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Measuring the Performance of University-Industry R&D Collaborations: An Empirical Research

Master's Degree Dissertation

Master's Degree in Engineering Project Management

Dissertation developed under the orientation of:

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Abstract

Cooperation in Research & Development is, nowadays, a topic on the agenda of policy makers and a means to stimulate innovation, with diverse funding being used to promote cooperation between companies and between companies and public institutions. A clear example of one of these public institutions is university, which is stated to have joined a system that is also composed by industry and government.

The collaborations between university and industry are, possibly, the most important strategic instrument used to increase the efficiency and effectiveness of industrial investments in Research & Development. Given this, the collaborations in Research & Development between university and industry have been increasing, which assigns even more importance to the need for measuring the performance of these collaborations.

Considering this need, the present dissertation focused on developing the initial version of an existing method, which uses a weighted scoring approach, to measure the performance of the collaborations in Research & Development between university and industry. For this purpose, it was used the Design Science Research methodology, through which it occurred the development and creation of the method as an artifact.

The developed method is composed by thirty-one performance indicators and was applied in the Innovative Car HMI program, which results from a partnership between the University of Minho and Bosch Car Multimedia Portugal. The performance measurement of this program, at the time of the method's application, resulted in a score of 4,4 (scale 1–5).

Additionally, a questionnaire to evaluate the developed method was administered to different university members with experience in collaborations in Research & Development between university and industry. From the thirty-one performance indicators that compose the method, twenty-nine were evaluated as having a level of relevance above 3 (scale 1–5) and, from these, nineteen were evaluated as having a high level of relevance (equal to or above 4).

Keywords

Performance Measurement; University-Industry Collaborations; Research & Development; Weighted Scoring Approach; Program Management.

Resumo

A cooperação em Investigação e Desenvolvimento é, hoje em dia, um tópico na agenda dos decisores políticos e um meio de estimular a inovação, sendo que diversos financiamentos são empregues a promover a cooperação entre empresas e entre empresas e instituições públicas. Um claro exemplo de uma destas instituições públicas é a universidade, sobre a qual se diz que se tem juntado a um sistema que é também formado pela indústria e pelo governo.

As colaborações entre universidade e indústria são, possivelmente, o instrumento estratégico mais importante para aumentar a eficácia e eficiência dos investimentos industriais em Investigação e Desenvolvimento. Dado isto, as colaborações em Investigação e Desenvolvimento entre universidade e indústria têm vindo a aumentar, o que atribui ainda maior importância à necessidade de medir o desempenho destas colaborações.

Considerando esta necessidade, a presente dissertação focou-se em desenvolver a versão inicial de um método já existente, que usa uma abordagem de pontuação ponderada, para medir o desempenho das colaborações em Investigação e Desenvolvimento entre universidade e indústria. Para tal, foi usada a metodologia *Design Science Research*, por meio da qual ocorreu a criação e avaliação do método enquanto um artefacto.

O método desenvolvido é composto por trinta e um indicadores de desempenho e foi aplicado no programa Innovative Car HMI, que resulta de uma parceria entre a Universidade do Minho e a Bosch Car Multimedia Portugal. A medição do desempenho deste programa, à data da aplicação do método, teve um resultado de 4,4 (escala 1–5).

Adicionalmente, um questionário para avaliar o método desenvolvido foi realizado a diferentes membros da universidade com experiência em colaborações em Investigação e Desenvolvimento entre universidade e indústria. Dos trinta e um indicadores de desempenho, vinte e nove foram avaliados como tendo um nível de relevância acima de 3 (escala 1–5) e, destes, dezanove foram avaliados com um nível de relevância alto (igual ou superior a 4).

Palavras-Chave

Medição de Desempenho; Colaborações Universidade-Indústria; Investigação e Desenvolvimento; Abordagem de Pontuação Ponderada; Gestão de Programas.

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List of Abbreviations and Acronyms

Bosch	Bosch Car Multimedia Portugal
DSRM	Design Science Research Methodology
HMIExcel	Human Machine Interface Excellence
IC-HMI	Innovative Car HMI
MPUIC	Measuring the Performance of University-Industry R&D Collaborations
PgPMO	Program and Project Management Office
PMBOK	Project Management Body of Knowledge
R&D	Research and Development
UMinho	University of Minho

1. INTRODUCTION

The present research is conducted as a dissertation of the Master's Degree in Engineering Project Management, from University of Minho, and the current Chapter has introductory purposes. Thus, this Chapter contemplates the motivation and background behind the development of the dissertation (Section 1.1), defines the objectives of the research (Section 1.2), provides an overview of the research methodology (Section 1.3) and, lastly, sketches the structure of the dissertation (Section 1.4).

1.1 Motivation and Background

University and industry have a long history between them, which started several decades ago in the past. As a matter of fact, the value of university-industry collaborations was already recognized in the late nineteenth century, a time where there were already relationships established between universities and great chemical companies, such as Bayer, the German pharmaceutical firm (Bower, 1993). Also, during World War I, the National Research Council of the United States reunited university scientists with industry scientists in order to support the war effort (Rast, Khabiri, & Senin, 2012).

More recently, during the 1970s, policy makers in the United States advocated that the long delay between the finding of new knowledge at universities and its use by industry was having a serious negative effect in the global competitiveness of American firms (Marshall, 1985; Siegel, Waldman, Atwater, & Link, 2003). Acknowledging this delay, the United States Congress, in 1980, attempted to remove possible barriers to technology transfer from university to industry through the enactment of the Bayh-Dole Act[1] (Siegel, Waldman, Atwater, et al., 2003).

Likewise, a number of countries of Europe (Grimaldi, Kenney, Siegel, & Wright, 2011; Wright, Clarysse, Lockett, & Knockaert, 2008) and Asia (Grimaldi et al., 2011; Kodama, 2008) adopted similar legislation. As a result of the development experienced in the United States from the early 1990s, structural changes in the external environment were introduced in Europe with

[1] The Bayh-Dole Act is a United States legislation that introduced a homogeneous patent policy and allowed universities to have ownership of the patents emerging from research funded by federal government.

the objective of promoting a more active function for universities in technology transfer (Grimaldi et al., 2011).

In spite of their long history, university-industry interactions are still a contemporary subject of discussion. Currently, the majority of European countries have been concerned by legislative changes that, even when not aligned with the Bayh-Dole Act and not allowing universities to have the legal ownership of patents, also aim to stimulate the commercialization of results deriving out of public research. These changes in legislation affect factors related to the process through which universities transfer knowledge and technology (Grimaldi et al., 2011).

Accordingly, a major topic concerning policy makers nowadays is the cooperation in Research and Development (R&D) as a means to stimulate innovation. Most European Union and national public funding for R&D is applied at stimulating cooperation between firms and between firms and public institutions, in order to promote economic growth and improve the performance of the national system of innovation (López, 2008). Thus, organizations are progressively engaging with external sources of innovation, in addition to their internal R&D (Chesbrough, 2006b; Perkmann & Walsh, 2007), and universities are one of those external sources. Apart from the mission of teaching and researching, universities are also claimed to include the mission of economic and social development (Pablo D'Este & Perkmann, 2011; Etzkowitz, 1998). Considering this new mission, universities are stated to join a coherent system, that also incorporates industry and government, and is the basis of innovation and economic progress (Pablo D'Este & Perkmann, 2011; Etzkowitz & Leydesdorff, 2000).

Given the fact that industrial investments in R&D are one of the most important drivers of economic growth and development, the collaborations between university and industry are an important strategic instrument – possibly, the most important – to increase the efficiency and effectiveness of these investments (Cunningham & Link, 2014). The joint research endeavors between university and industry can assume a format of single university-industry collaboration, as it is being mentioned hitherto, but also strategic alliances and joint ventures (Brocke & Lippe, 2015; Hagedoorn, Link, & Vonortas, 2000), and inter and intra-collaboration on several levels (Brocke & Lippe, 2015; Katz & Martin, 1997).

The context of this dissertation adopts the definition in which university-industry collaborations are "trusting, committed and interactive relationships between university and industry entities, enabling the diffusion of creativity, ideas, skills and people with the aim of creating mutual value over time" (Plewa & Quester, 2007, p. 371). This definition is complemented with the definition of collaborative research projects, which, according to Brock and Lippe (2015), are "a temporary organization that exist for the purpose of building and evaluating novel results under a pre-defined research objective and with constraints on resources, costs, and time" (p. 1024). Within collaborative research projects, the financing, planning, and execution are performed by a consortium of academic, public, and industry entities. The work within these collaborative research projects is carried out in a collaborative scenario characterized by its heterogeneous partners, a specific application context, the collective responsibilities, and, frequently, a support through public funding (Brocke & Lippe, 2015).

Furthermore, the R&D collaborations between universities and industries have been increasing (Perkmann, Neely, & Walsh, 2011), which is assigning even more importance to the need for monitoring and assessing the outcomes of these collaborations (Grimaldi & von Tunzelmann, 2002). Acknowledging this need, an important challenge is to evaluate university-industry R&D collaborations. However, few attempts have been yet made in this regard, despite being a subject of interest to the entities involved and to policy makers (Iqbal, Khan, Iqbal, & Senin, 2011).

While monitoring and assessing university-industry R&D collaborations, it is important to define the difference that exists between success and performance. On the one hand, the success of a project can only be measured after the project is completed, while, on the other hand, the performance of a project can be measured throughout the life cycle of the project. Accordingly, a system of project metrics is only complete with both measures of success and performance, and a way to link both these measures is to assess the precision with which performance is able to predict the future success (Cooke-Davies, 2002). Given this difference, measuring the success of university-industry R&D collaborations requires the assessment of the program/project after its conclusion, allowing to match the provided benefits with the expected ones (Grimaldi & von Tunzelmann, 2002), while measuring the performance of university-industry R&D collaborations requires the assessment of the ongoing program/project, in order to enable adjustments and improvements (Perkmann, Neely, et al., 2011).

A successful project management is confronted by many challenges when facing projects within research collaborations. This is due to specific factors of these projects, such as high uncertainty and risks, heterogeneous partners, or substantial pressure concerning creativity and innovativeness (Barnes, Pashby, & Gibbons, 2006; Brocke & Lippe, 2015). For this reason, individual project management attention to the projects' needs and particularities is essential so that these collaborative research projects can reach success (Brocke & Lippe, 2015; Lenfle, 2008; Shore & Cross, 2005). Thus, the management of research collaborations would benefit from an answer to the existing need for measuring the outcomes of university-industry R&D collaborations (Grimaldi & von Tunzelmann, 2002), namely from a tool capable of measuring the performance of university-industry collaborations when they are still occurring and the success after their conclusion.

Accordingly, an effort to measure the performance of university-industry R&D collaborations has been employed by the supervisors of this dissertation and a respective tool was developed. More specifically, in a previous research, Fernandes et al. (2017) proposed a method that intends to measure the performance and the success of research collaborations throughout the program/project life cycle, particularly, the performance and success of university-industry R&D collaborations. In order to do so, a series of retrospective (lagging) and prospective (leading) performance indicators were combined. The measurement method was achieved after the authors conducted a detailed review of current research in the area through published literature. As a result, the work of Perkmann, Neely and Walsh (2011) was used as the main theoretical foundation of the method, due to the similarity of objectives and robustness, and the work of Seppo and Lilles (2012) was used as the main source of performance indicators.

Nevertheless, the research of Fernandes et al. (2017) focuses solely on the development of the stated method and presents only preliminary results, which implies a need of a further development and an application in a case study of a university-industry R&D collaboration (Fernandes et al., 2017). Thus, considering the increasingly number of R&D collaborations between university and industry, and the importance of measuring their performance, this dissertation focus on developing this stated method for measuring the performance of university-industry R&D collaborations, henceforth denominated as the MPUIC method. This method has a weighted scoring approach as its theoretical foundation and is going to applied in a university-industry R&D collaboration, namely in the IC-HMI program, which is the second phase of a strategic partnership established for collaborative R&D, back in 2012, between University of Minho and Bosch Car Multimedia Portugal.

All things considered, the central **research question** that guides this dissertation is articulated as follows: *how to measure the performance of university-industry R&D collaborations?*

1.2 Research Objectives

The research question identified in the previous Section of the present Chapter drives the development of this dissertation. However, in order to reach an answer to that question, it is first necessary to clearly define the research objectives.

Therefore, the **main objective** of this dissertation is to develop the MPUIC method as a tool capable of measuring the performance of university-industry R&D collaborations. With the purpose of achieving this main objective, a series of **specific research objectives** are proposed as follows:

- **Research Objective 1**: Identify the difficulties in applying the initial version of the method for measuring the performance of university-industry R&D collaborations (MPUIC method);
- **Research Objective 2**: Improve the method for measuring the performance of university-industry R&D collaborations (MPUIC method);
- **Research Objective 3**: Demonstrate the application of the method for measuring the performance of university-industry R&D collaborations (MPUIC method) in a university-industry R&D collaboration;
- **Research Objective 4**: Evaluate the developed method for measuring the performance of university-industry R&D collaborations (MPUIC method) as an effective solution.

Moreover, the research objectives are set to be achieved in a sequential form.

First, the difficulties in applying the initial version of the MPUIC method are identified (Research Objective 1) in Section 4.2. Then, in Section 4.3, the MPUIC method is proposed as an improvement of its initial version that intends to overcome the initial difficulties before proceeding to an actual application (Research Objective 2). Afterwards, the application of the

MPUIC method as a proposed improvement is demonstrated in a case study of a university-industry R&D collaboration (Research Objective 3), in Chapter 5. Last but not least, in Chapter 6, the MPUIC method is evaluated as an effective solution to measure the performance of university-industry R&D collaborations (Research Objective 4).

The accomplishment of these research objectives is directly linked with the results expected from the research in this dissertation. More specifically, it is projected that the developed MPUIC method can be a tool with a simple form of application and able to be applied in similar university-industry R&D collaborations, considering the adjustments that each specific context would require.

1.3 Research Methodology Overview

Overall, the research design to be used throughout this dissertation as a means to achieve its research objectives is represented by the Design Science Research Methodology. This methodology is constituted by six sequential activities and can result in an iteration of the activities. Table 1 provides an overview of the research methodology, namely the activities of the research design, the research strategy, and the techniques and procedures used in data collection and data analysis. As a way to solve recognized problems in organizations, this research methodology presupposes the creation and evaluation of artifacts. In order to create and evaluate the resulting artifact of this dissertation – the MPUIC method –, it is necessary to collect and analyze data. A complete description of this research methodology is provided in Chapter 3.

In this manner, the case study is the research strategy chosen for this dissertation and is underpinning the activity of Demonstration of the MPUIC method. As stated by Saunders, Lewis, and Thornhill (2009), “case study strategy can be a very worthwhile way of exploring existing theory” (p. 147). More specifically, the case study chosen is the IC-HMI program, which results from a strategic partnership established between University of Minho and Bosch Car Multimedia Portugal.

Moreover, the research techniques that are going to be used in order to collect data are document analysis in the Demonstration activity and questionnaire, both in the Demonstration and Evaluation activities. In order to analyze these collected data, the software Microsoft Excel and IBM SPSS Statistics are set to be used.

Table 1 – Overview of the research methodology used in the dissertation

Activity of the Design Science Research Methodology	Research Strategy	Techniques and Procedures	
		Data Collection	Data Analysis
1. Problem Identification and Motivation	–	–	–
2. Definition of the Objectives for a Solution	–	–	–
3. Design and Development	–	–	–
4. Demonstration	Case Study	Document Analysis Questionnaire	Microsoft Excel IBM SPSS Statistics
5. Evaluation	–	Questionnaire	Microsoft Excel
6. Communication	–	–	–

1.4 Structure of the Dissertation

This dissertation is organized into seven chapters. The first and current Chapter presents the theme of the research and the motivation and background that lead to the development of this dissertation (Section 1.1). Moreover, considered as essential aspects of any research, this Chapter also presents the research objectives (Section 1.2) and the research methodology (Section 1.3).

The second Chapter, titled as "Literature Review", is devoted to the literature review and raises the state of the art of the subjects associated to measuring the performance of university-industry R&D collaborations. Therefore, following a brief introduction to the respective Chapter in Section 2.1, the subject of project and program management is presented in Section 2.2. Then, the topics of innovation and R&D are addressed in Section 2.3 and the collaboration between university and industry is addressed in Section 2.4. Moreover, Section 2.5 reviews the subject of performance measurement and Section 2.6 reviews the subject of project and program success. Lastly, Section 2.7 examines the topic of measuring the performance of university-industry collaborations.

The third Chapter, titled as “Research Methodology”, outlines the research methodology used in the dissertation, namely the research design (Section 3.1), the data collection (Section 3.2), and the data analysis (Section 3.3).

The fourth Chapter, titled as “Design and Development of the MPUC Method”, presents the design and development of the MPUIC method. More specifically, the initial version of the method is presented in Section 4.1 and the difficulties in applying that initial version are presented in Section 4.2. Finally, in Section 4.3, the MPUIC method is proposed as an improvement of its initial version that aims to overcome the previous difficulties.

The fifth Chapter, titled as “Results: Demonstration of the MPUIC Method’s Application”, demonstrates the application of the MPUIC method in a case study of a university-industry R&D collaboration, namely in the IC-HMI program.

The sixth Chapter, titled as “Discussion: Evaluation of the MPUIC Method”, evaluates the developed MPUIC method as an effective solution to measure the performance of university-industry R&D collaborations.

Finally, the seventh Chapter, titled as “Conclusions”, provides the main conclusions of this dissertation, as well as its limitations. Additionally, areas of future work are identified.

2. LITERATURE REVIEW

2.1 Introduction

As previously stated, this dissertation focuses on measuring the performance of university-industry R&D collaborations and, to perceive the importance of this subject, one should understand its fundamentals. Thus, the current Chapter raises the state of the art that is the theoretical foundation sustaining this dissertation.

Therefore, project and program management are the topics reviewed in Section 2.2, while innovation and R&D are reviewed in Section 2.3. Moreover, Section 2.4 addresses the university-industry collaboration and its different aspects. Then, performance measurement is the topic regarded in Section 2.5, while, in Section 2.6, the topic of project and program success is addressed. Lastly, the performance measurement of university-industry collaborations is reviewed in Section 2.7.

2.2 Project and Program Management

There are several definitions to describe the concept of project. For instance, according to the Project Management Body of Knowledge (PMBOK), a project is defined as "a temporary endeavor undertaken to create a unique product, service, or result" (Project Management Institute, 2017a, p. 4). The Individual Competence Baseline, a standard for competences, defines a project as an endeavor to accomplish defined deliverables in accordance with specific requirements, such as constraints of time, cost, or resources (IPMA, 2015). For the PRINCE2 method, a project is a temporary organization with the objective of delivering one or more business products (AXELOS, 2017). Considering these definitions of project, it is possible to conclude that a project is perceived as an endeavor limited in time, subject to certain requirements, with the purpose of delivering a unique outcome.

Accordingly, the project life cycle consists in the series of phases that a project goes through, from start to finish. Even if projects vary in size and complexity, a typical project can be represented, as illustrated in Figure 1, in a life cycle with the following generic phases (Project Management Institute, 2017a):

1. Starting the Project;

2. Organizing and Preparing;
3. Carrying Out the Work;
4. Ending the Project.

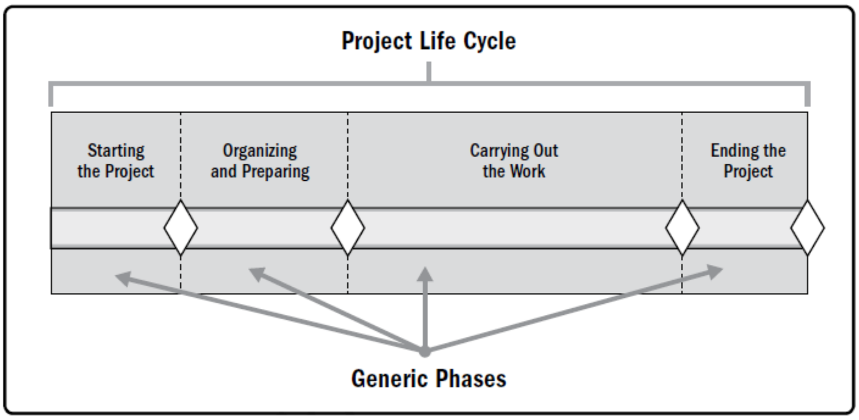

Figure 1 – Generic representation of a project life cycle

Retrieved from Project Management Institute (2017a).

