Gerenciamento de Projetos**. Rio de Janeiro: LTC, 2012.

COLLAN, M.; FEDRIZZI, M.; LUUKKA, P. New closeness coefficients for fuzzy similarity based fuzzy topsis: An approach combining fuzzy entropy and multidistance. **Advances in Fuzzy Systems**, v. 2015, 2015.

COLLAN, M.; LUUKKA, P. Evaluating r&d projects as investments by using an overall ranking from four new fuzzy similarity measure-based topsis variants. **IEEE Transactions on Fuzzy Systems**, v. 22, n. 3, p. 505–515, 2014.

CONKA, T.; VAYVAY, .; SENNAROğLU, B. A combined decision model for r&d project portfolio selection. **International Journal of Business Innovation and Research**, v. 2, n. 2, p. 190–202, 2008.

COOPER, R.; EDGETT, S.; KLEINSCHMIDT, E. Portfolio management in new product development: lessons from the leaders i. **Research Technology Management**, v. 40, n. 5, p. 16–28, 1997.

COOPER, R.; EDGETT, S.; KLEINSCHMIDT, E. Portfolio management in new product development: lessons from the leaders ii. **Research Technology Management**, v. 40, n. 6, p. 43–52, 1997.

COOPER, R.; EDGETT, S.; KLEINSCHMIDT, E. New problems, new solutions: making portfolio management more effective. **Research Technology Management**, v. 43, n. 2, p. 18–33, 2000.

CRISTóBAL, J. S. Multi-criteria decision-making in the selection of a renewable energy project in spain: The vikor method. **Renewable energy**, v. 36, n. 2, p. 498–502, 2011.

CROSS, D.; THOMSOM, S.; SINCLAIR, A. **Research in Brazil - A report for CAPES by Clarivate Analytics**. [S.l.]: Clarivate Analytics, 2016.

CZAJKOWSKI, A. F.; JONES, S. Selecting interrelated r&d projects in space technology planning. **IEEE Transactions on Engineering Management**, EM-33, n. 1, p. 17–24, 1986.

DAVIS, L.; WILLIAMS, G. Evaluating and selecting simulation software using the analytic hierarchy process. **Integrated Manufacturing Sys- tems**, v. 5, n. 1, p. 23–32, 1994.

ECKHAUSE, J.; GABRIEL, S.; HUGHES, D. An integer programming approach for evaluating r&d funding decisions with optimal budget allocations. **IEEE Transactions on Engineering Management**, v. 59, n. 4, p. 679–691, 2012.

EILAT, H.; GOLANY, B.; SHTUB, A. R&d project evaluation: An integrated dea and balanced scorecard approach. **Omega**, v. 36, n. 5, p. 895–912, 2008.

ELONEN, S.; ARTTO, K. Problems in managing internal development projects in multi-project environments. **International Journal of Project Management**, v. 21, n. 6, p. 395–402, 2003.

ESHLAGHY, A.; RAZI, F. A hybrid grey-based k-means and genetic algorithm for project selection. **International Journal of Business Information Systems**, v. 18, n. 2, p. 141–159, 2015.

EXAME. **Com avanço de 5 posições, Brasil é 64º país mais inovador do planeta**. 2018. Disponível em: <https://exame.abril.com.br/economia/com-avanco-de-5-posicoes-brasil-e-64o-pais-mais-inovador-do-planeta/>.

FANG, Y.; CHEN, L.; FUKUSHIMA, M. A mixed r&d projects and securities portfolio selection model. **European Journal of Operational Research**, v. 185, n. 2, p. 700–715, 2008.

FRICKE, S.; SHENHAR, A. Managing multiple engineering projects in a manufaturing support environment. **IEEE Transactions on Engineering Management**, v. 47, n. 2, p. 258–268, 2000.