This generic project life cycle usually demonstrates certain characteristics. The levels of cost and staffing, for instance, are low in the start of the project, increase as the work is performed, and drop quickly as the project comes to an end. In terms of risk, this factor is highest at the start of the project and decreases throughout the life cycle as decisions and deliverables are attained, as Figure 2 illustrates. The influence of stakeholders in the final characteristics of the project's outcome, without seriously impacting cost and schedule, is also highest at the start and decreases as project advances toward completion (Project Management Institute, 2017a).

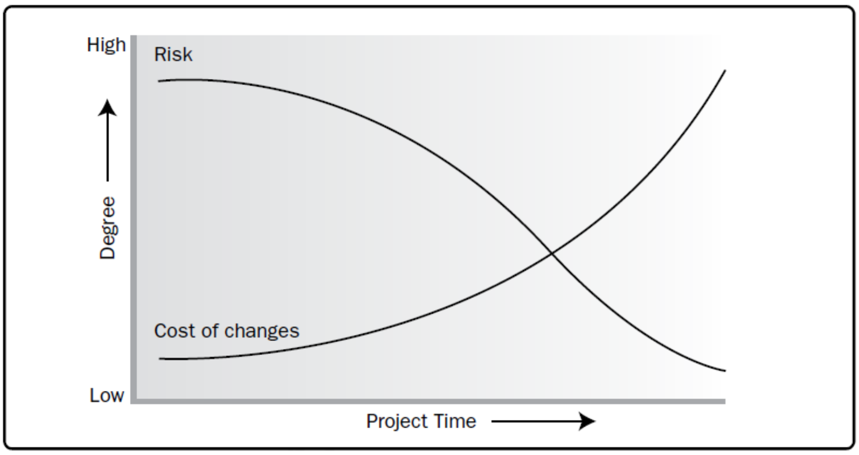

Figure 2 – Impact of risk and cost of changes over project time

Retrieved from Project Management Institute (2017a).

Acknowledging the concepts of project and project life cycle, it is now appropriate to approach project management. Initially, project management definitions emphasized the variables of time, cost, and scope – also referred to as the "iron triangle" (Atkinson, 1999). However, recent definitions highlight other elements, such as working with stakeholders, and their importance (Jugdev & Müller, 2005). In these definitions, project management is described as encompassing cultural, structural, practical, and interpersonal aspects (Cleland & Ireland, 2002). Project management is now used by companies as a way to create business value and gain competitive advantage (Jugdev & Müller, 2005) and, according to the PMBOK, can be defined as the application of knowledge, skills, tools, and techniques to project activities, in order to achieve the project requirements (Project Management Institute, 2017a).

In the same way as projects, programs are a form of reaching the objectives of an organization (Patanakul & Pinto, 2017). A program is defined as a temporary organization coordinately managed to achieve a strategic goal and can be composed by sub-programs, projects, activities and processes, or teams and departments (IPMA, 2015). The benefits a program can obtain are only available due to the coordinated management, rather than the individual one (Project Management Institute, 2017b). Moreover, programs are frequently considered as a decisive means for establishing organizational change, developing new products, processes, and services. Moreover, programs enable firms to maintain a technological or innovative advantage in the marketplace (Patanakul & Pinto, 2017).

As well as a project, a program is also characterized by a particular life cycle. According to The Standard for Program Management (Project Management Institute, 2017b), all programs, regardless their duration, are implemented using a life cycle with three major phases, namely:

- Program Definition;
- Program Delivery;
- Program Closure.

A typical program passes through an initiation endeavor, a development endeavor, and an end (Patanakul & Pinto, 2017). Projects within a program can start any time after the start of the program. The start of a program, in turn, can be marked by a funding approval or by the assignment of the program manager (Project Management Institute, 2017b).

This dissertation adopts the concept of program life cycle defined in the research of Fernandes et al. (2015) as part of a new program and project management approach dedicated to support university-industry R&D collaborations. In such approach, the program life cycle is divided into four phases as follows (Fernandes et al., 2015):

1. Program Preparation, in which the main objectives are the alignment of a common strategy to both entities, the identification of the program scope and the search for the necessary resources to support new R&D projects;
2. Program Initiation, which intends to ensure the initial planning of the program and the alignment of the program objectives and outcomes with the stakeholders. It also aims to create a program management office, or identical, to support the program governance;
3. Program Benefits Delivery, an iterative phase throughout which the projects that constitute the program are planned, integrated and managed, in order to ease the delivery of the expected program benefits;
4. Program Closure, the ending phase which intends to execute a controlled closure of the program and has importance in evaluating the sustainability of the collaboration.

Figure 3 illustrates the phases of the program life cycle and relates them with the project life cycle.

Program management is strategic by nature (Patanakul & Pinto, 2017) and it connects the execution and the strategy, given that program management combines deliverables and work flows of several projects in order to develop and deliver an integrated outcome which can be a product, a service, or a capability (Milošević, Martinelli, & Waddell, 2007). Overall, program management consists in the application of knowledge, skills, and principles to a program to meet the program objectives, as well as to obtain benefits and control otherwise unavailable, if the program components were managed individually. To do so, the program components are aligned by the program management (Project Management Institute, 2017a).

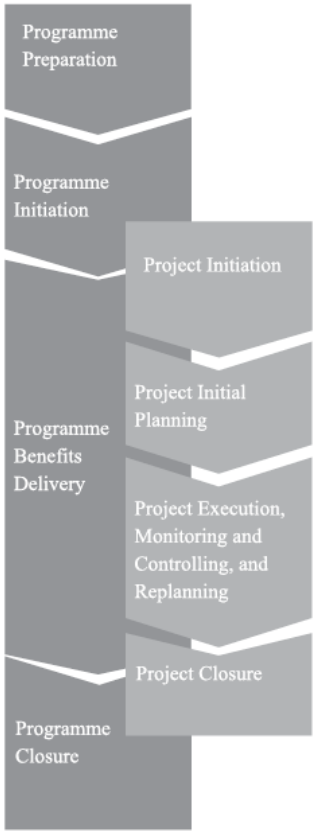

Figure 3 – Program and project life cycles
Retrieved from Fernandes et al. (2018)

2.3 Innovation through Research & Development Projects

Collaborative R&D projects are one of the main policy actions used to promote innovation (Grimaldi & von Tunzelmann, 2002). However, innovation is beyond being a new idea or a new invention. Correspondingly, the Oslo Manual provides a general definition of innovation, according to which "an innovation is a new or improved product or process (or combination thereof) that differs significantly from the unit's previous products or processes and that has been made available to potential users (product) or brought into use by the unit (process)" (OECD/Eurostat, 2018, p. 32). Innovation entails implementation, which can be by using the innovation or by making it accessible for use by firms, individuals, or organizations. As a dynamic and universal activity, innovation occurs over all sectors of an economy and is not limited to the sector of business enterprise (OECD/Eurostat, 2018).

Nowadays, in many industries, the logic of a closed innovation that supports an internal and central approach to R&D has turned obsolete. Rather, the logic now prevailing in these industries is one of open innovation that combines external ideas and knowledge with internal

R&D (Chesbrough, 2003). The firms' pursuit for innovation is stimulating them to collaborate with universities (Pablo D'Este & Perkmann, 2011; Perkmann, King, & Pavelin, 2011; Perkmann & Walsh, 2007; Seppo & Lilles, 2012), which constitutes a strong example of the aforementioned variation in the logic supporting innovation. For this reason, one should understand the concepts related with the innovation process, which are discussed in this Section.

In the past, during the most of the 20th century, companies that invested more in internal R&D were the most successful ones. Due to the large investments, those companies discovered the best ideas and in greater number, thereby reaching to the market first than their competitors and earning most of the profits. These profits were reinvested in more internal R&D which, in turn, led to more discoveries. A virtuous cycle of innovation was, therefore, tacitly held (Chesbrough, 2003). Throughout this period, a closed innovation model, as the one illustrated in Figure 4Figure *4*, prevailed. A self-reliance philosophy controlled the R&D operations of many important industrial corporations and companies had to be responsible for the generation, development, and commercialization of their ideas, in order for them to reach successful innovation (Chesbrough, 2003).

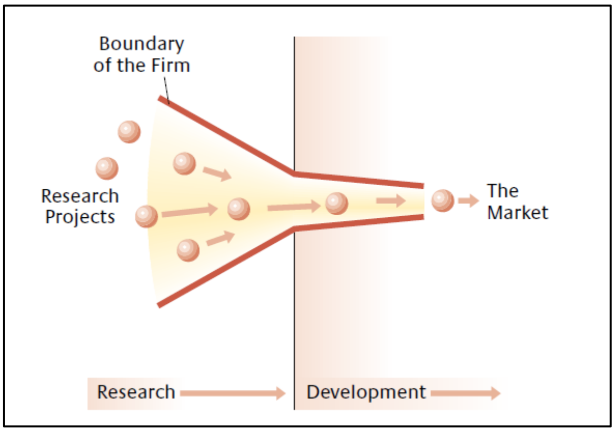

Figure 4 – The closed innovation model

Retrieved from Chesbrough (2003).

However, at the end of the 20th century, the virtuous cycle underpinning closed innovation was interrupted. As stated by Chesbrough (2003), two of the main factors causing such interruption were:

- The substantial increase of knowledge workers in number and in mobility, which made it difficult for companies to control their ideas and expertise;

- The increasingly availability of private venture capital, which helped new firms to commercialize ideas.

At this time, if companies did not address their discoveries timely, the scientists and engineers involved could do it on their own, in a startup created with private venture capital. Then, the startup could obtain further financing in case of success, or it could be bought at an interesting price. In either way, the successful startup would generally seek the commercialization of another technology, instead of reinvesting in new discoveries. Overall, the company that originally made the discovery would not profit from its investment, and the startup that collected the benefits would not reinvest to obtain new discoveries. In this manner, the virtuous cycle of closed innovation was, therefore, interrupted (Chesbrough, 2003).

Accordingly, a new model of open innovation is now held and companies commercialize both external and internal ideas by using outside and in-house pathways to the market. The boundaries between firms and their exterior environment are more absorptive, which ease the movement of innovation between the two. The essence of open innovation is the abundance of knowledge and its prompt use, in case of generating value for the creator company. However, internal knowledge of companies should not be restricted to the internal market pathways, neither should these pathways to the market be limited to the internal knowledge of the companies (Chesbrough, 2003), as Figure 5 exemplifies.

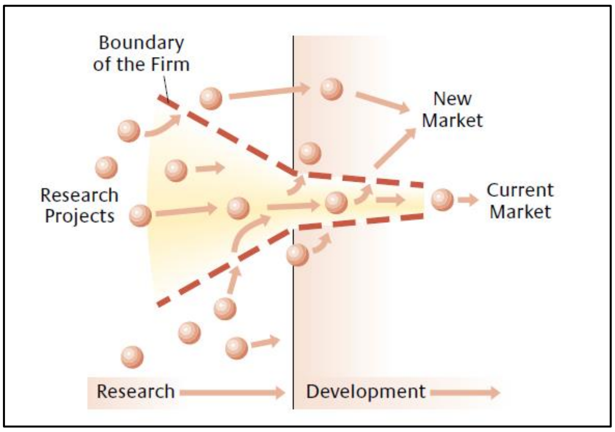

Figure 5 – The open innovation model

Retrieved from Chesbrough (2003).

As Chesbrough (2003) clarifies, not all industries are (or will) held an open innovation model. In fact, distinct businesses can be situated on a continuous scale of innovation, going from primarily closed to totally open. There are industries in both of the extremes, but there are also others transitioning from closed to open innovation in which their locus of innovation "has migrated beyond the confines of the central R&D laboratories of the largest companies and is now situated among various startups, universities, research consortia and other outside organizations" (Chesbrough, 2003, p. 38).

Even though both the closed and open models of innovation are able to discard bad ideas which at first appeared promising, the open innovation models are also able to retrieve projects which, despite not appearing promising at first, turn out to be surprisingly valuable. Since many opportunities are not aligned with the businesses of companies or require external technology to achieve their potential, companies with a strong closed innovation approach are likely to ignore them, only to realize later that some discarded projects were highly valuable. This is, however, less likely occur in companies with an open innovation approach. These companies maintain projects of that type and end up reaping benefits from the strong commercial value that the projects turn out to have (Chesbrough, 2003).

After acknowledging the fundamentals of innovation, one should also comprehend a strongly related concept – research and development, which is discussed next.

According to the Frascati Manual, a worldwide standard for R&D measurement, research and development (R&D) consists of "creative and systematic work undertaken in order to increase the stock of knowledge – including knowledge of humankind, culture and society – and to devise new applications of available knowledge" (OECD, 2015, p. 44). Likewise, R&D is always focused on new findings. Thus, it is highly uncertain about the final outcome and the time and resources required, it involves planning and budgeting, and it intends to produce results that can be freely transferred or exchanged in a marketplace (OECD, 2015). Additionally, the Frascati Manual (OECD, 2015) considers three types of R&D, namely:

- Basic research, which focuses mainly on the acquisition of new knowledge regarding the foundations of a certain phenomenon and observable facts, not considering its application or use;
- Applied research, which also focuses on the acquisition of new knowledge but, in this case, for practical purposes;

- Experimental development, which draws the knowledge obtained from research and practical experience to produce additional knowledge, under the form of new or improved products or processes.

The previous types of R&D are not identified in any specific order. Several flows of information and knowledge encompass the R&D system, which means that, for instance, basic research can lead straight to new products or processes and vice-versa (OECD, 2015).

Furthermore, an R&D activity is constituted by the amount of actions which R&D performers undertake to create new knowledge and, usually, a set of R&D activities can be gathered to form an R&D project. Whereas an R&D activity aims to accomplish specific or general objectives, an R&D project is organized and managed to reach a specific purpose (OECD, 2015). In order to identify and classify activities as R&D, five core criteria have to be fulfilled whenever an R&D activity is undertaken. Thus, an R&D activity must (OECD, 2015):

- Aim at new findings (novel);
- Base on original, not obvious, concepts and hypotheses (creative);
- Be uncertain about the final outcome (uncertain);
- Be planned and budgeted (systematic);
- Lead to results that could be possibly reproduced (transferable and/or reproducible).

As mentioned, R&D activities can usually be grouped to form R&D projects, which are organized and managed for a specific purpose and have their own objectives and expected outcomes (OECD, 2015). Having uncertainty and risk associated, the purpose of R&D projects is to increase revenues or to reduce costs, in the future. Companies should, for this reason, consider these projects as part of their long-term strategy, rather than isolated projects. Particularly, R&D projects should be considered as sequential decisions, starting in research as the first stage and, as future stages, the decisions of implementation or commercialization (Morris, Teisberg, & Kolbe, 1991).

Given the presence of uncertainty and risk in R&D projects, there is a need to assess their success or failure. In the research of Pinto and Mantel (1990), the authors identified three performance aspects which can be used to benchmark projects, and, therefore, assess their success or failure. These aspects should be considered when managing a project and can be described as follows (J. K. Pinto & Mantel, 1990):

- The implementation process of management itself: an internal measure of the performance of the project team, which includes, for instance, satisfying the schedule, budget, and technical goals. Hence, efficiency is the primary issue for the implementation process;
- The perceived value of the project: focuses on the potential impact on users caused by the project and relies on the project team's perception in relation to the work they performed for the client;
- The client satisfaction with the delivered project: an external measure of effectiveness, consisting in the client satisfaction, which may differ from the perception of the project team.

These performance aspects reveal that uncertainty is present in the assessment of project performance, since they are biased, are probably based on criteria with conflicting elements, and are subject to shifts due to internal or external pressures. For this reason, the perceived causes of project success or failure are likely to differ across projects, depending on the measure used to assess performance (J. K. Pinto & Mantel, 1990).

Thus, the process of managing R&D projects should be optimized and efforts should be employed to ensure the project's perceived value and satisfaction. This is why project management practices must be considered, since they influence the success of both project management and project investment (Badewi, 2016).

2.4 University-Industry Collaboration

The universities' role is facing ongoing changes (Piva & Rossi-Lamastra, 2013) and these educational institutions are contributing to industrial change through knowledge transfer in distinct areas, such as spin-offs, licensing and patenting, contract research, consultancy, and mobility of graduates and researchers (Wright et al., 2008). As a consequence, firms are progressively establishing collaborative relationships with universities (Piva & Rossi-Lamastra, 2013). In order to situate university-industry R&D collaborations in the extensive range of existing interactions between science and industry, this Section discusses the subject of university-industry collaboration according to the existing literature.

2.4.1 Forms

The forms of university-industry collaboration commonly addressed in practice and considered in literature are Joint Ventures, Networks, Consortia, and Alliances (Barringer & Harrison, 2000), and such distinct forms differ according to the extent to which university and industry are linked (Ankrah & AL-Tabbaa, 2015). However, authors do not concur on the definitions and differences of the diverse forms of university-industry collaboration (Bruneel, D'Este, & Salter, 2010). This is coherent with the findings from the systematic review on university-industry collaboration employed by Ankrah and AL-Tabbaa (2015) and, in turn, this systematic review confirms Blackman and Segal's perspective (1991) wherein it is considered to be difficult to categorize all the different linkages between university and industry.

Nonetheless, in their systematic review, Ankrah and AL-Tabbaa (2015) were able to categorize the linkages between university and industry into six main categories broad in scope, namely:

- Personal Informal Relationships;
- Personal Formal Relationships;
- Third Party;
- Formal Targeted Agreements;
- Formal Non-Targeted Agreements;
- Focused Structures.

Table 2 identifies these six categories and evidences their vast scope with the organizational forms that constitute each one of them (Ankrah & AL-Tabbaa, 2015).

Additionally, D'Este and Perkmann (2011) consider three main forms of collaboration as follows. To start, Collaborative (or joint) Research consists in the formal collaborative arrangements in which the objective is cooperation on R&D projects (Hall, Link, & Scott, 2001) that, in many cases, have contribution of public funding (Pablo D'Este & Perkmann, 2011). Alternatively, Contract Research consists in research that is commercially relevant to industry in a direct way and, for that reason, usually is not eligible for public support (Pablo D'Este &

Perkmann, 2011). Contract research is commissioned by industry and the work is typically more applied when in comparison to collaborative research arrangements (Van Looy, Ranga, Callaert, Debackere, & Zimmermann, 2004). To conclude, there is Consulting, which consists in research or advisory services that academic researchers provide to industry clients (Perkmann & Walsh, 2008). This form is frequently commissioned by the industry partner and the income is attributed individually to academics, even though it may be directed through university research accounts so that it contributes to research (Pablo D'Este & Perkmann, 2011).

This dissertation focuses will focus on a university-industry R&D collaboration case study which, considering the categorization of Ankrah and AL-Tabbaa (2015), is treated as a Formal Targeted Agreement. Moreover, of the abovementioned main forms of collaboration considered by D'Este and Perkmann (2011), the case study addressed in this dissertation is a Collaborative Research.

Table 2 – Organizational forms of university-industry collaboration
Adapted from Ankrah and AL-Tabbaa (2015).

Category	Organizational Forms
Personal Informal Relationships	▪ Academic spin-offs ▪ Individual consultancy (paid for or free) ▪ Information exchange forums ▪ Collegial interchange, conference, and publications ▪ Joint or individual lectures ▪ Personal contact with university academic staff or industrial staff ▪ Co-locational arrangement
Personal Formal Relationships	▪ Student internships and sandwich courses ▪ Students' involvement in industrial projects ▪ Scholarships, Studentships, Fellowships and postgraduate linkages ▪ Joint supervision of PhDs and Masters theses ▪ Exchange programs (e.g., secondment) ▪ Sabbaticals periods for professors ▪ Hiring of graduate students ▪ Employment of relevant scientists by industry ▪ Use of university or industrial facility (e.g., lab, database, etc.)
Third Parties	▪ Institutional consultancy (university companies including Faculty Consulting) ▪ Liaison offices (in universities or industry) ▪ General Assistance Units (including technology transfer organizations) ▪ Government Agencies (including regional technology transfer networks) ▪ Industrial associations (functioning as brokers) ▪ Technological Brokerage Companies

Table 2 (continued) – Organizational forms of university-industry collaboration
Adapted from Ankrah and AL-Tabbaa (2015).