G1. **Brasil sobe 5 posições em ranking mundial de inovação, após 2 anos estagnado**. 2018. Disponível em: <https://g1.globo.com/economia/noticia/brasil-sobe-5-posicoes-em-ranking-mundial-de-inovacao-apos-2-anos-estagnado.ghtml>.

GARZA-REYES, J. Lean and green–a systematic review of the state of the art literature. **Journal of Cleaner Production**, v. 102, p. 18–29, 2015.

GHASEMZADEH, F.; ARCHER, N. Project portfolio selection through decision support. **Decision Support Systems**, v. 29, n. 1, p. 73–88, 2000.

GOMES, L.; GOMES, C. **Tomada de decisão gerencial: enfoque multicritério**. 4. ed. São Paulo: Atlas, 2012.

GOVINDAN, K. et al. Multi criteria decision making approaches for green supplier evaluation and selection: a literature review. **Journal of Cleaner Production**, v. 98, p. 66–83, 2015.

GRAVES, S.; RINGUEST, J. Choosing the best solution in an r&d project selection problem with multiple objectives. **Journal of High Technology Management Research**, v. 3, n. 2, p. 213–224, 1992.

GRAY, C.; LARSON, E. **Project Management**. USA: McGraw-Hill, 2000.

GUSTAFSSON, J.; SALO, A. Contingent portfolio programming for the management of risky projects. **Operations Research**, v. 53, n. 6, p. 946–956, 2005.

HARKER, P.; VARGAS, L. The theory of ratio scale estimation: Saaty's analytic hierarchy process. **Management Science**, v. 33, n. 11, p. 1383–1403, 1987.

HASSANZADEH, F.; COLLAN, M.; MODARRES, M. A Practical Approach to R&D Portfolio Selection Using the Fuzzy Pay-Off Method. **IEEE Transactions on Fuzzy Systems**, 20, n. 4, p. 615–622, 2012.

HASSANZADEH, F.; COLLAN, M.; MODARRES, M. A practical R&D selection model using fuzzy pay-off method. **International Journal of Avances Manufacturing Technology**, 58, n. 1-4, p. 227–236, 2012.

HASSANZADEH, F.; NEMATI, H.; SUN, M. Robust optimization for interactive multiobjective programming with imprecise information applied to r&d project portfolio selection. **European Journal of Operational Research**, v. 238, n. 1, p. 41–53, 2014.

HEIDENBERGER, K. Dynamic project selection and funding under risk: A decision tree based milp approach. **European Journal of Operational Research**, v. 95, n. 2, p. 284–298, 1996.

HENIG, M.; KATZ, H. R&d project selection: A decision process approach. **Journal of Multi-Criteria Decision Analysis**, v. 5, n. 3, p. 169–177, 1996.

HEYDARI, T.; HOSSEINI, S.-M. S.; MAKUI, A. Developing and solving an one-zero non-linear goal programming model to r and d portfolio project selection with interactions between projects. **International Business Management**, v. 10, n. 19, p. 4516–4521, 2016.

HO, W.; XU, X.; DEY, P. Multi-criteria decision making approaches for supplier evaluation and selection: A literature review. **European Journal of operational research**, v. 202, n. 1, p. 16–24, 2010.

HOWMUCH.NET. **Find Out How Much Your Country Spends on Research Development**. 2018. Disponível em: <https://howmuch.net/articles/research-development-spending-by-country>.

HSU, Y.-G.; TZENG, G.-H.; SHYU, J. Fuzzy multiple criteria selection of government-sponsored frontier technology r&d projects. **R and D Management**, v. 33, n. 5, p. 539–551, 2003.

HUANG, C.-C.; CHU, P.-Y.; CHIANG, Y.-H. A fuzzy AHP application in government-sponsored R&D project selection. **Omega**, 36, n. 6, p. 1038–1052, 2008.

HWANG, C.; YOON, K. Multiple-attribute decision making: Methods and applications. **Multiple Attribute Decision Making**, p. 58–191, 1981.