Category	Organizational Forms
Formal Targeted Agreements	▪ Contract research (including technical services contract) ▪ Patenting and Licensing Agreements (licensing of intellectual property rights) ▪ Cooperative research projects ▪ Equity holding in companies by universities or faculty members ▪ Exchange of research materials or Joint curriculum development: ▪ Joint research programs (including Joint venture research project with a university as a research partner or Joint venture research project with a university as a subcontractor) ▪ Training Programs for employees
Formal Non-Targeted Agreements	▪ Broad agreements for university-industry collaborations ▪ Endowed Chairs and Advisory Boards ▪ Funding of university posts ▪ Industrially sponsored R&D in university departments ▪ Research grant, gifts, endowment, trusts donations (financial or equipment), general or directed to specific departments or academics
Focused Structures	▪ Association contracts ▪ Innovation/incubation centers ▪ Research, science and technology parks ▪ University-Industry Consortia ▪ University-Industry research cooperative research centers ▪ Subsidiary ownerships ▪ Mergers

The above six categories display an increasing level of organizational involvement, possible to be analyzed according to three different dimensions (Ankrah & AL-Tabbaa, 2015). As the first dimension, the organizational resource involvement from the university: this dimension intensifies from Personal Formal Relationships down the categories to Focused Structures, a category in which the entire university is involved in certain forms to collaborate with industry. However, this dimension is absent if the industry's contact with the university is established between an academical individual without any agreement signed with its university. Then, the length of the agreement: as the second dimension, it can range from short (yet renewable) in Personal Formal Relationships, to long in Focused Structures. Exceptionally, Third Parties may have a long length of the agreement in the cases where the relationship is developed into a more stable one. Lastly, the degree of formalization: this dimension is low or nonexistent for Personal Informal Relationships and possible to exist or not for Personal Formal Relationships and Third Parties (Ankrah & AL-Tabbaa, 2015). For the remaining categories, the relations are formalized (Bonaccorsi & Piccaluga, 1994).

Altogether, this dissertation considers the descriptions stated in the introductory Chapter, not only the one in which university-industry collaborations are set to be constituted by heterogeneous partners, collective responsibilities, specific application context, and financial support (Brocke & Lippe, 2015); but also the description in which collaborative research projects are assumed as a temporary organization which intends to achieve innovative results, considering a defined research objective and constraints on resources, costs, and time (Brocke & Lippe, 2015). Moreover, it is also complemented with Plewa and Quester's definition (Plewa & Quester, 2007), wherein university-industry relationships are considered "trusting, committed and interactive relationships between university and industry entities, enabling the diffusion of creativity, ideas, skills and people with the aim of creating mutual value over time." (p. 371).

2.4.2 Motivations

The motivations that underpin the interest of both university and industry to collaborate with one another are identified in the systematic review performed by Ankrah and AL-Tabbaa (2015).

The university side is increasingly encouraging university-industry collaborations as a reaction to government policy and as an strategic institutional policy (Howells, Nedeva, & Georghiou, 1998; Perkmann, King, et al., 2011). Additionally, university can access complementary expertise, equipment and facilities, as well as employment opportunities for university graduates (Ankrah & AL-Tabbaa, 2015). Moreover, Ankrah and AL-Tabbaa (2015) highlight the access to funding for research, the personal financial gains for academics, the discovery of new knowledge or test application of theory, the exposure of students and faculty to practical problems, and the publication of papers. Further significant motivation consists in the societal pressure on universities to enter in these relationships with industry, the contribution to the economy in regional or national terms (Ankrah & AL-Tabbaa, 2015), and the academics' quest for recognition in the industrial scientific community (Siegel, Waldman, Atwater, & Link, 2004).

With regard to the industry side, these collaborations also are a form of response to government initiatives or policy, as well as a strategic institutional policy. Besides that, industry gets contact with students for summer internship or hiring (Ankrah & AL-Tabbaa,

2015) and, in some cases, the hiring of faculty members or senior researchers for consulting is also possible (Perkmann, King, et al., 2011). In addition, industry can experience several improvements in terms of efficiency, namely: cost savings, financial benefits from research results, national incentives for the development of these collaborations, enhancement of the technological capacity and economic competitiveness, shortening product life cycle, and human capital development. Moreover, these collaborations allow industry to achieve solutions to specific problems, to subcontract R&D, to reduce or share risk, and to access new knowledge, technology, expertise and complementary know-how (Ankrah & AL-Tabbaa, 2015). Also as motivation is the possibility, which frequently occurs, of industry to enhance its image and reputation by linking with an important academic institution (Siegel, Waldman, & Link, 2003).

2.4.3 Barriers

Despite the referred motivations which lead university and industry to collaborate with each other, these collaborations face considerable challenges. Bruneel et al. (2010) identify two type of barriers to collaboration, namely:

- Orientation-related barriers, which are associated to differences in the orientations of university and industry;
- Transactional-related barriers, which are associated to conflicts over intellectual property and handling with university administration.

Concerning the orientation-related barriers, whereas university's primary focus is on creating new knowledge and educating, industry is focused on capturing knowledge that can be used for competitive advantage. A central obstacle to university-industry collaboration consists in the contrasting institutional norms governing public and private knowledge (Dasgupta & David, 1994).

The development of reliable and public knowledge has been essential to the university's growth, which leads to support from government for research (Bruneel et al., 2010; Geuna, Steinmeuller, & Salter, 2003). To the academics, the establishment of reputation through their publication is determinant to their success and career sustainability (Bruneel et al., 2010). Moreover, the majority of research that has support from government is applied, or with a practical orientation, and focused on solving problems through the use of science (Pavitt, 2001), and, although scientists frequently disagree on the benefits of cooperating with industry (Welsh, Glenna, Lacy, & Biscotti, 2008), several fields of research, such as engineering, imply interaction with industry (Rosenberg & Nelson, 1994). Researchers in areas more oriented to practice are more inclined to engage on real world problems and interact with industry, which often means that their status is also determined by their standing in industry, in addition to the reputation between their colleagues (Bruneel et al., 2010).

In industry, however, the knowledge creation primarily aims to appropriate the knowledge for private gain, and the openness to external entities is applied as a strategic instrument to obtain competitive advantage (Bruneel et al., 2010; Chesbrough, 2006a). Such openness of industry occurs, for example, between firms of the same sector (Bruneel et al., 2010). For example, through publications to indicate their expertise and defend their areas of technology (Cockburn & Henderson, 1998; Hicks, 1995), through open source software projects to reduce the costs in their development activities (von Hippel & von Krogh, 2003), and even through strategic trade of information with competitors (von Hippel, 1987).

Considering the differences in what concerns knowledge creation between university and industry, it is likely that conflicts arise in collaborations because of the different positions of the partners. While researchers may intend to divulge research results to obtain priority, industry may intend to keep such information unrevealed or appropriating it. Moreover, university and industry may disagree on the issues to explore in a research project and on the types of outputs (Bruneel et al., 2010).

Furthermore, university is having an increasingly proactive attitude over the management of their collaborations with industry, attempting to create important intellectual property to promote the development of technology transfer (Bruneel et al., 2010). This leads to transactional-related barriers.

The attempts on the part of university to capture intellectual property have impacted the nature of scientific efforts (Bruneel et al., 2010; Scott Shane, 2004). Moreover, these endeavors also caused a growth in university patenting and originated a focus on universities to create important intellectual property and use it for financial benefits (Mowery & Ziedonis, 2002).

In some cases, however, serious conflicts between university and industry partners have arisen from these attempts on the part of university to obtain commercial gains from research (S. Shane & Somaya, 2007). Such conflicts are frequently emphasized by the expectations that universities have about the commercial capacity of their research (Clarysse, Wright, Lockett, Mustar, & Knockaert, 2007) and can consequently be a substantial barrier that dissuades industry from engaging in collaborations with university (Bruneel et al., 2010).

The two previous barriers and identified conflicts that may arise in university-industry collaboration are coherent with Barnes, Pashby and Gibbons's (2006) research, in which a so-called "cultural gap" is mentioned. The authors stated that the factors identified and related to such gap encompassed "conflicts over ownership of intellectual property (IP), academic freedom to publish, and differences of priorities, time horizons and areas of research focus" (p. 396). All these conflicts have been previously identified in this Section. Additionally, having presented a good practice model focusing in university-industry research collaboration, Barnes, Pashby and Gibbons (2006) suggest that regardless of the particular nature of the "cultural gap", most problems related with it can be eased with proper collaboration or project management.

2.4.4 Facilitators and Inhibitors

The systematic review performed by Ankrah and AL-Tabbaa (2015) listed several factors that can either facilitate or inhibit university-industry collaboration, according to the way they are dealt with. The factors were found to positively affect the perceived success of knowledge and technology transfer if properly managed but, on the contrary, a negative impact tends to occur on the perceived success of knowledge and technology transfer if the factors were ignored or mistreated (Ankrah & AL-Tabbaa, 2015). Table 3 Table *3*illustrates the abundance of such factors under the seven categories adopted by Ankrah and AL-Tabbaa (2015), which are:

- Capacity and Resources;
- Legal issues, and Contractual Mechanisms;
- Management and Organization Issues;
- Issues Relating to the Technology;
- Political Issues;

- Social Issues;
- Other Issues.

The diversity of factors (Ankrah & AL-Tabbaa, 2015) confirmed the view in which the success of university-industry collaboration derives from an interaction of factors and from the aggregate result of both negative and positive impacts that those factors cause (Barnes, Pashby, & Gibbons, 2002). Moreover, the category with most factors listed is the Management and Organizational Issues category, which supports Siegel, Waldman, and Link's (2003) view wherein these factors are critical to facilitate or inhibit university-industry collaboration.

In the same Table 3, it is also possible to identify factors which have been previously mentioned as university-industry barriers and stated in different research. Specifically, the factors concerning differences between university and industry in knowledge creation and their primary focus, which may result in conflicts in the areas of research to be explored or the time horizons to publish results, as well as the conflicts concerning ownership of intellectual property and its commercialization.

Table 3 – Factors that facilitate or inhibit university-industry collaboration
Adapted from Ankrah and AL-Tabbaa (2015).

Category	Factors
Capacity and Resources	▪ Adequate resources (funding, human and facilities) ▪ Incentive structures for university researchers ▪ Recruitment and training of technology transfer staff ▪ Capacity constraints of small and medium-sized enterprises
Legal issues, and Contractual Mechanisms	▪ Inflexible university policies including intellectual property rights, patents, and licenses and contractual mechanisms ▪ Treatment of confidential and proprietary information ▪ Moral responsibility versus legal restrictions (research on humans)
Management and Organization Issues	▪ Leadership/Top management commitment and support ▪ Collaboration champion ▪ Teamwork and flexibility to adapt ▪ Communication ▪ Mutual trust and commitment (and personal relationships) ▪ Corporate stability ▪ Project management ▪ Organization culture (cultural differences between the world of academia and of industry) ▪ Organization structure (university administrative structure and firm structure) ▪ Firm size (size of organization) ▪ Absorptive capacity ▪ Skill and role of both university and industry boundary spanners ▪ Human capital mobility/personnel exchange

Table 3 (continued) – Factors that facilitate or inhibit university-industry collaboration Adapted from Ankrah and AL-Tabbaa (2015).

Category	Factors
Issues Relating to the Technology	▪ Nature of the technology/knowledge to be transferred (tacit or explicit; generic or specialized; academic rigor or industrial relevance)
Political Issues	▪ Policy/legislation/regulation to guide/support/encourage university-industry collaboration (support such as tax credits, information networks and direct advisory assistance to industry)
Social Issues	▪ Enhancement in reputation/prestige
Other Issues	▪ Low level of awareness of university research capabilities ▪ Use of intermediary (third party) ▪ Risk of research ▪ Cross-sector differences/similarities ▪ Geographic proximity

Furthermore, three factors influencing university-industry collaboration were highlighted in the research of Bruneel et al. (2010), namely:

- Experience of collaboration;
- Breadth of interaction channels;
- Inter-organizational trust.

The analysis within the research of Bruneel et al. (2010) stated the effects of these factors in university-industry barriers and how they can either facilitate or inhibit collaborations. In particular, having prior experience in research collaboration was shown to reduce orientation-related barriers between university and industry. Likewise, greater levels of inter-organizational trust reduce both orientation-related and transactional-related barriers. Lastly, the breadth of interaction channels reduces orientation-related barriers but increases the ones which are transactional-related (Bruneel et al., 2010).

With respect to experience of collaboration, collaborators with this prior experience employ efforts which should help to reduce orientation-related barriers, since a convergence attitude between partners is promoted. Transactional-related barriers may, however, persist even with prior experience of collaboration if proper adjustments are not used, due to, for example, disagreements on the distribution of rewards from research (Bruneel et al., 2010).

On the other hand, high levels of inter-organizational trust are expected to be linked with reduced orientation-related and transaction-related barriers (Bruneel et al., 2010), given that this trust indicates the capability of university and industry to work together to solve problems, and to adjust with each other's needs and expectations (McEvily, Perrone, & Zaheer, 2003; Santoro & Gopalakrishnan, 2001).

Moreover, an increased breadth of interaction channels may converge the attitudes of university and industry and help them to succeed in dealing with misalignments caused by contrasting institutional norms, which reduces orientation-related barriers. This wider breadth of interaction channels can, however, increase transactional conflicts, since it is more likely that industry and its collaborations may have to handle university administration and its several regulations and procedures (Bruneel et al., 2010).

2.4.5 Outcomes

In the same way as any different type of inter-organizational relationship, collaboration between university and industry has positive and negative outcomes for both partners or, to put it simply, benefits and drawbacks. Despite the linkage established by several studies between the motivations and the benefits realized in university-industry collaboration[2], not all benefits could be listed in the motivations previously identified in this Section (Ankrah & AL-Tabbaa, 2015). A possible categorization of benefits realized by university and industry is the one Ankrah and AL-Tabbaa (2015) used, in which benefits are listed as:

- Economic Benefits;
- Institutional Benefits;
- Social Benefits.

The first category consist in benefits to the overall economy, the second one to benefits obtained by university and industry, and, lastly, the third category consists in benefits related to society or to sociability promotion (Ankrah & AL-Tabbaa, 2015).

Furthermore, a recent research with respect to benefits realization in university-industry R&D collaboration (Fernandes, Pinto, Araújo, & Machado, 2017) identified a total of thirty-three benefits and listed them according to the several sources from which they may arise. Accordingly, the benefits were categorized in relation to their typology (strategic, economic, operational, or social), nature (tangible or intangible), incidence (direct or indirect), time

[2] For example, Geisler (1995) and Lee (2000).

impact (short or long term), agent (university, industry, or both), and scope (value creation, strategy, resources quality/performance, knowledge, or inter-relational) (Fernandes, Pinto, Araújo, & Machado, 2017). This is a detailed categorization that covers a wide range of sources from which benefits arise, but, nonetheless, is still consistent with the categorization of Ankrah and AL-Tabbaa (2015).

Then, in opposition to benefits, there are the drawbacks. Despite referring to negative outcomes, the acknowledgement of potential drawbacks is important for both university and industry in order to reduce failure and establish the success of their collaboration. Thus, drawbacks can be listed in different categories according to Ankrah and AL-Tabbaa (2015), namely:

- Deviation from Mission or Objective;
- Quality Issues;
- Conflicts;
- Risks.

Moreover, given that access to funding for research is a motivation that drives university to collaborate with industry, as previously mentioned, it is expected that university is put in a vulnerable position due to its smaller power and control over the collaboration (Ankrah & AL-Tabbaa, 2015). This vulnerable position is frequent in cross-sector collaboration in which industry is the main partner (AL-Tabbaa, Leach, & March, 2014) and, in the case of university-industry collaborations, is likely to lead to a set of other drawbacks. For example, the pressure by industry to quicken results or the risk of blocking the dissemination of knowledge in agreement with industry request (Ankrah & AL-Tabbaa, 2015).

2.5 Performance Measurement

University and industry are seeking to improve the management of their research collaborations (Kirkland, 2005) that can either be financed by government funds or the funding can be provided by the industrial partner of the collaboration (Philbin, 2008). An important feature to reach for this improvement is the development of effective performance metrics (Frey, Lohmeier, Lee, & Tollefson, 2006), a subject addressed in this Section.

Given that the performance obtained by a business is a function of the efficiency and effectiveness of its actions, three major concepts related with performance must be clarified before entering into more detail (Neely, Gregory, & Platts, 1995):

- Performance measurement, as the process of quantifying the efficiency and effectiveness of actions;
- Performance measure, as the metric used to quantify an action in terms of efficiency and/or effectiveness;
- Performance measurement system, as the series of metrics utilized to quantify both the efficiency and effectiveness of actions.

In a business environment that is in continuous change, performance measurement is drawing increasingly attention over the last decades and organizations are recognizing its importance (Bezerra & Gomes, 2016). Moreover, performance measurement is considered an essential principle of management, since it identifies gaps between the current and the expected performance which, in turn, allows to perform adjustments in order to close those gaps (Weber & Thomas, 2005).

According to Pillai, Joshi, and Rao (2002), the concept of performance measurement usually implies the identification of performance metrics and the corresponding criteria for their calculation. These authors also state that performance measurement has a significant function in ensuring the success of a project (Pillai et al., 2002). Moreover, performance measurement informs about the activities and eases the achievement of the customer expectations and strategic objectives (Wegelius-Lehtonen, 2001).

Three levels of analysis with regard to a performance measurement system can be highlighted, as illustrated in Figure 6 (Neely et al., 1995):

1. The individual performance measures;
2. The performance measurement system itself, as an entity (the series of performance measurements);
3. The relationship between the performance measurement system and the environment in which it is used.

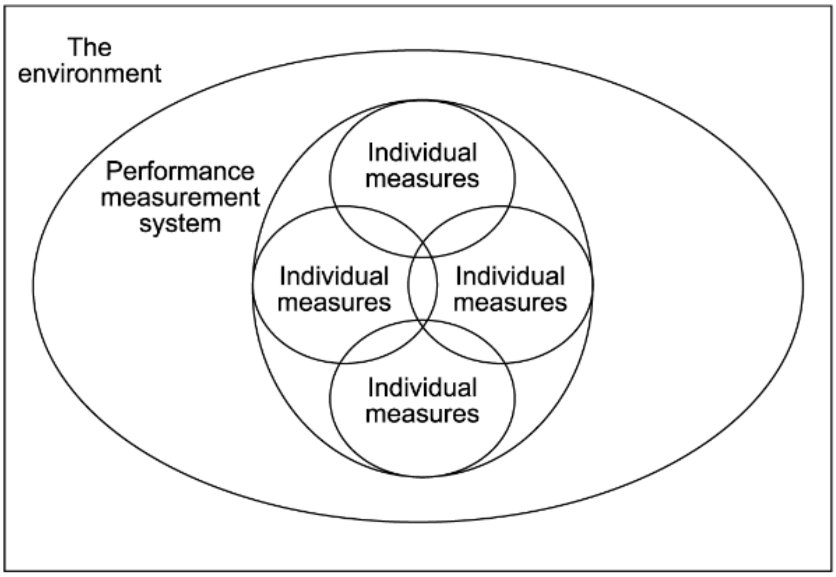

Figure 6 – Levels of a performance measurement system
Retrieved from Neely et al. (1995).

Additionally, the performance measurement systems are used to measure and control several activities and are formed by two main elements as follows (Agostino & Sidorova, 2016):

- Metrics: indicators that simplify the quantification of a certain item of control that can be either an organization, an individual, a product or a service;
- Methods: approaches necessary to calculate the metrics.

For this reason, all performance measurement systems are composed by a set of individual performance measures. In turn, these measures can be categorized in several ways through diverse performance measurement frameworks (Neely et al., 1995), some of which are described next.

Balanced Scorecard

Developed by Kaplan and Norton, the balanced scorecard is one of the most widely acknowledged frameworks (Neely et al., 2000). This framework constitutes a set of measures able to give a prompt and comprehensive view of the business. It includes not only financial measures, with the results of past actions, but also operational measures, which constitute the drivers of future financial performance. Moreover, the balanced scorecard approaches business from four main perspectives: financial perspective, costumer perspective, internal business perspective, and innovation and learning perspective (Kaplan & Norton, 1992).

Figure 7 exhibits these perspectives and relates each one of them with questions that the balanced scorecard is able to answer.

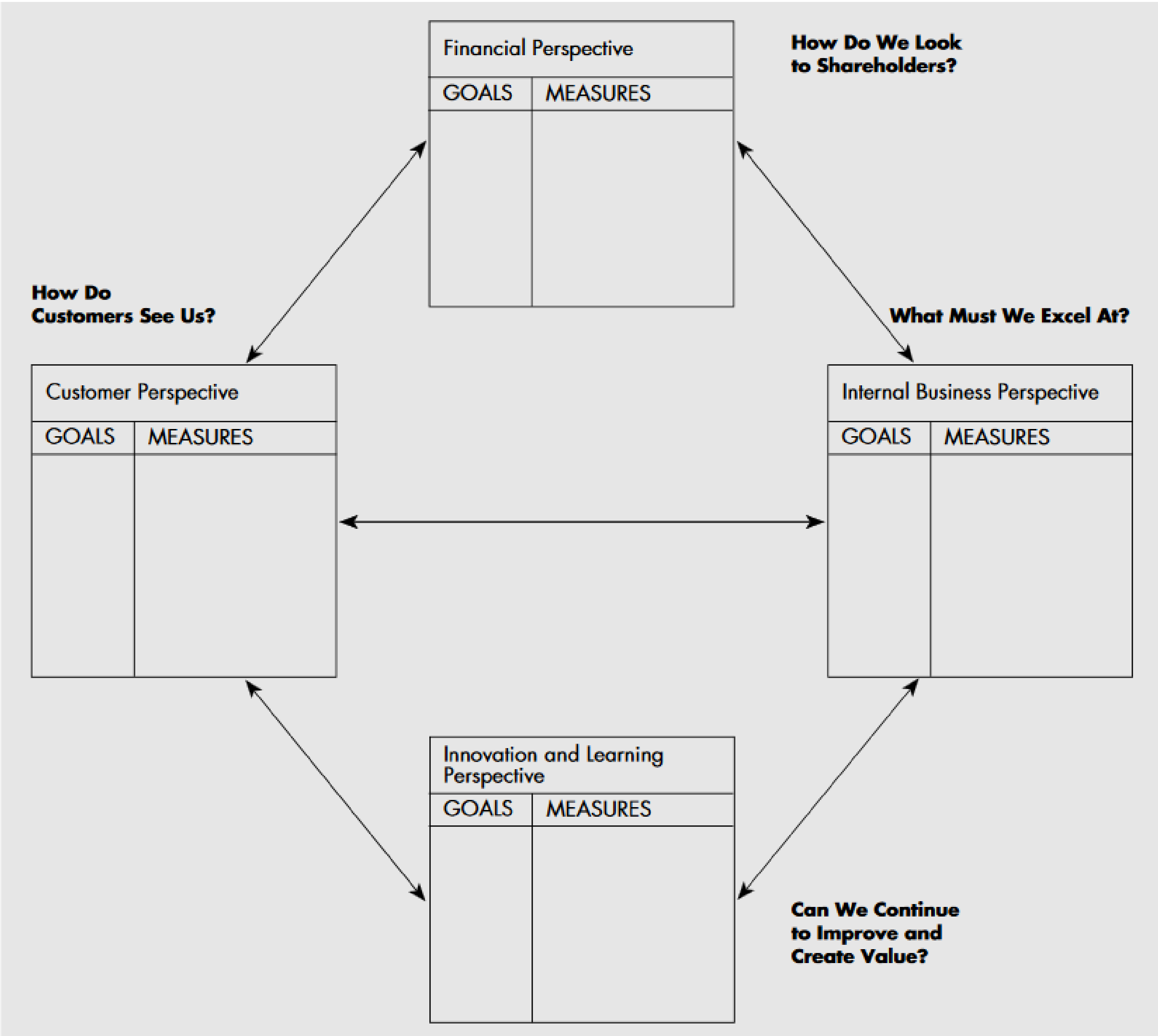

Figure 7 – Balanced scorecard

Retrieved from Kaplan and Norton (1992).

Performance Measurement Matrix

The performance measurement matrix was presented in by Keegan et al. (1989) and, similarly to the balanced scorecard, it integrates different dimensions of business performance, such as financial, non-financial, internal, and external. However, and conversely to the balanced scorecard, this matrix is not specific in the links between the distinct dimensions (Neely et al., 2000). Figure 8 illustrates the performance measurement matrix.

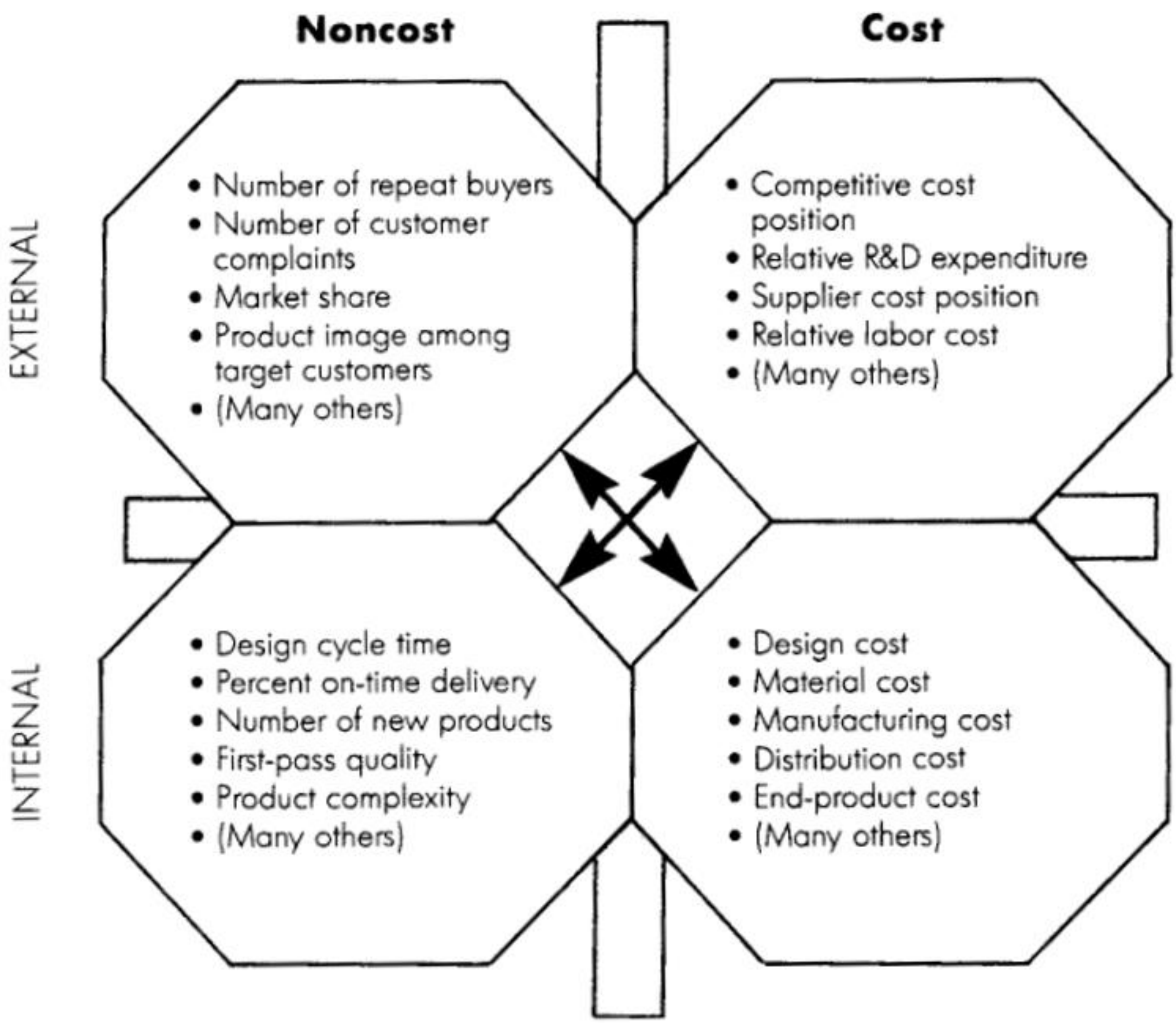

Figure 8 – Performance measurement matrix

Retrieved from Keegan et al. (1989).

Results and Determinants Framework

The results and determinants framework was developed by Fitzgerald et al. (1991) and overcomes the criticism made to the performance measurement matrix, in which the links between the distinct dimensions were not explicit. According to this specific framework, there is a type of measurement that focus on results and other type that focus on the determinants of the results. This distinction between the two basic types of performance measurement is interesting, since it emphasizes that the results vary in function of past performance with regard to the determinants (Neely et al., 2000). Table 4 identifies the two types of performance measurement and lists their dimensions and types of measures.

Table 4 – Results and determinants framework

Adapted from Brignall et al. (1991)

	Dimensions of performance	Types of measure
Results	Financial performance	Relative market share and position Sales growth Measures of the customer base
	Competitiveness	Profitability Liquidity Capital structure Market ratios
Determinants	Quality	Reliability Responsiveness Aesthetics/appearance Cleanliness/tidiness Comfort Friendliness Communication Courtesy Competence Access Availability Security
	Flexibility	Volume flexibility Delivery speed flexibility Specification flexibility
	Resource utilization	Productivity Efficiency
	Innovation	Performance of the innovation process Performance of individual innovations

Performance Pyramid

The performance pyramid was developed by Cross and Lynch (1988) with the purpose of linking the strategy of an organization with its operations and, to do that, objectives are displayed from the top down and measures from the bottom up. This performance measurement system contemplates four levels of objectives as a function of external effectiveness (left side of the pyramid) and internal effectiveness (right side of the pyramid) (Kurien & Qureshi, 2011), as Figure 9 shows.

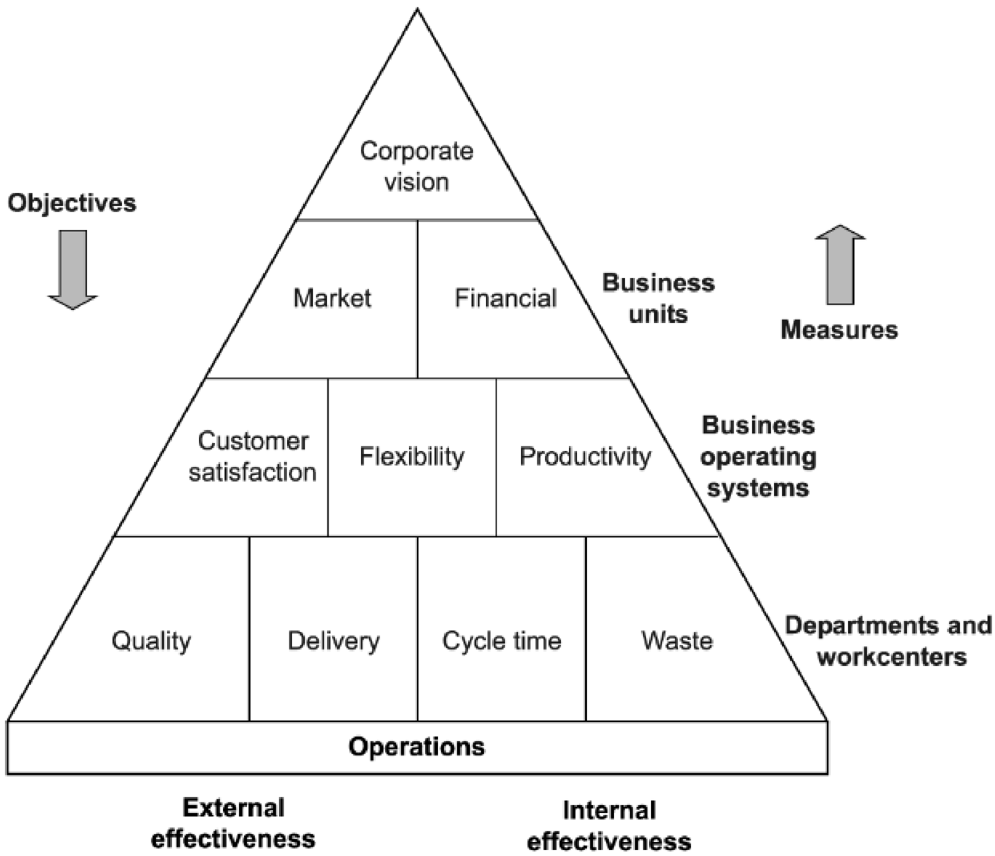

Figure 9 – Performance pyramid
Retrieved from Tangen (2004).

As for performance measures, these metrics allow to measure and improve the efficiency and quality of the business processes, as well as to identify prospects for improvements in the performance of these processes (Wegelius-Lehtonen, 2001). According to Parmenter (2007), there are four types of performance measures, namely: key result indicators, result indicators, performance indicators, and key performance indicators.

Wegelius-Lehtonen (2001) considers two dimensions in the classifications of performance measurement. In the first dimension, named use of measure, a division is established between improvement and monitoring measures (Wegelius-Lehtonen, 2001):

- Improvement measures: are important for new development and cooperation projects, these measures have no regular frequency to be applied and their purpose is to realize about the current performance level and the improvement potential;
- Monitoring measures: are required for the continuous control of companies' daily actions.

The second dimension, named focus of measure, indicates the organization level in which measures are used. Different levels of organization require distinct measures and, therefore, information should be available for the purpose of both strategic management (at company level) and operational management (at factory level) (Wegelius-Lehtonen, 2001).

Regardless their type or dimension, performance measures are required to be situated in a strategic context, since they influence and stimulate action (Neely et al., 1995).

2.6 Project and Program Success

Project success can be accounted as the ultimate objective for most projects. There are, however, different definitions of success to different industries, project teams or individuals, wherein each has its specific definition (Chan & Chan, 2004). Generally, the most important aspects in defining the success of a project have been the project management metrics of time, cost, scope, and quality. In addition, project success may consider criteria related to the organizational strategy and business results (Project Management Institute, 2017a).

However, two aspects regarding success in projects should be distinguished, namely project success and project management success. In particular, project success is measured against the general objectives of the project and project management success is measured against the common measures of performance, such as time, cost, and quality (Cooke-Davies, 2002; de Wit, 1988). In addition to scope, cost, and time management, Müller and Jugdev (2012) reached the conclusion that project success is also influenced by the teamwork and affected by the interactions of personal, project, team, and organizational success.

An additional distinction which is also important to be established is the one between success criteria and success factors. In general, success factors are the inputs to the management system that, directly or indirectly, influence the success or the failure of a project or business, while success criteria are the measures by which the success or the failure of a project or business is determined (Cooke-Davies, 2002).

Regarding success factors, they relate to both the organization (such as top management support) and the external environment (for instance, politics, economy, social, technological, or client) (Jugdev & Müller, 2005). Moreover, Cooke-Davies (2002) considers that success factors can be divided into factors that lead to project management success, factors that lead to a successful project, and factors that lead to consistently successful projects. The author also identified a total of twelve factors which, in one way or another, are considered as critical to project success (Cooke-Davies, 2002). Likewise, Fortune and White (2006) reviewed several studies focused on this subject and were able to identify twenty-seven different critical success factor, in which the top three most cited are the support from senior management, a set of clear realistic objectives, and a strong/detailed plan kept up to date. However, the authors also demonstrated that the agreement among authors on success factors is only limited (Fortune & White, 2006), which is in line with the view of Wateridge (1995) that a consensus of opinion among researchers on the success factors does not appear to exist.

As for success criteria, they simply refer to the principles or standards by which project success can be judged (Lim & Mohamed, 1999). To this matter, the criteria of time, cost, and quality are the basic ones to project success and are identified in most researches regarding this subject (Chan & Chan, 2004). Referred to as the “iron triangle” by Atkinson (1999), these three criteria are continuously mentioned on the several definitions of project management that have been developed (Atkinson, 1999). However, perceiving the “iron triangle” as the main success criteria can be considered a limited view in this respect (Westerveld, 2003).

Coupled with the distinctions between concepts, project success has been a subject of study by several authors. According to Shenhar et al. (1997), project success is divided into four time-dependent dimensions, as Figure 10 describes. To start, the project efficiency corresponds to the period during the execution of a project and immediately upon its completion. Then, the impact on customer is determined when the project has been delivered and the business success after the achievement of a considerable level of sales. Finally, due to its long-term nature, the last dimension is determined three to five years after the completion of the project (Chan & Chan, 2004).

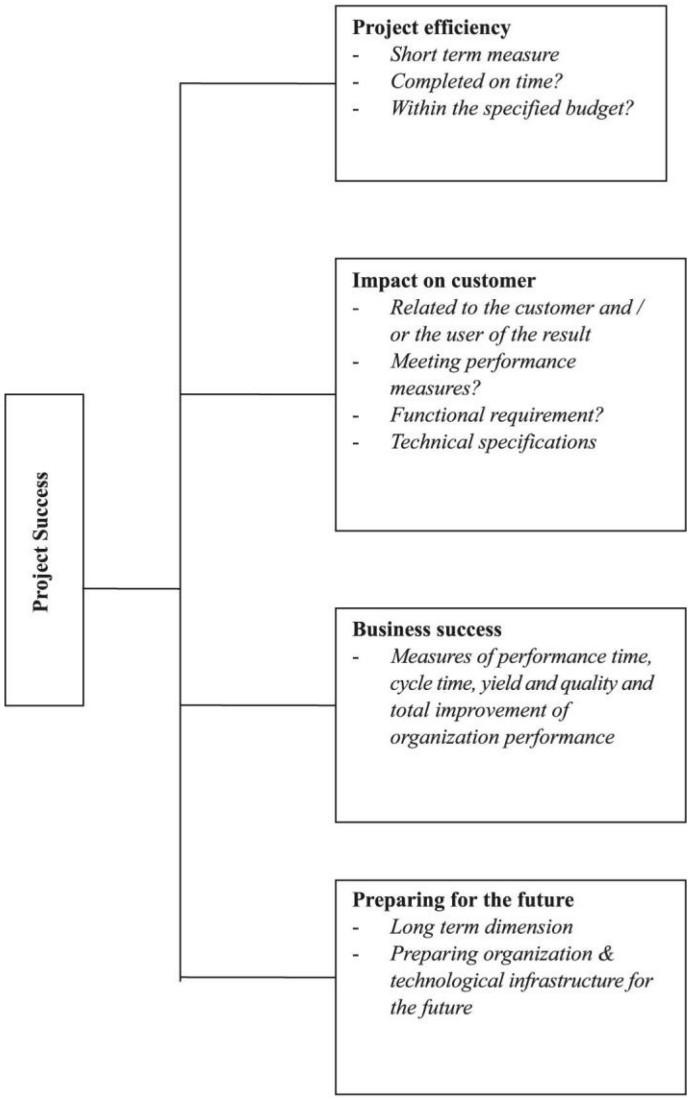

Figure 10 – The four dimensions of project success
Retrieved from Chan and Chan (2004).

In a similar way, Atkinson (1999) proposed a model in which project success is divided into three elements, namely: 1) the process, in the delivery stage; 2) the system, in the post-delivery stage; and 3) the benefits, in the post-delivery stage. Figure 11 presents these elements within Atkinson's model of measuring project success.

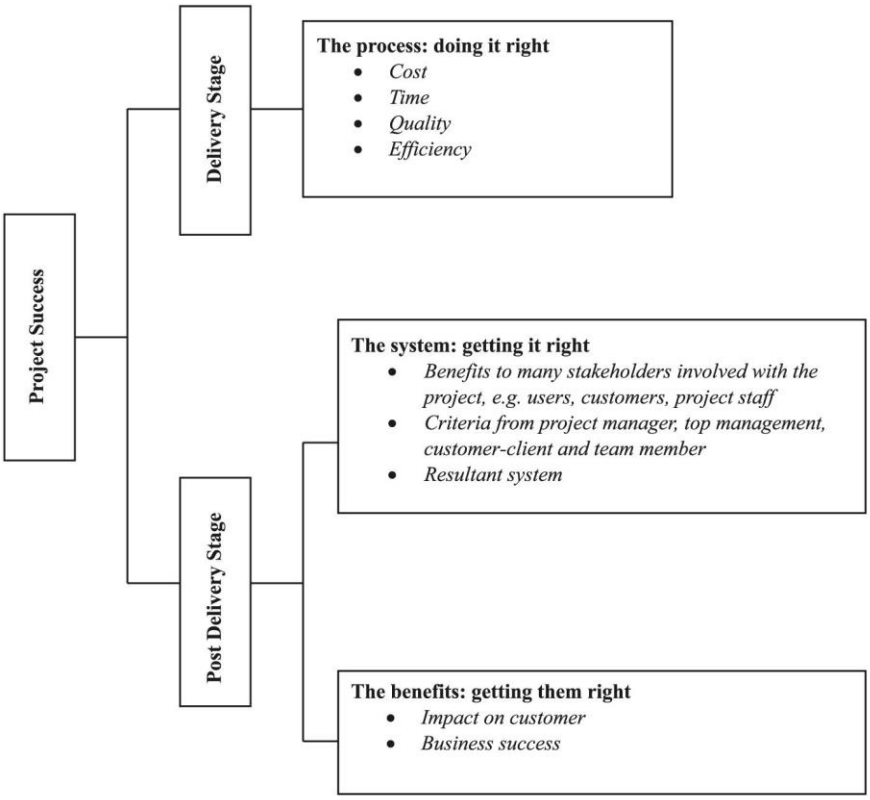

Figure 11 – Model of measuring project success

Retrieved from Chan and Chan (2004).