IMOTO, S.; YABUUCHI, Y.; WATADA, J. Fuzzy regression model of r&d project evaluation. **Applied Soft Computing Journal**, v. 8, n. 3, p. 1266–1273, 2008.

JAFARIZADEH, B.; KHORSHID-DOUST, R. R. A method of project selection based on capital asset pricing theories in a framework of mean–semideviation behavior. **International Journal of Project Management**, v. 26, p. 612–619, 2008.

JAHANGIRIAN, M. et al. Simulation in manufacturing and business: A review. **European Journal of Operational Research**, v. 203, n. 1, p. 1–13, 2010.

JENG, D.; HUANG, K.-H. Strategic project portfolio selection for national research institutes. **Journal of Business Research**, v. 68, n. 11, p. 2305–2311, 2015.

JONAS, D. Empowering project portfolio managers: how management involvement impacts project portfolio management performance. **International Journal of Project Management**, v. 28, n. 8, p. 818–831, 2010.

JUNG, U.; SEO, D. An anp approach for r&d project evaluation based on interdependencies between research objectives and evaluation criteria. **Decision Support Systems**, v. 49, n. 3, p. 335–342, 2010.

KAISER, M. G.; ARBI, F. E.; AHLEMANN, F. Successful project portfolio management beyond project selection techniques: Understanding the role of structural alignment. **International Journal of Project Management**, v. 33, n. 1, p. 126–139, 2015.

KARASAKAL, E.; AKER, P. A multicriteria sorting approach based on data envelopment analysis for r&d project selection problem. **Omega (United Kingdom)**, v. 73, p. 79–92, 2017.

KARAVEG, C.; THAWESAENGSKULTHAI, N.; CHANDRACHAI, A. A combined technique using sem and topsis for the commercialization capability of r&d project evaluation. **Decision Science Letters**, v. 4, n. 3, p. 379–396, 2015.

KARSAK, E. A generalized fuzzy optimization framework for R&D project selection using real options valuation. **Computational Science and Its Applications - ICCSA 2006, PT 3**, 3982, p. 918–927, 2006.

KENDALL, G.; ROLLINS, S. **Advanced project portfolio management and the PMO: multiplying ROI at warp speed**. [S.l.]: J. Ross Publishing, 2003.

KHAN, A.; KEUNG, J. Systematic review of success factors and barriers for software process improvement in global software development. **IET Software**, v. 10, n. 5, p. 125–135, 2016.

KUMAR, S. Ahp-based formal system for r&d project evaluation. **Journal of Scientific and Industrial Research**, v. 63, n. 11, p. 888–896, 2004.

LARSON, E.; GRAY, C. **Project management: The managerial process**. 6. ed. [S.l.]: McGraw-Hill Education, 2016.

LIANG, D. et al. Method for three-way decisions using ideal topsis solutions at pythagorean fuzzy information. **Information Sciences**, v. 435, p. 282–295, 2018.

LIBERATORE, M. R&d project selection. **Telematics and Informatics**, v. 3, n. 4, p. 289–300, 1986.

LIBERATORE, M. An expert support system for r&d project selection. **Mathematical and Computer Modelling**, v. 11, n. C, p. 260–265, 1988.

LIBERATORE, M. J. Extension of the analytic hierarchy process for industrial r&d project selection and resource allocation. **IEEE Transactions on Engineering Management**, EM-34, n. 1, p. 12–18, 1987.

LINDE, K.; WILLICH, S. N. How objective are systematic reviews? differences between reviews on complementary medicine. **Journal of the Royal Society of Medicine**, v. 96, n. 1, p. 17–22, 2003.

MACCRIMMON, K. **An overview of multiple objective decision making, in: Cochrane and Zeleny**. [S.l.]: Multiple Criteria Decision Making (University of South Carolina Press), 1973.