Lim and Mohamed (1999) proposed two viewpoints from which to measure project success, namely the macro and micro viewpoints, as illustrated in Figure 12. The macro viewpoint consists in the achievement of the original concept of the project, hence the components of satisfaction, utility, and operation. In turn, the micro viewpoint deals with achievements of smaller components, such as time, cost, or quality (Lim & Mohamed, 1999).

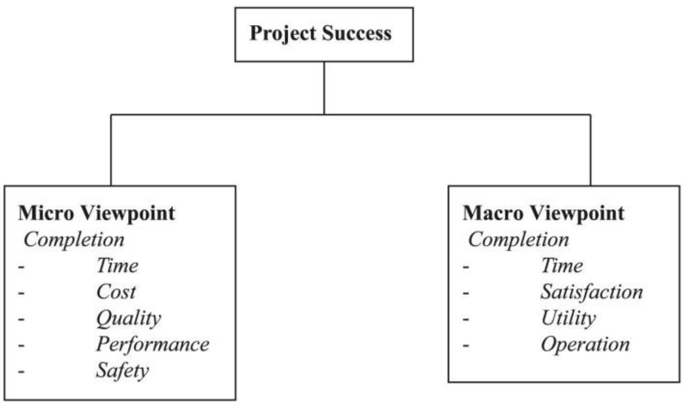

Figure 12 – Micro and macro viewpoints of project success

Retrieved from Chan and Chan (2004).

The same concepts of project success apply to program success, as programs have their roots in projects (Maylor, Brady, Cooke-Davies, & Hodgson, 2006). Additionally, program success relates with the achievement of organizational strategies (Maylor et al., 2006; Partington, 2000) and organizational change (Lycett, Rassau, & Danson, 2004; Pellegrinelli, 1997; Reiss et al., 2006).

However, little constructs for program success are found in literature (Shao, Müller, & Turner, 2012). Nonetheless, Shao and Müller (2011) attempted to develop these constructs and identified six dimensions, namely: program efficiency, impact on program team, stakeholder satisfaction, business success, preparation for the future, and social effects. Despite the identification of these dimensions, the related measurements were not defined (Shao et al., 2012). In their research, Shao, Müller, and Turner (2012) introduced several measurements to a construct for program success. It was concluded that program context may not have a direct interaction with program success, but it defines the context for program management and may influence other factors with impact on program success (Shao et al., 2012). For this reason, it is stated that program context needs a careful management, as suggested by previous studies (Lycett et al., 2004; Pellegrinelli, 2002; Pellegrinelli, Partington, Hemingway, Mohdzain, & Shah, 2007). Moreover, as the type of programs usually are not manageable, program managers should devote to the management of program context characteristics (Shao et al., 2012).

2.7 Measuring the Performance of University-Industry Collaborations

Measuring the performance allows a university-industry collaboration to develop in an efficient and effective manner. Additionally, it can also allow to perceive when adjustments to the organization and/or the objectives of the collaboration are required. However, in spite of the extreme importance of this measurement, a structured and generally accepted system of indicators to evaluate the results of these collaborations has not yet been developed (Piva & Rossi-Lamastra, 2013).

Given the objective of collaborations between university and industry to produce innovation outcomes, the development and use of systems of indicators to evaluate these collaborations is a difficult endeavor. Innovation, as a complex and multidimensional concept, does not adjust to traditional metrics and requires a wide variety of indicators to be evaluated (Smith, 2005). Moreover, the complexity of innovation increases proportionately to the heterogeneity of the parties involved. University-industry collaborations highly reflect such heterogeneity (Piva & Rossi-Lamastra, 2013).

Three aspects must be considered so that an effective measurement system for university-industry collaborations can be developed, namely (Piva & Rossi-Lamastra, 2013):

- A clear recognition of the multiple objectives pursued by firms, so that the measurement can determine if and when each objective is accomplished.
- Awareness in regard to the specific problems of university-industry collaboration and their causes.
- Consideration regard the existence of different types of outputs, since they can be tangible or intangible, and expected or fortuitous.

Nonetheless, the primary studies concerning the subject of measuring the performance of projects executed in university-industry collaborations date back to the early 1990s (Piva & Rossi-Lamastra, 2013). According to Thune (2011), in order to measure the collaboration performance, these early studies were based on the satisfaction of project members (Barnes et al., 2002; Cukor, 1992; Mora-Valentin, Montoro-Sanchez, & Guerras-Martin, 2004; Plewa & Quester, 2006a, 2006b) or on the continuity of the collaboration over time as an indicator of success (Bouty, 2000; Cyert & Goodman, 1997; Geisler, 2001; Mora-Valentin et al., 2004; Santoro, 2000).

Many years later, Grimaldi and von Tunzelmann (2002; 2003) considered quantitative indicators to evaluate the performance of university-industry collaboration. These authors elaborated a composite indicator that contemplates the direct and the indirect/future results of the collaboration. Notably, the direct results are measured in terms of the number of patents and scientific publications produced within the collaboration. As for the indirect/future results, these are measured by means of qualitative information regarding the potential of the patents and scientific publications, as well as the appearance of technological spin-offs. A third aspect is also assessed, namely the correspondence of the initial objectives with the results achieved (Piva & Rossi-Lamastra, 2013).

In 2011, a balanced scorecard for measuring university-industry collaborations was proposed (Al-Ashaab, Flores, Doultsinou, & Magyar, 2011), in which Al-Ashaab et al. (2011) defined several key performance indicators for university-industry collaboration. The balanced scorecard considers six perspectives, namely: (1) competitiveness; (2) sustainable development; (3) innovation; (4) strategic partnerships; (5) human capital; and (6) internal business processes.

Iqbal et al. (2011) developed a model comprising the following five steps: (1) constraints; (2) evaluation metrics; (3) success criteria; (4) tangible outcomes; (5) comparison of success criteria and tangible outcome. The constraints affecting university-industry collaborations are first identified, as well as the evaluation metrics. These metrics, in turn, are associated to success criteria which then enables to reach a result that, with the tangible outcome, allows to establish a comparison (Iqbal et al., 2011).

The most significant contribution in this regard, however, is probably the research of Perkmann et al. (2011). In this research, the authors identified four stages of the university-industry collaborations (inputs, in-process activities, outputs, and impacts) and developed a success map which explains how these collaborations work and identifies the cause and effect relationships underpinning success (Bremser & Barsky, 2004; Perkmann, Neely, et al., 2011). Moreover, a set of performance indicators for each stage of the collaborations was also proposed.

More recently, Seppo and Lilles (2012) further developed the success map and the indicators proposed by Perkmann et al. (2011) by describing the indicators for measuring different types of university-industry collaborations activities. Moreover, in order to measure university-industry collaborations, Seppo and Lilles (2012) argue that focus should be given to the economic impact of the collaboration and to relationship-based indicators, rather than to input and output indicators.

3. Research Methodology

Research methodology is a form to systematically solve the research problem. That is to say, it is how research is developed scientifically. The decisions adopted by the researcher in his research are explained in the research methodology, as well as the logic supporting them (Kothari, 2004). Therefore, all research must be linked to a research methodology capable to proper explain the work developed. A clear definition of the adopted research methodology allows to validate the procedures used and the results obtained in a research, leading to well-founded answers to the research question. For this reason, the research methodology is considered an essential part of this research.

Given the above, this Chapter describes the research methodology used in the development of this dissertation. Section 3.1 defines the research design and explains how it was implemented in this research, associating the different activities with the research process developed during the dissertation. Subsequently, Section 3.2 clarifies how data was collected and, lastly, Section 3.3 describes how that data was analyzed.

3.1 Research Design

The research design used throughout the development of this dissertation assumes the form of **Design Science Research Methodology** (DSRM). This methodology aims to solve recognized problems in organizations through the creation and evaluation of artifacts (Hevner, March, Park, & Ram, 2004). The artifacts are grouped in four types, namely: constructs, models, methods, and instantiations (Hevner et al., 2004; March & Smith, 1995). Overall, the DSRM results in a designed artifact that incorporates a solution to an observed problem.

3.1.1 Presentation of the DSRM

Henceforth, the DSRM process model proposed by Peffers, Tuunanen, Rothenberger, and Chatterjee (2007) is assumed. This process model, illustrated in Figure 13, is a synthesis of seven representative papers and presentations, achieved as a result of an analysis of key prior literature performed by Peffers et al. (2007).

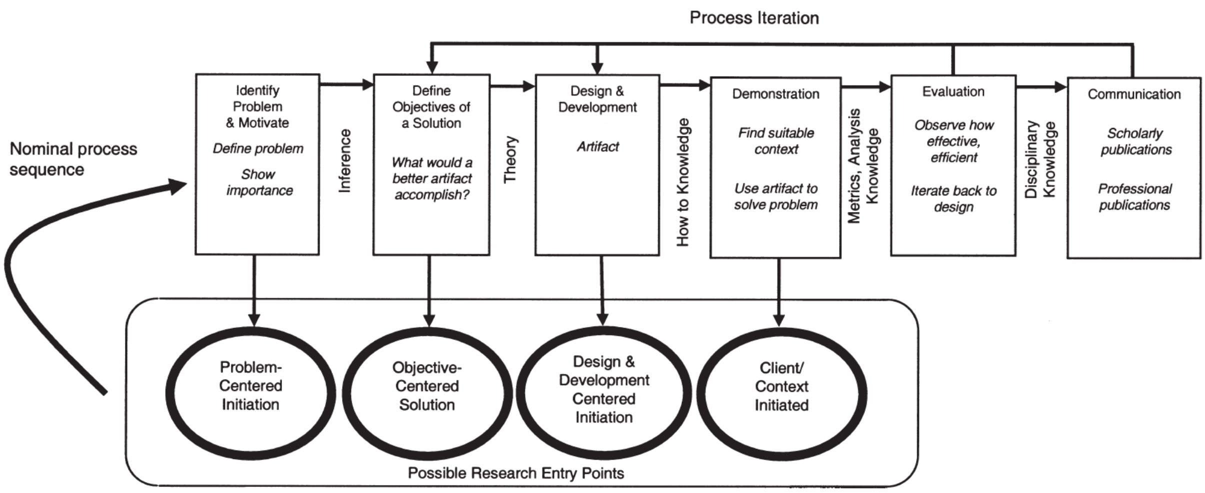

Figure 13 – Design Science Research Methodology process model
Retrieved from Peffers et al. (2007).

Despite the nominal sequence of the process model, researchers can initiate the process in any of the four initial activities, not necessarily the first one. This leads to different possible research entry points and different sequences of activities, depending on the activity in which researchers initiate the process (Peffers et al., 2007).

The complete nominal sequence, starting in activity 1, is a problem-centered approach. This occurs if the idea for a research was obtained from the observation of a problem or from future work suggested in former research. An objective-centered solution starts in activity 2 and it can be generated by a need of an industry or by a research that can be solutioned with the development of an artifact. Starting in activity 3, a design and development-centered approach refers to the existence of an artifact that has not been yet linked as a solution for the specific problem in which it is going to be used. This artifact might have been produced in a different research domain, it might have already been used in a different problem, or it might have emerged as a parallel idea. Lastly, a client/context-initiated solution can base itself on the observation of a practical solution that worked. Nonetheless, in this case, the researchers have to apply rigor to the process retroactively, so that it results in a design science solution (Peffers et al., 2007).

The six activities constituting the DSRM process model proposed by Peffers et al. (2007) are described next.

1. Problem Identification and Motivation

This initial activity defines the specific problem of the research and justifies the value of a solution. It may be appropriate to conceptualize the problem in order to allow the capture of its complexity by the solution, considering that the problem definition will be employed to develop an artifact that can effectively produce a solution. The justification of the value of a solution motivates the researcher and the audience of the research to work towards the solution and to accept the results. It also helps to comprehend the researcher's understanding of the problem. This activity requires knowledge of the state of the problem and the importance of its solution (Peffers et al., 2007).

2. Definition of the Objectives for a Solution

The objectives of a solution are inferred in this activity, in view of the problem previously defined in the first activity and the awareness of what is possible and feasible. These objectives, which should be inferred logically from the problem specification, can be quantitative, if a solution that would be better than the existing ones is discussed, or qualitative, if a new artifact expected to support solutions not yet addressed is proposed. Furthermore, knowledge of the state of problems and existing solutions (if any), and their efficacy, are required in this activity (Peffers et al., 2007).

3. Design and Development

Within this activity, the artifact is created. As previously stated, the artifacts can be constructs, models, methods, or instantiations (Hevner et al., 2004; March & Smith, 1995), or any object that has a research contribution incorporated in the design. It is in this activity that the artifact's desired functionality is established and, afterwards, the artifact is actually created. In order to progress from the objectives defined in the previous activity to the design and development in the current activity, it is necessary to have knowledge of theory that can be used in a solution (Peffers et al., 2007).

4. Demonstration

The fourth activity consists in demonstrating the use of the artifact to provide a solution to the problem. Such demonstration can involve experimentation, simulation, case study, proof, or other appropriate action. Effective knowledge in using the artifact to solve the problem is necessary (Peffers et al., 2007).

5. **Evaluation**

The evaluation within this activity is the observation and measurement of how well the artifact supports a solution to the problem. The objectives defined of a solution, in activity 2, are compared to actual obtained results from use of the artifact in the demonstration, in activity 4. This evaluation can be made in many forms, according to the nature of the problem. It can include items such as a comparison of artifact's functionality with the solution objectives, objective quantitative performance measures (budgets or items produced), surveys results, feedback from clients, or simulations. In conceptual terms, the evaluation could include any proper empirical evidence or logical proof. After completing this activity, the researchers can decide to iterate back to activity 3, in order to improve the artifact, or proceed to the following activity, leaving further improvement to future projects. The referred iteration can be feasible or not, depending on the nature of the research (Peffers et al., 2007).

6. **Communication**

The last activity consists in communicating the problem and its importance, the artifact and its utility and originality, the accuracy of its design, and its effectiveness to researchers and other relevant audience. The structure of this process model might be used by researchers to organize the paper in scholarly research publications. Knowledge of the disciplinary culture is required in this communication activity (Peffers et al., 2007).

As previously mentioned, the nominal sequence from activity 1 to activity 6 might not always be used, since researchers can start in any of the first four activities and move from there.

3.1.2 Application of the DSRM in this dissertation

This dissertation is initiated in activity 1 and uses the nominal sequence, as it will be further explained. In order to enlighten the adoption of the DSRM, next are explained the same six activities of the process model assumed (Peffers et al., 2007) that are employed, in practice, throughout the development of this dissertation.

1. **Problem Identification and Motivation, in practice**

Given the increasingly number of university-industry R&D collaborations (Perkmann, Neely, et al., 2011), measuring the performance of these form of collaboration acquires even more importance (Grimaldi & von Tunzelmann, 2002). Acknowledging this, a method capable of properly measuring the performance of university-industry R&D collaborations would support universities and industries throughout their collaborations, enabling them to achieve a better performance and greater success.

However, it has not yet been developed an organized and generally accepted system of indicators able to measure the performance of these collaborations (Piva & Rossi-Lamastra, 2013). This research identifies this fact as a problem and has the motivation of overcoming it.

This activity corresponds to Section 1.1 of the dissertation, which explains the motivation and background that leads to the development of this research.

2. Definition of the Objectives for a Solution, in practice

In view of the problem identified in the previous activity, the main objective of this dissertation is the development of a method capable of measuring the performance of university-industry R&D collaborations. To achieve this main objective, three specific objectives are defined within this activity and are stated as follows:

- <u>Objective 1</u>: Define a set of relevant performance indicators for measuring the performance of university-industry R&D collaborations.
- <u>Objective 2</u>: Identify a proposal for the weights of importance of each program phase, each process component, and each performance indicator.
- <u>Objective 3</u>: Develop a set of simple and easy criteria tables to use in each performance indicator for measuring the performance of university-industry R&D collaborations.

These objectives are seen as possible and feasible to achieve, and are inferred logically from the problem specification, performed in the first activity.

3. Design and Development, in practice

This activity is the core of the DSRM and of this dissertation and consists in the design and development of the artifact which, in the case of this research, is the MPUIC method. It will be within this activity that the desired functionality of the MPUIC method is established and the artifact is actually created.

The initial version of the MPUIC method (Fernandes et al., 2017) presented only preliminary results. In this dissertation, the MPUIC method continues to be developed, namely with the incorporation of criteria tables in the weighted scored approach.

The following Chapter 4 of the dissertation explains this design and development activity, discussing the initial version and the development of the MPUIC method.

4. **Demonstration, in practice**

The demonstration within this activity reveals the use of the MPUIC method to provide a solution to the problem identified in the first activity. Thus, the MPUIC method is going to be applied in a real case study of a university-industry R&D collaboration.

The case study used is the one described in the following Section 3.2 of the present Chapter. Furthermore, Chapter 5 reports the application of the method in the case study.

5. **Evaluation, in practice**

In this activity, an evaluation is performed in order to observe and measure how the method constitutes a solution to the problem. Such evaluation is made by means of a questionnaire.

This activity corresponds to the following Chapter 6 of the dissertation, which evaluates the MPUIC method as a solution to the initial problem.

6. **Communication, in practice**

All the communication associated to the MPUIC method is performed through the writing of this dissertation and of a future research article, wherein is presented the problem and its importance, the artifact and its utility and originality, the accuracy of the design and its effectiveness.

3.2 Data Collection

Given the research design defined in the previous Section, several techniques are set to be used in this dissertation as a means to collect data, namely in the Demonstration and Evaluation activities. Also, one should note that a case study is chosen as the research strategy for this dissertation. Thus, in the Demonstration activity, a questionnaire and document analysis are used to collect the necessary data. As for the Evaluation activity, a questionnaire, different from the previous one, is used to collect the required data.

The research strategy (case study) and the research techniques that are going to be used to collect data (document analysis and questionnaire) are explained next in this Section.

Case Study Description

The case study used as research strategy in this dissertation is the IC-HMI program, the second phase of a strategic partnership established between University of Minho (UMinho) and Bosch Car Multimedia Portugal (Bosch) in July 2012 for collaborative R&D, concerning the development and production of advanced car multimedia solutions (Fernandes et al., 2015). This partnership, which is financially supported by the European Union, opened a new path in collaborations between industry and educational institutions and has been considered a model of excellence in Europe ("Programa INNOVATIVE CAR HMI," 2018).

UMinho, founded in 1973, is considered one of the most prestigious universities in Portugal and is also gradually becoming more prominent in international terms. Its mission is to create, spread and apply knowledge, by promoting higher education. UMinho supports innovation and values knowledge, which is demonstrated by the existing partnerships with companies, the industrial property licensing (157 patents registered, between 2010 and 2015), the promotion of spin-offs (more than 40 spin-offs launched) or the R&D projects (432 projects).

Bosch is located in Braga, Portugal, since its foundation in 1990. Bosch is the main plant of the Car Multimedia division of Bosch Group and produces a wide-range of electronic products, such as navigation systems, steering angle sensors, and car radios. Bosch in Braga is recognized for its know-how and, beyond that, is the largest Bosch company in Portugal.

Before the IC-HMI program, the first phase of the partnership between UMinho and Bosch lasted from 2013 to 2015 and was characterized by Human Machine Interface Excellence (HMIExcel), a program that encompassed a series of multidisciplinary R&D projects combined into the applications domains of product development, quality control and production management (E. B. Pinto et al., 2016). The information characterizing the HMIExcel, such as the time period, the investment made, or the results achieved, is outlined in Table 5.

UMinho and Bosch understand the value of project management to support a collaboration like the one existing between them (Fernandes et al., 2018). Thus, they have developed a program and project management approach, designated as PgPM approach, specifically dedicated to program and project management of collaborative university-industry R&D collaborations (Fernandes et al., 2015). Moreover, since the HMIExcel program, UMinho and Bosch have been investing in an infrastructure designated as Program and Project

Management Office (PgPMO). This is a structure of the type Project Management Office which has a serving role and supports the Program Coordination and the Project Teams (Fernandes et al., 2018). Figure 14 illustrates the program organization of the university-industry R&D collaboration established between UMinho and Bosch.

Table 5 – HMIExcel information
Adapted from Fernandes et al. (2018).