MADEY, G. R.; DEAN, B. V. Strategic planning for investment in r&d usiong decision analysis and mathematical programming. **IEEE Transactions on Engineering Management**, EM-32, n. 2, p. 84–90, 1985.

MALCZEWSKI, J. **GIS and Multi-Criteria Decision Analysis**. [S.l.]: John Wiley  Sons, Inc., 1999.

MALHOTRA, R. A systematic review of machine learning techniques for software fault prediction. **Applied Soft Computing**, v. 27, p. 504–518, 2015.

MARCONDES, G. A. B. et al. Using mean-Gini and stochastic dominance to choose project portfolios with parameter uncertainty. **Engineering Economist**, 62, n. 1, p. 33–53, 2017.

MARDANI, A.; JUSOH, A.; ZAVADSKAS, E. Fuzzy multiple criteria decision-making techniques and applications–two decades review from 1994 to 2014. **Expert Systems with Applications**, v. 42, n. 8, p. 4126–4148, 2015.

MARDANI, A. et al. Application of multiple-criteria decision-making techniques and approaches to evaluating of service quality: a systematic review of the literature. **Journal of Business Economics and Management**, v. 16, n. 5, p. 1034–1068, 2015.

MARTINS, S. et al. Gerenciamento de projetos: um caso prático de aplicação de metodologia na academia. **Revista Brasileira da Educação Profissional e Tecnológica**, v. 1, n. 6, p. 61–73, 2013.

MARTINSUO, M. Project portfolio management in practice and in context. **International Journal of Project Management**, v. 31, n. 6, p. 794–803, 2013.

MEADE, L.; PRESLEY, A. R&d project selection using the analytic network process. **IEEE Transactions on Engineering Management**, v. 49, n. 1, p. 59–66, 2002.

MEDAGLIA, A. L.; GRAVES, S. B.; RINGUEST, J. L. A multiobjective evolutionary approach for linearly constrained project selection under uncertainty. **European Journal of Operational Research**, 179, n. 3, p. 869–894, 2007.

MENDOZA, G.; MARTINS, H. Multi-criteria decision analysis in natural resource management: a critical review of methods and new modelling paradigms. **Forest ecology and management**, v. 230, n. 1-3, p. 1–22, 2006.

MIZUNO, S. **Gerência para melhoria da qualidade - As sete novas ferramentas do controle de qualidade**. Rio de Janeiro: Livro Técnico e Científico, 1993.

MOHAGHAR, A. et al. An integrated approach of fuzzy anp and fuzzy topsis for r&d project selection: A case study. **Australian Journal of Basic and Applied Sciences**, v. 6, n. 2, p. 66–75, 2012.

MOHANTY, R. et al. A fuzzy ANP-based approach to R&D project selection: a case study. **International Journal of Prodution Research**, 43, n. 24, p. 5199–5216, 2005.

MONTAJABIHA, M.; KHAMSEH, A. A.; AFSHAR-NADJAFI, B. A robust algorithm for project portfolio selection problem using real options valuation. **International Journal of Managing Projects in Business**, v. 10, n. 2, p. 386–403, 2017.

MUNNS, A.; BJERMI, B. The role of project management in achieving project success. **International journal of project management**, v. 14, n. 2, p. 81–87, 1996.

NEGóCIOS Época. **Ao cortar investimentos em ciência, Brasil assassina o futuro**. 2018. Disponível em: <https://epocanegocios.globo.com/Brasil/noticia/2018/04/ao-cortar-investimentos-em-ciencia-brasil-assassina-o-futuro.html>.

NEUMANN, J. V.; MORGENSTERN, O. **Theory of games and economic behavior**. 2. ed. [S.l.]: Princeton University Press, 1947.

ORAL, M. Action research contextualizes dea in a multi-organizational decision-making process. **Expert Systems with Applications**, v. 39, n. 7, p. 6503–6513, 2012.