Item	Value
Time period	26 months (May 2013 to June 2015)
Investment	19,2 million Euros
Projects	14
Scientific publications	32
Registered patents	12
Deliverables	162
Bosch recruitment	35 new staff admitted
UMinho recruitment	60 new researchers admitted
Human resources involved	around 300 researchers and collaborators

The Program Coordination is composed by four members: two Program Directors (one from UMinho and one from Bosch) and two Program Managers (one from UMinho and one from Bosch). As a matter of fact, each role of the program organization has a representative of UMinho and another of Bosch (Fernandes et al., 2018).

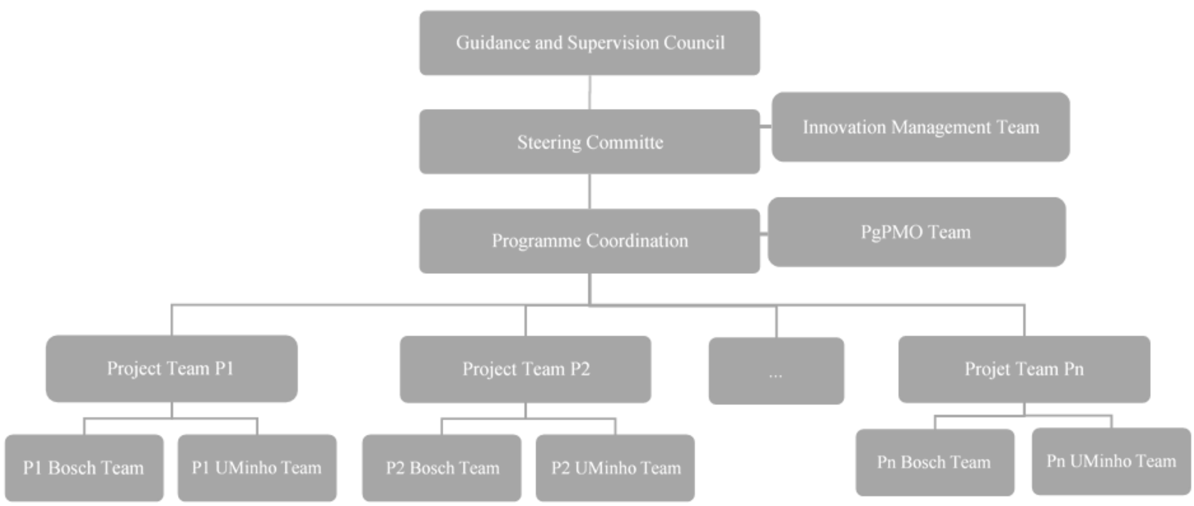

Figure 14 – Program organization between UMinho and Bosch
Retrieved from Fernandes et al. (2018).

A key fact to point out is that the abovementioned program and project management approach was still not conceptualized when the HMIExcel program was initiated. For this reason, the adoption of this approach within the HMIExcel program was only partial, since it skipped the Program Preparation and Program Initiation phases (Fernandes et al., 2015). Nevertheless, the adoption of this program and project management approach by the HMIExcel program lead to the following observations (Fernandes et al., 2015):

- The early setup of the program management office, or identical structure, and supporting team, is essential for programs to achieve success. This is emphasized by the typical fact of universities and industries not having this supporting office to manage and support their complex collaboration;
- A significantly improvement is achieved when face-to-face progress meetings between program management office and projects teams are conducted regularly. These meetings must be complemented with an overall communication routine;
- Including representatives of each entity, university and industry, in every structure of the program organization is essential to collaborative decision making and conflicts resolution;
- One of the main difficulties in the program management is the procurement process in both organizations because of the excess of bureaucracy, which is not appropriate for this context;
- The funding nature of the collaborative R&D contracts complicates the engagement of human resources, which usually only have work contracts for the time period of the corresponding program. This limits the performance of the programs.

All things considered, HMIExcel is considered a successful program for a variety of reasons. The planned scope, time, cost, and quality were achieved, and the stakeholders demonstrated high levels of satisfaction regarding the program. Moreover, several objectives planned for the mid and long-term were already achieved and a doctoral program between Bosch and UMinho, targeting the preparation of PhD students in industry, was established. A local Bosch Academy aiming the preparation and requalification of human capital is also going to be created. Finally, HMIExcel contributed to the awarding of Bosch with the prize of "Leading with Vision, Inspiration & Integrity" in the EFQM Excellence Award 2015 (E. B. Pinto et al., 2016).

The success achieved with the HMIExcel program contributed to the partnership's decision to develop a new program, named Innovative Car HMI (IC-HMI). As mentioned in the beginning of this Section, this program is the research strategy chosen for this dissertation and is also the second phase of the partnership between Bosch and UMinho (E. B. Pinto et al., 2016). Moreover, the IC-HMI program is the case scenario in which the main subject of this dissertation, the MPUIC method, is going to be applied. For these reasons, it is essential to present the IC-HMI program.

The IC-HMI program is the result of two applications, INNOVCAR and IFACTORY, but its size and complexity lead Bosch and UMinho to operationalize it a single R&D program. The investment involved in such program amounts to 54,7 million Euros for the time period of three years, from July 2015 to June 2018 (Fernandes, Pinto, Araújo, & Machado, 2017). Table 6 illustrates some information of the program, including values planned in terms of publications and patent applications, as well as the number of new staff and new researchers admitted by Bosch and UMinho, respectively.

Table 6 – IC-HMI information

Adapted from Fernandes et al. (2018).

Item	Value
Projects	30
Technical and scientific publications	72[a]
Patent applications	22[b]
Deliverables	417
Bosch recruitment	94 new staff admitted
UMinho recruitment	173 new researchers admitted

[a] until June 2021; [b] until June 2018

Both Bosch and UMinho identified the main benefits they expected from the IC-HMI program during the Program Preparation phase, including them in the application for the funding. Bosch expected to experience business and products diversification leading to sustained growth, to consolidate its reputation among costumers and within the Bosch Group itself and, lastly, to increase the international accumulated sales volumes. Correspondingly, UMinho expected the improvement of its recognition by the scientific community and the reinforcement of its scientific and technological knowledge transfer into industry (Fernandes, Pinto, Araújo, & Machado, 2017). Furthermore, the IC-HMI program manages its identified benefits with a benefits management approach that uses the iterative principle of the well-known PDCA cycle (Plan, Do, Check, Act). This approach is constituted by the four following phases: identify expected benefits, plan benefits realization, pursue benefits realization, and transfer and ensure benefits sustainability (Fernandes, Pinto, Araújo, & Machado, 2017).

Document Analysis

The data collected through the research technique of document analysis can be referred to as documentary secondary data. These type of data are frequently used in research projects that use primary collection data as well (Saunders et al., 2009), which is the case of this dissertation. Additionally, documentary secondary data includes written materials and documents that can be analyzed both quantitatively and qualitatively (Saunders et al., 2009). In the case of this dissertation, the analysis is quantitative and implies the collection of different documents related to the IC-HMI program, namely:

- The list of the academic researchers of UMinho and their engineering sub-discipline;
- The number of Steering Committee meetings (planned and performed);
- The number of result-sharing events (planned and performed);
- The number of innovation meetings (planned and performed);
- The number of progress meetings (planned and performed);
- The number of patent applications (submitted and planned);
- The list and the number of publications (published and planned);
- The number of deliverables (total and executed on time);
- The list of PhDs and research assistants recruited by Bosch;
- The education qualifications of Bosch collaborators;
- The number of master’s degree dissertations and PhDs theses obtained under the IC-HMI program context.

These documents are made available by the representative of UMinho in the program's infrastructure designated as PgPMO which, as mentioned earlier in this Section, has a serving role and supports the Program Coordination and the Project Teams (Fernandes et al., 2018).

Questionnaire

The case study research strategy can make use of the technique denominated as questionnaire (Saunders et al., 2009), as occurs in this dissertation. Questionnaire is a general term that includes all techniques of data collection wherein the respondents are asked to answer to the same questions in a predetermined order (Saunders et al., 2009). Figure 15 illustrates the different types of questionnaire considered.

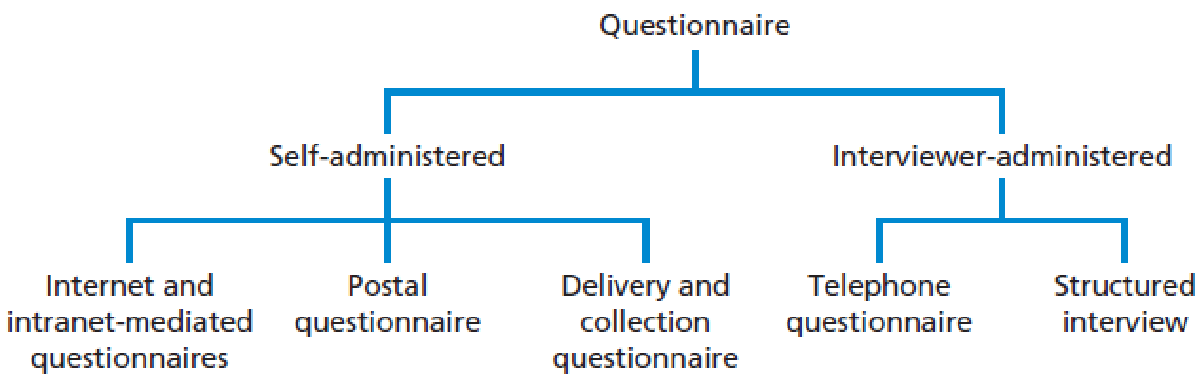

Figure 15 – Types of questionnaire

Retrieved from Saunders et al. (2009).

Concerning this dissertation, two different questionnaires are used: first, one in the Demonstration activity of the DSRM process model and then, other in the Evaluation activity of the same process model. According to Figure 15, both of them are considered self-administered questionnaires. However, the questionnaire used in the Demonstration activity is administered electronically through the Internet (an Internet-mediated questionnaire), while the questionnaire used in the Evaluation activity is delivered by hand to each respondent (a delivery and collection questionnaire).

Regarding the first questionnaire, used in the Demonstration activity, it consists in a questionnaire to which the researcher of this dissertation was granted access for the data of the responses, and not elaborated nor administered by the researcher himself. The data collected through this questionnaire is used in the application of the MPUIC method, in Chapter 5, and includes:

- The position of the respondents in the IC-HMI program;
- The years of previous experience of the respondents in the function they assume in the IC-HMI program;
- The education qualifications of the respondents;
- The contribution resulting from the participation in the IC-HMI program to the development of the respondents' academic/professional career;
- The respondents' satisfaction about the effective dedication of the UMinho researchers in the project of the IC-HMI program in which the respondents were involved;
- The respondents' satisfaction about the effective dedication of the Bosch collaborators in the project of the IC-HMI program in which the respondents were involved.

Accordingly, this questionnaire was anonymous, administered electronically using the Internet, and was made available to the IC-HMI stakeholders to respond during the first days of October 2018, with the objective of evaluating how the IC-HMI program functioned. More specifically, two topics were evaluated: (1) the global appreciation of the IC-HMI stakeholders in relation to the IC-HMI program itself, and (2) the perceived importance of the IC-HMI stakeholders about the program and project management practices adopted. The sample of this questionnaire corresponds to 218 respondents.

The second questionnaire (see Appendix I), used in the Evaluation activity, was elaborated and administered by the researcher of this dissertation. The questionnaire was divided into four parts, namely:

1. Characterization of the Respondent
2. Level of Relevance of the Performance Indicators
3. Weight of the Different Elements
4. Level of Simplicity and Ease of Use of Criteria Tables

The objective of this questionnaire was to collect data in order to evaluate the MPUIC method as a solution to the problem identified in the first activity of the DSRM process model (Problem Identification and Motivation), thus it was administered to university members with experience in the context of university-industry R&D collaborations. This Evaluation is described in Chapter 6 and the sample of this questionnaire corresponds to 13 respondents.

3.3 Data Analysis

The data collected from the research techniques described in the previous Section of the current Chapter is going to be analyzed quantitatively. Quantitative data in raw form has very little meaning before it is processed, hence the need to analyze and interpret it, turning data into information (Saunders et al., 2009). In order to perform the data analysis, the spreadsheets of Microsoft Excel and the statistical analysis software IBM SPSS Statistics are used.

Accordingly, the analysis of the data obtained from the document analysis was performed using the spreadsheets of Microsoft Excel, namely in the calculations necessary to apply the MPUIC method in the IC-HMI program. To do so, a set of functions was used, such as =SUM(), =AVERAGE(), and =COUNTIF().

Likewise, the spreadsheets of Microsoft Excel were also used to analyze the data obtained from the second questionnaire, used in the Evaluation activity, to obtain numerical measures of descriptive statistics and describe the data collected. The most significant descriptive statistics used include the mean, median, mode, and standard deviation. For a certain variable, the mean is the average score answered by the respondents and is obtained as the division of the sum of all responses under the total number of responses. Given that outliers values can influence the value of the mean, this measure of central tendency is complemented by other measures: (1) the median, which is not sensitive to outliers values and represents the value lying at the midpoint of the frequency distribution of the observed values; (2) the mode, which represents the value that occurs most frequently; (3) and the standard deviation, which is a measure of dispersion around the mean.

Furthermore, the analysis of the data obtained from the first questionnaire, used in the Demonstration activity, was performed using the software IBM SPSS Statistics. A descriptive analysis was made to the data of the answers of certain questions, required to apply the MPUIC method in the IC-HMI program. More specifically, the numerical measures of descriptive statistics were obtained through frequency tables and crosstabulation of variables.

4. Design and Development of the MPUIC Method

This Chapter corresponds to the third activity of the DSRM and reports the design and development of the MPUIC method, the artifact underpinning this dissertation. To do so, Section 4.1 first describes an initial version of the MPUIC method proposed by Fernandes, Pinto, Araújo, et al. (2017). Then, Section 4.2 states the existing difficulties associated to the application of that initial version and, lastly, Section 4.3 presents the MPUIC method as a proposed improvement that intends to overcome the previously identified difficulties.

4.1 Initial Version of the MPUIC Method

The method developed in an earlier research wherein the supervisors of this dissertation were involved (Fernandes, Pinto, Araújo, Magalhães, et al., 2017) is acknowledged as the work underpinning this dissertation and is the initial version of the MPUIC method. With the objective of measuring the performance of university-industry R&D collaborations, the method developed by these authors combines both retrospective (lagging) and prospective (leading) performance indicators (Fernandes, Pinto, Araújo, Magalhães, et al., 2017).

Accordingly, Fernandes, Pinto, Araújo, et al. (2017) achieved the initial version of the MPUIC method through a detailed review of the existing literature on the subject of performance measurement in university-industry R&D collaborations, as well as by the analysis of two case studies arising from the strategic partnership established between UMinho and Bosch – namely, the HMIExcel and IC-HMI programs, which are previously explained in Section 3.2. This method uses the work of Perkmann, Neely, and Walsh (2011) as its main theoretical foundation, due to the similarity of objectives and robustness. In addition, the work of Seppo and Lilles (2012) is used as the main source of performance indicators (Fernandes, Pinto, Araújo, Magalhães, et al., 2017).

Given that the initial version of the MPUIC method results from the need of the partnership between UMinho and Bosch for a quantitative tool able to measure and compare the performance of their collaborative R&D programs/projects, the authors adopted the program and project management life cycle used by the partnership (Fernandes, Pinto, Araújo, Magalhães, et al., 2017). Therefore, as stated by Fernandes et al. (2017), the four phases of this life cycle (namely, Program Preparation, Program Initiation, Program Benefits Delivery, and Program Closure) are linked to the four phases suggested by Perkmann et al. (2011) in their work (namely, Inputs, In-process activities, Outputs, and Impacts). Additionally, the method also considers a Post-Program phase that links to the Impacts phase defined by Perkmann et al. (2011). As Figure 16 illustrates, the phases used by each set of authors are closely related.

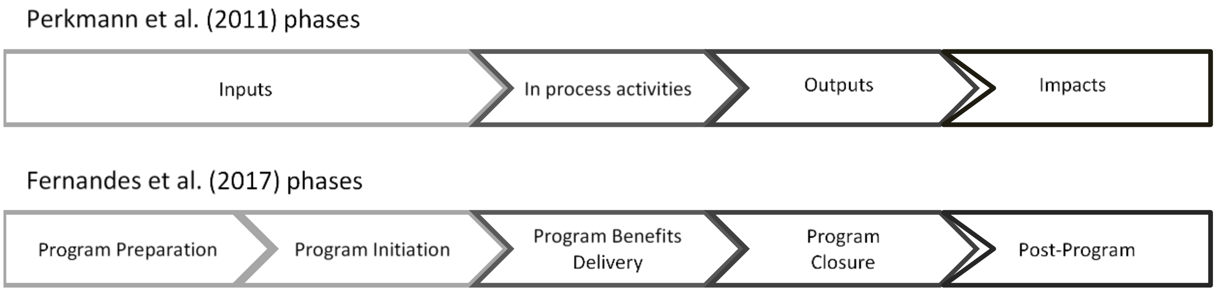

Figure 16 – Linkage between Perkmann et al. (2011) and Fernandes et al. (2017) phases Adapted from Fernandes et al. (2017).

Table 7 displays the initial version of the MPUIC method. It is possible to observe that this method organizes the performance indicators in process components which, in turn, are associated to the different phases of the program. Additionally, although it is not displayed in the table, the method distinguishes the process components (and, consequently, the performance indicators) according to which partners of the collaboration they relate to: university, industry, or both university and industry.

In this initial version, the highlights in bold refer to process components and performance indicators that were added by Fernandes, Pinto, Araújo, et al. (2017), as a result of their analysis of the HMIExcel and IC-HMI programs and the review of important references, namely the work of Seppo and Lilles (2012). This means that the highlighted process components and performance indicators were not included in the work of Perkmann et al. (2011), the main theoretical foundation of this method (Fernandes, Pinto, Araújo, Magalhães, et al., 2017).

Table 7 – Initial version of the MPUIC method

Retrieved from Fernandes et al. (2017).

Phase	Phase weight	Process component	Component weight	Performance indicator	PI weight
Program Preparation	25%	Researchers' capability	15%	1. Scientific impact (researchers' h-index)	40%
				2. % of researchers involved with past experiences in UI collaborative R&D projects	30%
				3. % of senior researchers (not research assistants)	30%
		Researchers' motivation	15%	4. % of research income from industry	100%
		Industry collaborators' capability	15%	**5. % of industry team collaborators with a postgraduate degree or a higher level of qualification (postgraduate, master or PhD)**	50%
				6. % of collaborators involved in past experiences of UI collaborative R&D programs/projects	50%
		Industry collaborators' motivation	15%	**7. Existence of innovation policy**	100%
		Opportunities/ challenges	20%	**8. Nº of opportunities/challenges**	100%
		Applied research	20%	9. % of projects ideas with joint objective setting	100%
Program Initiation	5%	**Governance established**	100%	**10. Joint governance model setting**	100%
Program Benefits Delivery	50%	Collaboration intensity	25%	**11. % Steering committee meetings (performed/planned)**	15%
				12. % result-sharing events	20%
				13. % Workplace meetings	25%
				14. % Progress meetings	20%
				15. % Technical team meetings	20%
		Technology	15%	16. Nr. of complete standard patent or other IP applications	100%
		New knowledge	15%	17. Nr. of publications	50%
				18. Nr. of joint publications	50%
		Management and organization quality	10%	**19. % Technical deliverables (reports or prototypes) executed on time**	100%
		Governance embedment	10%	**20. Governance model embedment**	100%
		Human capital	25%	**21. % Recruitment of PhD's by industry**	20%
				22. % Recruitment of research assistants (graduates) by industry partners	20%
				23. Perception of the impact of the program in the development of the academic or professional career	20%
				24. Structure of collaborators' qualification	20%
				25. Nr. of master's and PhD degrees	20%
Program Closure	15%	Innovations	50%	26. Nr. of new products	50%
				27. Nr. of new process improvements	50%
		Solution concepts	35%	28. Nr. of new solution concepts	50%
				29. Increase TRLs	50%
		New project ideas	15%	30. Nr. new project ideas	100%
Post-program	5%	Technology achievement	30%	31. Nr. of patents granted	100%
		Turnover	40%	**32. Turnover growth**	100%
		Partnership sustainability	30%	**33. Value of new collaborative research projects generated**	100%

Furthermore, different weights were proposed by the authors of the initial version of the MPUIC method to all the performance indicators, process components, and program phases. These weights are based on the impact that each element has to the performance of university-industry R&D collaborations, in view of the authors' experience regarding the case studies used in their research (HMIExcel and IC-HMI). However, the authors also stated that these weights are likely to change according to the context and the importance attributed to each performance indicator, process component, and program phase. Thus, the weights should be attributed in accordance to the specific program or project that might use the method to measure its performance (Fernandes, Pinto, Araújo, Magalhães, et al., 2017).