ORAL, M.; KETTANI, O.; LANG, P. A Methodology for Collective Evaluation and Selection of Industrial Research and Development projects. **Management Science**, 37, n. 7, p. 871–885, 1991.

PILLAI, A.; JOSHI, A.; RAO, K. Performance measurement of r&d projects in a multi-project, concurrent engineering environment. **International Journal of Project Management**, v. 20, n. 2, p. 165–177, 2002.

PINTO, J.; PRESCOTT, J. Variations in critical success factors over the stages in the project life cycle. **Journal of Management**, v. 14, n. 1, p. 5–18, 1988.

PMI. **A Guide to the Project Management Body of Knowledge (PMBOK Guide)**. 6. ed. Pennsylvania: Project Management Institute, Inc., 2017.

POHEKAR, S.; RAMACHANDRAN, M. Application of multi-criteria decision making to sustainable energy planning—a review. **Renewable and sustainable energy reviews**, v. 8, n. 4, p. 365–381, 2004.

RABBANI, M. et al. A comprehensive model for r and d project portfolio selection with zero-one linear goal-programming. **International Journal of Engineering, Transactions A: Basics**, v. 19, n. 1, p. 55–66, 2006.

RIBEIRO, R. Fuzzy multiple attribute decision making: a review and new preference elicitation techniques. **Fuzzy sets and systems**, v. 78, n. 2, p. 155–181, 1996.

RINGUEST, J.; GRAVES, S. The linear multi-objective r&d project selection problem. **IEEE Transactions on Engineering Management**, v. 36, n. 1, p. 54–57, 1989.

RINGUEST, J.; GRAVES, S. The linear r&d project selection problem: An alternative to net present value. **IEEE Transactions on Engineering Management**, v. 37, n. 2, p. 143–146, 1990.

RINGUEST, J.; GRAVES, S. Formulating r&d portfolios that account for risk. **Research Technology Management**, v. 42, n. 6, p. 40–43, 1999.

RINGUEST, J.; GRAVES, S. Formulating optimal r&d portfolios. **Research Technology Management**, v. 48, n. 6, p. 42–47, 2005.

RINGUEST, J.; GRAVES, S.; CASE, R. Mean-gini analysis in r&d portfolio selection. **European Journal of Operational Research**, v. 154, n. 1, p. 157–169, 2004.

SAATY, T. **The Analytic Hierarchy Process**. New York: McGraw Hill, 1980.

SAATY, T. Decision making with the analytic hierarchy process. **International journal of services sciences**, v. 1, n. 1, p. 83–98, 2008.

SAMPAIO, R.; MANCINI, M. Estudos de revisão sistemática: um guia para síntese criteriosa da evidência científica. **Revista Brasileira de Fisioterapia**, v. 11, n. 1, p. 83–89, 2007.

SAVAGE, L. **The foundations of statistics**. 2. ed. [S.l.]: Wiley, 1954.

SHIN, C.-O.; YOO, S.-H.; KWAK, S.-J. Applying the analytic hierarchy process to evaluation of the national nuclear r&d projects: The case of korea. **Progress in Nuclear Energy**, v. 49, n. 5, p. 375–384, 2007.

SINGH, R. Prioritizing the factors for coordinated supply chain using analytic hierarchy process (ahp). **Measuring Business Excellence**, v. 17, n. 1, p. 80–97, 2013.

STARR, M.; ZELENY, M. **MCDM - state and future of the arts**. [S.l.]: TIMS Stud. Management Sci., 1977.

STEWART, T. A multi-criteria decision support system for r&d project selection. **Journal of the Operational Research Society**, v. 42, n. 1, p. 17–26, 1991.

STEWART, T. A critical survey on the status of multiple criteria decision making theory and practice. **Omega**, v. 20, n. 5-6, p. 569–586, 1992.

STEWART, T. Multiple objective project portfolio selection based on reference points. **Journal of Business Economics**, v. 86, n. 1-2, p. 23–33, 2016.