The MPUIC Method as a Weighted Scoring Approach

The MPUIC method has as theoretical foundation the weighted scoring approach. The weighted scoring approach is a simple, direct, and effective approach to combine data terms (Bitman & Sharif, 2008). To do so, weighted scoring approaches require a well-defined number as an input to each criteria. Most of the times, however, the criteria used in weighted scoring approaches to perform an evaluation are subjective and may not be well defined (Cochran & Chen, 2005), hence the use of classifications such as "high", "medium", "low", and so forth. Classifications of this kind frequently replace the well-defined numbers (Cochran & Chen, 2005) in the evaluation of features in a weighted scoring approach. These weighted scoring approaches are based on scoring models, which are often used in R&D project selection since they are consistent with other selection models (Lucas & Moore, 1976), but have the already stated advantage of allowing the combination of both qualitative and quantitative factors (Moore & Baker, 1969).

In addition to the use of both quantitative and qualitative aspects in a unified manner, weighted scoring approaches also integrate the possibility to customize the system through the specification of weights which act like coefficients (Bitman & Sharif, 2008) and can be changed in function of the specific context. This criteria weighting is important since it allows to reflect priorities (Moore & Baker, 1969). Moreover, if necessary, it is also possible to include or remove criteria (Lucas & Moore, 1976), provided that all criteria are measurable on a scale, either a natural or artificial one, and a measurement unit is assigned to the criteria, such as a currency unit (euros, for example) or percentage (Lucas & Moore, 1976).

Given its characteristics, the weighted scoring approach is underpinning the MPUIC method. This type of approach is employed not only through the use of various qualitative and quantitative performance indicators, but also through the attribution of coefficients to each program phase, process component, and performance indicator. In the MPUIC method, these coefficients are denominated as weights and are represented by percentages. Through the attribution of these weights, the different impacts of all elements that constitute the method are considered to the overall performance of university-industry R&D collaborations and, consequently, are reflected in the final score reached through the application of the MPUIC method.

In order to comprehend the MPUIC method as a whole, one should first fully understand the elements that constitute the initial version that is being presented in this Section. Thus, the initial version of the MPUIC method is described next throughout its five phases.

Program Preparation phase (performance indicators 1–9)

In the first phase, the objective is to outline the R&D program and obtain financial support (Fernandes et al., 2015). Thus, this phase first considers the researchers' capability, taking into account their h-index (Czarnecki, Kaźmierkowski, & Rogalski, 2013; Perkmann, Neely, et al., 2011; Seppo & Lilles, 2012), their past experience in university-industry R&D collaborations (Seppo & Lilles, 2012), and the presence of senior researchers (Fernandes, Pinto, Araújo, Magalhães, et al., 2017), that is to say, the researchers effectively contracted by the university and not the researchers with fellowships. Then, the researchers' motivation is also considered through the percentage of the university's research income from industry (Adams, Bessant, & Phelps, 2006; Perkmann, Neely, et al., 2011; Seppo & Lilles, 2012), whereby it is expected that the motivation of the researchers increases with higher values of income (Fernandes, Pinto, Araújo, Magalhães, et al., 2017).

Moreover, three new process components were added by Fernandes et al. (2017) in this phase, as highlighted in bold. It was suggested that the capability and motivation should also be measured in the industry side, hence the addition of the industry collaborators' capability and industry collaborators' motivation components. The capability of the industry collaborators can be measured by means of two performance indicators, namely: the percentage of collaborators with a postgraduate degree or a higher level of qualification

(Seppo & Lilles, 2012) and the percentage of collaborators with past experience university-industry R&D collaborations (Barnes et al., 2002). As for the motivation of the industry collaborators, a performance indicator to measure the existence of innovation policy is proposed by the authors, wherein the idea consists in the existence of certain pressures to reach innovation, such as market pressure (Fernandes, Pinto, Araújo, Magalhães, et al., 2017). In addition, the third process component that was added, opportunities/challenges, consists in the necessary input to outline any R&D program/project and can be measured through the number of opportunities and challenges to be studied from this phase forward (Iqbal et al., 2011).

Lastly, this phase considers the importance of applied research, through the extent to which objectives and potential solutions of each initial idea are jointly determined by both industry and university (Perkmann, Neely, et al., 2011).

Program Initiation phase (performance indicator 10)

This phase intends to ensure the initial planning of the program, as well as the alignment of its objectives and outcomes with the stakeholders that effectively will be entailed throughout the execution of the program (Fernandes et al., 2015). Therefore, governance established is the only component considered in this phase and can be measured through the degree to which a joint governance model is established.

The point here is that the objectives within a university-industry R&D collaboration should be clearly defined between both partners, due to their differences in requirements and expectations, and the end results of these R&D programs/projects, which are frequently hard to predict. To do so, the establishment of a governance model as a support to the program management and the management of the inherent projects is seen as a good practice that is able to contribute to program management, degree of commitment, trust, communication, and team spirit (Barnes et al., 2006; Chiesa, Frattini, Lazzarotti, & Manzini, 2009).

Program Benefits Delivery phase (performance indicators 11–25)

Here, the projects that constitute the program are planned, integrated and managed, so that the expected program benefits are delivered (Fernandes et al., 2015). This phase first considers the intensity of the collaboration due to the knowledge transmission that is facilitated with a frequent interaction between the partners (Perkmann, Neely, et al., 2011), hence the collaboration intensity component. This interaction through diverse channels is likely to reduce the gap between science and its application (P. D'Este & Patel, 2007), thus the five performance indicators regarding meetings and events that are considered to measure the intensity of the collaboration (P. D'Este & Patel, 2007; Seppo & Lilles, 2012).

Moreover, high-quality research should result in the generation of new scientific knowledge (Perkmann, Neely, et al., 2011) and the development of new technologies (Fernandes, Pinto, Araújo, Magalhães, et al., 2017). Thus, the method includes patent applications submitted to measure the technology component; and total publications (Perkmann, Neely, et al., 2011; Seppo & Lilles, 2012), as well as publications jointly developed by university and industry members (Seppo & Lilles, 2012; Tijssen, van Leeuwen, & van Wijk, 2009), to measure the new knowledge component. Since the key to successful collaborations is influenced by how well they are managed, the component of management and organizational quality was added by the authors and can be measured recurring to the percentage of technical deliverables executed on time (Barnes et al., 2006).

Finally, the human capital component considers five performance indicators, namely: the recruitment by the industry partner of PhDs (Seppo & Lilles, 2012) and the recruitment of researchers with fellowships (Perkmann, Neely, et al., 2011; Seppo & Lilles, 2012), as two distinct performance indicators; the perception by both university and industry members of the impact of the program in the development of their careers (Seppo & Lilles, 2012); the structure of qualifications of the collaborators (Fernandes, Pinto, Araújo, Magalhães, et al., 2017); and the number of master's degree and PhD degrees, considering the dissertations and theses developed under the context of the program (Perkmann, Neely, et al., 2011; Seppo & Lilles, 2012).

Program Closure phase (performance indicators 26–30)

This phase has the objective of executing a controlled closure of program and evaluate the sustainability of the R&D collaboration (Fernandes et al., 2015). The performance indicators of product innovation and process innovation (Perkmann, Neely, et al., 2011) are considered under the component of innovations. Likewise, the performance indicators that consider new solutions, which are in between the simple ideas and the innovations ready to be exploited commercially (Perkmann, Neely, et al., 2011), are under the component of solutions concepts. Still under this component, the authors of the method included the performance indicator that considers the increase of technology readiness levels, and their evolution from the beginning of the projects until the present phase (Fernandes, Pinto, Araújo, Magalhães, et al., 2017). Last of all, under the component of new ideas is the performance indicator that regards the new project ideas generated during the ongoing program which might be proposed for a new R&D program (Perkmann, Neely, et al., 2011).

Post-program phase (performance indicators 31–33)

Lastly, this final phase considers the components of technology achievement, turnover, and partnership sustainability. The performance indicators suggested to measure these components are, respectively, the number of patents granted (Perkmann, Neely, et al., 2011; Seppo & Lilles, 2012), the growth of the sales volume of the industry partner (Seppo & Lilles, 2012), and the investment value of possible new R&D collaborations generated within the partnership. Moreover, the time horizon of the impacts to be measured within this phase is not immediate and may vary between one to three years after the Program Closure phase (Fernandes, Pinto, Araújo, Magalhães, et al., 2017).

After describing the theoretical foundation and the performance indicators that constitute the initial version of the MPUIC method, the actual steps for applying it are described next.

Steps for Applying the MPUIC method

One should note that, in a possible application of the MPUIC method, the performance indicators to be measured depend on the life cycle phase of the program/project by the time of the possible application. For instance, in an application of the method where the program/project is located in the Program Preparation phase, only the initial nine performance indicators would be considered. If, in a further application, the program/project is located in the Program Benefits Delivery phase, those first nine performance indicators associated to the Program Preparation phase are measured once again. In this case, however, the application must also consider and measure for the first time the performance indicators associated to the Program Preparation phase and the Program Initiation phase, and so forth.

In regard to the responsibility to actually apply the MPUIC method, it is suggested that this responsibility lies with the program/project manager, with the support from a Program Management Office team (Fernandes, Pinto, Araújo, Magalhães, et al., 2017). Finally, Fernandes et al. (2017) divide the application of the MPUIC method into the six steps that are described next.

In the **first step** to apply the MPUIC method it is necessary to assess the importance of each program/project phase, process component, and performance indicator, which translates in assigning them a weight as a form of percentage. Thus, according to the specific phase of the life cycle where the program/project is located, different weights must be assigned. This means that, for example, if the method is set to be applied in a program/project at the end of the Program Preparation phase, this phase should be assigned with a weight of 100% since all the remaining ones have no importance at that time, hence the 0%. In the Program Benefits Delivery phase, however, a weight should be assigned to the first three life cycle phases (namely, Program Preparation, Program Initiation, and Program Benefits Delivery), according to the importance of each to the performance of a specific university-industry R&D collaboration wherein the method is set to be applied, and so forth (Fernandes, Pinto, Araújo, Magalhães, et al., 2017).

The following two steps are interrelated and are essential to allow the application of the MPUIC method. In particular, the **second step** requires the collection of all the data necessary to measure each performance indicator and, afterwards, the **third step** uses this measurement data to score each performance indicator in a five-point scale (wherein 1 is very low, 2 is low, 3 is medium, 4 is high, and 5 is very high). On the one hand, the quantitative nature of some performance indicators simply requires the use of a rule that divides 100% into five percentage intervals with equal range, which is sufficient to directly correspond each percentage interval to each of the five scores and, thus, measure these performance indicators. On the other hand, the measurement of certain qualitative performance indicators entails a more complex criterion to attribute one of the five possible scores. In these cases, it is required the expert judgment of the accountable for applying the MPUIC method, who is suggested to obtain the perceptions of different stakeholders in order to measure the qualitative performance indicators (Fernandes, Pinto, Araújo, Magalhães, et al., 2017).

Furthermore, if the MPUIC method is applied with the program/project still ongoing, the performance indicators with a low score can be selected and prioritized (**fourth step**), so that actions can be defined in order to improve these low scoring performance indicators (**fifth step**). Conversely, if the MPUIC method is applied in a finished program/project, no actions can be established and only the success of the performance of the program/project can be achieved (Fernandes, Pinto, Araújo, Magalhães, et al., 2017).

Finally, the MPUIC method can be applied during any phase of the program/project management life cycle, but, as the **sixth step**, the authors suggest periodic assessments with intervals of six months to one year. It is also suggested that the first application of the method is at the end of the Program Preparation phase, followed by two or three applications during the Program Benefits Delivery phase, one application at the end of the Program Closure phase, and, finally, one last application in the Post-program phase (Fernandes, Pinto, Araújo, Magalhães, et al., 2017).

Considering the above description of the initial version of the MPUIC method and the steps of its application, it is now possible to advance to the following Section, wherein the difficulties in actually applying the MPUIC method are identified.

4.2 Difficulties in Applying the Initial Version of the MPUIC Method

The existing difficulties in applying the initial version of the MPUIC method are in accordance with the distinction established in the literature review (Section 2.5), with regard to three concepts:

- Performance measure
- Performance measurement
- Performance measurement system

Consequently, the initial difficulty encountered consists in the presence of infeasible and redundant performance indicators in the initial version of the MPUIC method. Thus, this difficulty relates to the **performance measures** adopted or, as defined in Section 2.5, to the metrics used to quantify the efficiency and/or effectiveness of a certain action (Neely et al., 1995).

Furthermore, a different difficulty perceived is centered in the actual application of the method, namely in the measurement of the performance indicators and in the complexity of attributing them a correspondent score. In contrast to tangible outcomes used in some performance indicators (such as patents, publications, or meetings), a high degree of subjectivism characterizes other performance indicators and hinders their measurement. Fernandes et al. (2017) recognize that the achievement of a general agreement on the criteria to be used to measure these subjective performance indicators is a complex endeavor. Altogether, this difficulty relates to the concept of **performance measurement** which, as stated in Section 2.5, is the process of quantifying the efficiency and effectiveness of actions (Neely et al., 1995).

All things considered, these identified difficulties affect the initial version of the MPUIC method which is considered as the **performance measurement system** and, as defined in Section 2.5, consists in the series of metrics used to quantify the efficiency and effectiveness of actions (Neely et al., 1995). In this case, the MPUIC method is the performance measurement system composed by a set of performance indicators used to quantify the efficiency and effectiveness of actions in the performance of university-industry R&D collaborations.

The acknowledgement of the abovementioned difficulties meets Research Objective 1, identified in Section 1.2, that consists in identifying the difficulties in applying the initial version of the MPUIC method. Therefore, these difficulties must be addressed so that an actual application of the MPUIC method may occur successfully.

4.3 MPUIC Method as a Proposed Improvement

The MPUIC method is a proposed improvement of its initial version that aims to overcome the existing difficulties before proceeding to the application in the IC-HMI program. In this proposed improvement, slight adjustments are made in the denomination of some performance indicators in order to facilitate their comprehension. Similarly, the denomination of “process component” is changed to “performance component”. Moreover, two main improvements in the MPUIC method are proposed, when compared to the initial version: the actual modifications in the performance indicators used (Subsection 4.3.1) and the incorporation of criteria tables within the weighted scoring approach (Subsection 4.3.2).

4.3.1 Modifications in the Performance Indicators Used

Regarding the initial difficulty identified in Section 4.2 in applying the initial version of the MPUIC method, which consists in the performance measures adopted, this Subsection proposes a set of modifications to the performance indicators used. The objective of these modifications is to replace the infeasible performance indicators and eliminate the existing redundancy.

First Modification

The performance indicator 4 of the initial version of the MPUIC method ("percentage of research income from industry") is replaced by a different performance indicator in the MPUIC method, namely the "percentage of researchers satisfied with the contribution of their participation in a collaboration with industry to the development of their academic careers". This performance indicators intends to measure the researchers' motivation.

Perkmann et al. (2011) acknowledge the difficulty of measuring the researchers' motivation directly. Thus, the authors suggest the share of industry contribution to the university research income as a form to capture how industry-friendly a university is and, from there, capture the researchers' motivation (Perkmann, Neely, et al., 2011). The main idea is that a high value of research income from industry indicates a higher researcher's motivation (Fernandes, Pinto, Araújo, Magalhães, et al., 2017). This income should, however, be measured against the average industry income for a certain scientific area, in order to account for differences across scientific areas (Perkmann, Neely, et al., 2011).

However, all these average values of research income from industry across different scientific area are not feasible to obtain, hence the proposal of a new performance indicator to measure the researchers' motivation, considered as a close alternative in different studies. Perkmann et al. (2011), the same authors who suggested the previous indicator to measure the researchers' motivation, indicate as an alternative the measuring of "researchers' views of the benefits they derive from industry contact" (p. 209). Likewise, Seppo and Lilles (2012) propose the "perception of researcher about the benefits from the cooperation with industry" (p. 213) as a performance indicator to measure the researchers' motivation.

Therefore, the proposed performance indicator in the MPUIC method to measure the researchers' motivation is the "percentage of researchers satisfied with the contribution of their participation in a collaboration with industry to the development of their academic careers". Although there may exist other small benefits to the researchers deriving from cooperating with industry, the majority of these benefits are included in the development of their academic careers.

An existing limitation of the proposed performance indicator is that it implies that a given university and industry are not collaborating together for the first time, but, instead, have a collaborative past between them. Otherwise, it is not possible to obtain data to measure the performance indicator proposed.

Second Modification

The performance indicator 7 of the initial version of the MPUIC method ("existence of innovation policy") is replaced by a different performance indicator in the MPUIC method, namely the "percentage of industry collaborators satisfied with the contribution of their participation in a collaboration with university to the development of their professional careers". This performance indicators intends to measure the industry collaborators' motivation.

In the Initial version of the MPUIC method, the idea is to measure the industry collaborators' motivation through the existence of innovation policy, that is to say, the existence of pressure to reach innovation, such as market pressure. However, this performance indicator is not feasible to use, given the number of pressures exerted on industry. Thus, a modification has to be proposed.

According to Seppo and Lilles (2012), a possible indicator to measure the firms' motivation is the "perception of the firm about the benefits from the cooperation with university" (p. 213). Similar to the idea of Seppo and Lilles (2012) to measure the firms' motivation, the MPUIC method proposes the measurement of the industry collaborators' motivation through their satisfaction of the collaboration with university as a form to develop their professional careers. The logic underpinning this alteration is identical to the one of the first modification, since it is considered that the majority of benefits to the industry collaborators deriving from cooperating with university are included in the development of their professional careers.

In the same way as the first modification, there is also an existing limitation in the performance indicator proposed here. Namely, the proposed performance indicator implies a collaborative past between university and industry, otherwise the data to measure the performance indicator proposed would not be obtainable.

Third Modification

The performance indicator 15 of the initial version of the MPUIC method ("percentage of technical team meetings") is replaced by a different performance indicator in the MPUIC method, namely the "percentage of researchers and industry collaborators satisfied about each other's effective dedication to the collaboration". This performance indicators intends to measure the collaboration intensity.

The initial performance indicator related to the percentage of technical team meetings is not considered to the MPUIC method given the fact that, in this level of meetings, many important but informal interactions between team members occur frequently. Given their informal character, these interactions are not registered neither considered as technical team meetings. Thus, they are not captured by the initial performance indicator, despite the importance which they often have to the intensity of the collaboration at this level.

Therefore, the MPUIC method replaces this performance indicator with one that measures the satisfaction of university and industry members with each other's effective dedication to the university-industry R&D collaboration.

Fourth Modification

The performance indicator 20 of the initial version of the MPUIC method ("governance model embedment") is no longer considered in the MPUIC method. This performance indicators intended to measure the governance embedment.

This removal is due to an overlap of criteria, since the deliverables executed on time (performance indicator 19 in the Initial version of the MPUIC method) are also able to measure how well a governance model is embedded in the university-industry R&D collaboration (Fernandes, Pinto, Araújo, Magalhães, et al., 2017). Any kind of overlap of criteria must be avoided, since, if it occurs, it leads to multiple counting and overestimation. In these cases of similar criteria, they can often be combined and form a single criterion (Lucas & Moore, 1976).

Therefore, to avoid overlap of criteria in the MPUIC method, a performance indicator that solely measures the governance model embedment no longer exists. Accordingly, the embedment of a governance model is now measured through the performance indicator that measures the deliverables executed on time, which is preserved in the MPUIC method.

Fifth Modification

As the last main modification, the performance indicator 23 of the Initial version of the MPUIC method ("perception of the impact of the program in the development of the academic or professional career") is no longer considered in the MPUIC method. This performance indicators intended to measure the human capital.

The mentioned perception of the collaboration impact to the careers is already measured by performance indicators 4 and 7 of the MPUIC method, as indicated in the first and second modifications. Therefore, to avoid overlap of criteria and the existence two performance indicators measuring identical aspects, the original performance indicator 2 is removed in the MPUIC method.

As a summary, Table 8 presents all modifications performed in the MPUIC method regarding the performance indicators used, in comparison to the initial version.