STUMMER, C.; HEIDENBERGER, K. Interactive r&d portfolio analysis with project interdependencies and time profiles of multiple objectives. **IEEE Transactions on Engineering Management**, v. 50, n. 2, p. 175–183, 2003.

SUN, H.; MA, T. A packing-multiple-boxes model for r&d project selection and scheduling. **Technovation**, v. 25, n. 11, p. 1355–1361, 2005.

TAYLOR, B.; MOORE, L.; CLAYTON, E. R and D Project Selection and Manpower Allocation with Integer Non-Linear Goal Programming. **Management Science**, 28, n. 10, p. 1149–1158, 1982.

THORE, A. **Technology Commercialization: DEA and Related Analytical Methods for Evaluating the Use and Implementation of Technical Innovation**. [S.l.]: Kluwer Academic Publishers, 2002.

TOLGA, A.; KAHRAMAN, C. Fuzzy multiattribute evaluation of r&d projects using a real options valuation model. **International Journal of Intelligent Systems**, v. 23, n. 11, p. 1153–1176, 2008.

TRANFIELD, D.; DENYER, D.; SMART, P. Towards a methodology for developing evidence-informed management knowledge by means of systematic review. **British journal of management**, v. 14, n. 3, p. 207–222, 2003.

TRIANTAPHYLLOU, E. **Multi-criteria decision making methods: a comparative study**. [S.l.]: Dordrecht: Springer, 2010.

TROTT, P. **Innovation Management and New Product Development**. England: Pearson Education Limited, 1998.

TURBAN, E. **Decision Support and Expert Systems**. New York: Wiley, 1988.

TURRIONI, J. B.; MELLO, C. H. P. **Metodologia de pesquisa em engenharia de produção**. Itajubá: UNIFEI: Programa de Pós-Graduação em Engenharia de Produção da Universidade Federal de Itajubá., 2012.

UIS. **How much your country invest in R&D?** 2018. Disponível em: <http://uis.unesco.org/apps/visualisations/research-and-development-spending/>.

WANG, J.; HWANG, W.-L. A fuzzy set approach for r&d portfolio selection using a real options valuation model. **Omega**, v. 35, n. 3, p. 247–257, 2007.

WANG, J.; XU, Y.; LI, Z. Research on project selection system of pre-evaluation of engineering design project bidding. **International Journal of Project Management**, v. 27, n. 6, p. 584–599, 2009.

WANG, J.-J. et al. Review on multi-criteria decision analysis aid in sustainable energy decision-making. **Renewable and Sustainable Energy Reviews**, v. 13, n. 9, p. 2263–2278, 2009.

WANG, K.; WANG, C.; HU, C. Analytic hierarchy process with fuzzy scoring in evaluating multidisciplinary r&d projects in china. **IEEE Transactions on Engineering Management**, v. 52, n. 1, p. 119–129, 2005.

WIT, A. D. Measurement of project success. **International journal of project management**, v. 6, n. 3, p. 164–170, 1988.

WU, J. et al. Bargaining game model in the evaluation of decision making units. **Expert Systems with Applications**, v. 36, n. 3 PART 1, p. 4357–4362, 2009.

YEH, C.-H. The selection of multiattribute decision making methods for scholarship student selection. **International Journal of Selection and Assessment**, v. 11, n. 4, p. 289–296, 2003.

ZAVADSKAS, E.; TURSKIS, Z.; KILDIENE, S. State of art surveys of overviews on mcdm/madm methods. **Technological and economic development of economy**, v. 20, n. 1, p. 165–179, 2014.

ZELENY, M. **Multiple Criteria Decision Making**. [S.l.]: McGraw-Hill, 1982.

ZOPOUNIDIS, C.; DOUMPOS, M. Multicriteria classification and sorting methods: a literature review, european journal of operational research. **Journal of Business Economics and Management**, v. 138, n. 2, p. 229–246, 2002.