Table 8 – Modifications in the performance indicators used in the MPUIC method

Modification to the Performance Indicator	Performance Indicator in the Initial Version of the MPUIC Method	Performance Indicator in the MPUIC Method
First Modification: Replacement	4. Percentage of research income from industry	4. Percentage of researchers satisfied with the contribution of their participation in a collaboration with industry to the development of their academic careers
Second Modification: Replacement	7. Existence of innovation policy	7. Percentage of industry collaborators satisfied with the contribution of their participation in a collaboration with university to the development of their professional careers
Third Modification: Replacement	15. Percentage of technical team meetings	15. Percentage of researchers and industry collaborators satisfied about each other's effective dedication to the collaboration
Fourth Modification: Removal	20. Governance model embedment	–
Fifth Modification: Removal	23. Perception of the impact of the program in the development of the academic or professional career	–

Finally, Table 9 displays the new version of the MPUIC method as a whole.

Table 9 – The MPUIC method

Program Phase	Weight	Related to*	Performance Component	Weight	Performance Indicator	Weight
Program Preparation	25 %	U	Researchers' capability	15 %	1. Average h-index of the academic researchers (excluding research assistants)	40 %
					2. Percentage of researchers with past experience in university-industry R&D collaborations	30 %
					3. Percentage of researchers involved that are not research assistants	30 %
		U	Researchers' motivation	15 %	4. Percentage of researchers satisfied with the contribution of their participation in a collaboration with industry to the development of their academic careers	100%
		I	Industry collaborators' capability	15 %	5. Percentage of industry collaborators with a post-graduation or a higher education qualification	50 %
					6. Percentage of industry collaborators with past experience in university-industry R&D collaborations	50 %
		I	Industry collaborators' motivation	15 %	7. Percentage of industry collaborators satisfied with the contribution of their participation in a collaboration with university to the development of their professional careers	100%
		U & I	Opportunities/challenges	20 %	8. Number of project ideas to be studied	100%
		U & I	Applied research	20 %	9. Percentage of initial project ideas in which the detailing of objectives and potential solutions is jointly determined by university and industry members	100%
Program Initiation	5 %	U & I	Established governance	100%	10. Degree of establishment of a joint governance model	100%
Program Benefits Delivery	50 %	U & I	Collaboration intensity	25 %	11. Rate of Steering Committee meetings (performed/planned)	15 %
					12. Rate of result-sharing events (performed/planned)	20 %
					13. Rate of innovation meetings (performed/planned)	25 %
					14. Rate of progress meetings (performed/planned)	20 %
					15. Percentage of researchers and industry collaborators satisfied about each other's effective dedication to the collaboration	20 %
		U & I	Technology	15 %	16. Rate of patent applications (submitted/planned)	100%
		U & I	New knowledge	15 %	17. Rate of publications (published/planned)	50 %
					18. Percentage of joint publications	50 %
		U & I	Management and organizational quality	20 %	19. Rate of deliverables executed on time	100%
		U & I	Human capital	25 %	20. Rate of recruitment of PhDs researchers from the program by the industry partner	25 %
					21. Rate of recruitment of research assistants from the program by the industry partner	25 %
					22. Variation in the percentage of collaborators with higher education qualifications	25 %
					23. Number of master's degree dissertations and PhD theses obtained under the program context	25 %

Table 9 (continued) – The MPUIC method

Program Phase	Weight	Related to*	Performance Component	Weight	Performance Indicator	Weight
Program Closure	15 %	I	Innovations	50 %	24. Number of new products and product improvements developed	50 %
					25. Number of new processes and process improvements developed	50 %
		I	Solution concepts	35 %	26. Number of new solutions concepts generated	50 %
					27. Increase of technology readiness levels (TRL), in comparison to the beginning of the projects within the program	50 %
		U & I	New ideas	15 %	28. Number of new project ideas generated from the program, which might result in a new R&D program	100 %
Post-Program	5 %	U & I	Technology achievement	30 %	29. Rate of patents granted (granted/submitted)	100%
		I	Sales growth	40 %	30. Variation of annual sales volume (net all discounts and taxes), from the program closing year to the year of the measuring	100%
		U & I	Partnership sustainability	30 %	31. Investment value of new university-industry R&D projects/programs generated	100%

* U – University; I – Industry; U & I – University and Industry

4.3.2 Incorporation of Criteria Tables within the Weighted Scoring Approach

As can be noted, the MPUIC method, in the same way as its initial version, continues to presuppose the use of a weighted scoring approach in order to the weights to function as coefficients. The weights indicated in the MPUIC method come from the initial version, except from the following alterations due to the removal of the two performance indicators.

- In the Initial version of the MPUIC method, the "governance model embedment" was the single indicator composing the performance component "governance model embedment", which was weighted with 10%. With the removal of this performance indicator and, consequently, this performance component, the weight is attributed to the performance component "management and organizational quality" which in the MPUIC method is weighted with 20% (its initial 10% plus this attribution). This attribution is logical, since the performance indicator composing this performance component ("rate of deliverables executed on time") is able to capture how well a governance model is embedded in the university-industry R&D collaboration.
- The second performance indicator removed, "perception of the impact of the program in the development of the academic or professional career", was one of the five performance indicators composing the performance component "human capital". This performance component weighted equally its five performance indicators, therefore, this equal distribution is also performed in the MPUIC method. With the indicated removal, this performance component in the MPUIC method is composed by one less performance indicator if compared to the initial version, but the four remaining performance indicators continue to be weighted equally, now with 25% instead of 20%.

In order to the weighted scoring approach underpinning the MPUIC method to be applied, criteria tables are going to be linked to each of the thirty-one performance indicators. By doing so, it is possible to define the minimum and maximum margins of each score in all performance indicators and measure them in a six-point scale: in addition to the five-point scale previously adopted by the Initial version of the MPUIC method (wherein 1 is very low, 2 is low, 3 is medium, 4 is high, and 5 is very high), the criteria tables also contemplate the score "0 – N/A" which can be used when certain performance indicator is not applicable.

Thus, the thirty-one criteria tables are explained next, throughout the five phases of the MPUIC method.

Program Preparation phase (performance indicators 1–9)

Table 10 is related to performance indicator 1 of the MPUIC method: the average h-index of the academic researchers (excluding research assistants).

This performance indicator (and the MPUIC method, in general) differentiates between researchers effectively contracted by the university (the academic researchers) and researchers with fellowships (the research assistants). The designation "researchers" isolated refers to both academic researchers and research assistants.

Table 10 – Criteria Table 1: h-index of the academic researchers

Criteria	Score
Not applicable	0 – N/A
h-index of the academic researchers (excluding research assistants) is < 50% of the average	1 – Very low
h-index of the academic researchers (excluding research assistants) is [50, 70[% of the average	2 – Low
h-index of the academic researchers (excluding research assistants) is [70, 90[% of the average	3 – Medium
h-index of the academic researchers (excluding research assistants) is [90, 110[% of the average	4 – High
h-index of the academic researchers (excluding research assistants) is ≥ 110% of the average	5 – Very high

The h-index stated in this performance indicator attempts to measure the impact of the scientific output of a certain researcher. As an illustration, if a researcher has an h-index of 7 it means that this researcher has 7 articles published, each of them with at least 7 citations. Hirsch (2005), the author who suggested the h-index, states that "a scientist has index *h* if *h* of his/her N_p papers have at least *h* citations each, and the other (N_p – h) papers have no more than *h* citations each" (p. 16569).

It is considered that the higher the h-index of the academic researchers, the higher their capability which, consequently, is expected to lead to higher performance of the university-industry R&D collaboration. To reach the h-index intervals of the criteria table, the expert judgment and experience of the supervisors of this dissertation are considered. However, the h-index of the academic researchers must be compared against a point of reference, so that an average is reached and a score is attributed. Thus, two points of reference possible to be used are proposed:

- A research that reaches the mean h-index of polish engineering sub-disciplines (Czarnecki et al., 2013), given that, in this research, the h-index of Portugal (84) is very close to the h-index of Poland (82). This research is going to be the point of reference used in the application of the MPUIC method, since the academic researchers of the case study in which the MPUIC method is going to be applied belong to the engineering field and, having a differentiation of several engineering sub-disciplines (electrical engineering, materials science, etc.), the measurement of the h-index of these researchers will be more precise.

- A research that reaches the h-index of world's countries on various science fields (Csajbók, Berhidi, Vasas, & Schubert, 2007). Here, all fields across several countries are considered, but in general terms. For example, the main field "engineering" is discriminated in the stated research, not dividing this field into its several disciplines. Thus, using this research as a point of reference would provide a less precise measurement of the h-index of researchers when compared to the previous proposal, namely of the researchers included in the case study wherein the MPUIC method is going to be applied.

Nevertheless, a limitation in using any of these two proposals as point of reference is the year of the researches. Since these researches are from 2013 and 2007, respectively, the h-index values considered in both of them may have varied until the present moment.

Next, Table 11 is related to performance indicator 2 of the MPUIC method: the percentage of researchers with past experience in university-industry R&D collaborations.

Table 11 – Criteria Table 2: researchers with past experience in university-industry R&D collaborations

Criteria	**Score**
Not applicable	0 – N/A
[0, 20[% of the researchers have past experience in university-industry R&D collaborations	1 – Very low
[20, 40[% of the researchers have past experience in university-industry R&D collaborations	2 – Low
[40, 60[% of the researchers have past experience in university-industry R&D collaborations	3 – Medium
[60, 80[% of the researchers have past experience in university-industry R&D collaborations	4 – High
[80, 100] % of the researchers have past experience in university-industry R&D collaborations	5 – Very high

As for the experience of the researchers (both academic researchers and research assistants) in university-industry R&D collaborations, the researcher of this dissertation, considering the expert judgment and experience of the supervisors, decided that having experience corresponds to having, at least, one year of past experience in university-industry R&D collaborations. Acknowledging this, the criteria table establishes five intervals of equal range by dividing equally the total of researchers (100%) by the five possible scores. It is considered that the higher the past experience of the researchers, the higher their capability which, consequently, is expected to lead to higher performance of the university-industry R&D collaboration.

The following Table 12 is related to performance indicator 3 of the MPUIC method: the percentage of researchers involved that are not research assistants.

Table 12 – Criteria Table 3: researchers involved are not research assistants

Criteria	Score
Not applicable	0 – N/A
[0, 10[% of the researchers involved are not research assistants	1 – Very low
[10, 20[% of the researchers involved are not research assistants	2 – Low
[20, 30[% of the researchers involved are not research assistants	3 – Medium
[30, 35[% of the researchers involved are not research assistants	4 – High
≥ 35% or more of the researchers involved are not research assistants	5 – Very high

This performance indicator relates to the difference established in the MPUIC method between academic researchers as researchers effectively contracted by the university, and research assistants as researchers with fellowships. These two types of researcher combined are designated simply as “researchers”, which refers to both academic researchers and research assistants.

The logic reflected through the criteria table of this performance indicator is that the researchers’ capability is positively affected by a high presence of researchers that are not research assistants or, in other words, the presence of academic researchers. In turn, a higher researchers’ capability is expected to lead to a higher performance of the university-industry R&D collaboration. However, it is unfeasible to universities to have a very high presence of academic researchers and a very low presence of research assistants. Thus, the percentages of academic researchers in a university-industry R&D collaboration has to take the previous fact into account, hence the intervals used in the criteria table, in accordance to the expert judgment and experience of the supervisors of this dissertation.

The next criteria table, Table 13Table 13, is related to performance indicator 4 of the MPUIC method: the percentage of researchers satisfied with the contribution of their participation in a collaboration with industry to the development of their academic careers.

Table 13 – Criteria Table 4: researchers satisfied with the contribution of their participation in a collaboration with industry to the development of their academic careers

Criteria	Score
Not applicable	0 – N/A
[0, 20[% of the researchers are satisfied with the contribution of their participation in a collaboration with industry to the development of their academic careers	1 – Very low
[20, 40[% of the researchers are satisfied with the contribution of their participation in a collaboration with industry to the development of their academic careers	2 – Low
[40, 60[% of the researchers are satisfied with the contribution of their participation in a collaboration with industry to the development of their academic careers	3 – Medium
[60, 80[% of the researchers are satisfied with the contribution of their participation in a collaboration with industry to the development of their academic careers	4 – High
[80, 100] % of the researchers are satisfied with the contribution of their participation in a collaboration with industry to the development of their academic careers	5 – Very high

Here, the criteria table simply establishes five intervals of equal range by dividing equally the total of researchers (100%) by the five possible scores, in order to measure the percentage of researchers satisfied with their participation in a collaboration with industry to the development of their careers. This performance indicator considers that the higher the percentage of researchers satisfied, the higher the researchers' motivation which, consequently, is expected to lead to higher performance of the university-industry R&D collaboration.

Below, Table 14 is related to performance indicator 5 of the MPUIC method: the percentage of industry collaborators with a post-graduation or a higher level of qualification.

Table 14 – Criteria Table 5: industry collaborators with a post-graduation or a higher education qualification

Criteria	Score
Not applicable	0 – N/A
[0, 20[% of the industry collaborators have a post-graduation or a higher education qualification	1 – Very low
[20, 40[% of the industry collaborators have a post-graduation or a higher education qualification	2 – Low
[40, 60[% of the industry collaborators have a post-graduation or a higher education qualification	3 – Medium
[60, 80[% of the industry collaborators have a post-graduation or a higher education qualification	4 – High
[80, 100] % of the industry collaborators have a post-graduation or a higher education qualification	5 – Very high

As for the performance indicator stated in this criteria table, it considers that a higher education qualification positively affects the industry collaborators' capability which, consequently, is expected to lead to higher performance of the university-industry R&D collaboration. To score the possible results of this performance indicator, the total of industry collaborators (100%) is simply divided into five intervals of equal range and each corresponds to a score in the scale from 1 to 5.

Below, Table 15 is related to performance indicator 6 of the MPUIC method: the percentage of industry collaborators with past experience in university-industry R&D collaborations.

Table 15 – Criteria Table 6: industry collaborators with past experience in university-industry R&D collaborations

Criteria	Score
Not applicable	0 – N/A
[0, 20[% of the industry collaborators have past experience in university-industry R&D collaborations	1 – Very low
[20, 40[% of the industry collaborators have past experience in university-industry R&D collaborations	2 – Low
[40, 60[% of the industry collaborators have past experience in university-industry R&D collaborations	3 – Medium
[60, 80[% of the industry collaborators have past experience in university-industry R&D collaborations	4 – High
[80, 100] % of the industry collaborators have past experience in university-industry R&D collaborations	5 – Very high

As well as performance indicator 2 of the MPUIC method and its criteria table (see Table 10), the performance indicator underpinning the criteria table here stated considers having experience as having, at least, one year of past experience in university-industry R&D collaborations. In addition, the same five intervals of equal range are established and it is considered that the higher the past experience of the industry collaborators, the higher their capability which, consequently, is expected to lead to higher performance of the university-industry R&D collaboration.

Next, Table 16 is related to performance indicator 7 of the MPUIC method: the percentage of industry collaborators satisfied with the contribution of their participation in a collaboration with university to the development of their professional careers. The idea of this performance indicator and its criteria table here stated is the same as the one used in performance indicator 4 of the MPUIC method (see Table 13) and its criteria table. The only small difference is that it is applied to the industry side, rather than to the university side. Thus, five intervals of equal range that divide equally the total of industry collaborators (100%) are established, as a means to measure the percentage of industry collaborators satisfied with their participation in a collaboration with university to the development of their careers.

Table 16 – Criteria Table 7: industry collaborators satisfied with the contribution of their participation in a collaboration with university to the development of their professional careers

Criteria	Score
Not applicable	0 – N/A
[0, 20[% of the industry collaborators are satisfied with the contribution of their participation in a collaboration with university to the development of their professional careers	1 – Very low
[20, 40[% of the industry collaborators are satisfied with the contribution of their participation in a collaboration with university to the development of their professional careers	2 – Low
[40, 60[% of the industry collaborators are satisfied with the contribution of their participation in a collaboration with university to the development of their professional careers	3 – Medium
[60, 80[% of the industry collaborators are satisfied with the contribution of their participation in a collaboration with university to the development of their professional careers	4 – High
[80, 100] % of the industry collaborators are satisfied with the contribution of their participation in a collaboration with university to the development of their professional careers	5 – Very high

The higher this percentage, the higher the industry collaborators' motivation which, consequently, is expected to lead to higher performance of the university-industry R&D collaboration.

The following Table 17 is related to performance indicator 8 of the MPUIC method: the number of project ideas to be studied.

Table 17 – Criteria Table 8: number of project ideas to be studied in the university-industry R&D collaboration

Criteria	Score
Not applicable	0 – N/A
The evaluator, with his expert judgment, perceives that the number of project ideas to be studied in the university-industry R&D collaboration is far below the expected	1 – Very low
The evaluator, with his expert judgment, perceives that the number of project ideas to be studied in the university-industry R&D collaboration is below the expected	2 – Low
The evaluator, with his expert judgment, perceives that the number of project ideas to be studied in the university-industry R&D collaboration meets the expected	3 – Medium
The evaluator, with his expert judgment, perceives that the number of project ideas to be studied in the university-industry R&D collaboration is above the expected	4 – High
The evaluator, with his expert judgment, perceives that the number of project ideas to be studied in the university-industry R&D collaboration is far above the expected	5 – Very high

The logic represented by the criteria table of this performance indicator is that the performance of a university-industry R&D collaboration is positively affected by a high number of project ideas to be studied in the collaboration. However, considering the subjectivism associated to the measurement of this performance indicator, a score must be attributed considering the expert judgment of a designated evaluator. The choice of this evaluator depends on the context of the university-industry R&D collaboration in which the MPUIC method is set to be applied.

The next criteria table, Table 18, is related to performance indicator 9 of the MPUIC method: the percentage of initial project ideas in which the detailing of objectives and potential solutions is jointly determined by university and industry members.

Table 18 – Criteria Table 9: initial project ideas with their objectives and potential solutions jointly determined by university and industry members

Criteria	Score
Not applicable	0 – N/A
[0, 20[% of the initial project ideas have their objectives and potential solutions jointly determined by university and industry members	1 – Very low
[20, 40[% of the initial project ideas have their objectives and potential solutions jointly determined by university and industry members	2 – Low
[40, 60[% of the initial project ideas have their objectives and potential solutions jointly determined by university and industry members	3 – Medium
[60, 80[% of the initial project ideas have their objectives and potential solutions jointly determined by university and industry members	4 – High
[80, 100] % of the initial project ideas have their objectives and potential solutions jointly determined by university and industry members	5 – Very high

Here, the criteria table divides equally the possible values of its performance indicator into five intervals of equal range. The logic is that the performance of a university-industry R&D collaboration is positively affected by a high number of initial project ideas that have their objectives and potential solutions jointly determined by university and industry.

Program Initiation phase (performance indicator 10)

Next, Table 19 is related to performance indicator 10 of the MPUIC method: the degree of establishment of a joint governance model.

Table 19 – Criteria Table 10: establishment of a joint governance model

Criteria	Score
Not applicable	0 – N/A
The evaluator, with his expert judgment, perceives that the establishment of a joint governance model is far below the expected	1 – Very low
The evaluator, with his expert judgment, perceives that the establishment of a joint governance model is below the expected	2 – Low
The evaluator, with his expert judgment, perceives that the establishment of a joint governance model meets the expected	3 – Medium
The evaluator, with his expert judgment, perceives that the establishment of a joint governance model is above the expected	4 – High
The evaluator, with his expert judgment, perceives that the establishment of a joint governance model is far above the expected	5 – Very high

Regarding this criteria table and the subjectivism of measuring its performance indicator, a score must be attributed through the expert judgment of a designated evaluator. Moreover, the evaluator is selected in function on the context of the university-industry R&D collaboration in which the MPUIC method is set to be applied. The logic is that the performance of a university-industry R&D collaboration is positively affected by a high degree of establishment of a joint governance model.

Program Benefits Delivery phase (performance indicators 11–23)

The following tables, Tables 20–23, are related, respectively, to performance indicators 11–14 of the MPUIC method:

11. the rate of Steering Committee meetings (performed/planned) (Table 20)
12. the rate of result-sharing events (performed/planned) (Table 21)
13. the rate of innovation meetings (performed/planned) (Table 22)
14. the rate of progress meetings (performed/planned) (Table 23)

Table 20 – Criteria Table 11: planned Steering Committee meetings that were performed

Criteria	Score
Not applicable	0 – N/A
[0, 20[% of the planned Steering Committee meetings were performed	1 – Very low
[20, 40[% of the planned Steering Committee meetings were performed	2 – Low
[40, 60[% of the planned Steering Committee meetings were performed	3 – Medium
[60, 80[% of the planned Steering Committee meetings were performed	4 – High
≥ 80% of the planned Steering Committee meetings were performed	5 – Very high

Table 21 – Criteria Table 12: planned result-sharing events that were performed

Criteria	Score
Not applicable	0 – N/A
[0, 20[% of the planned result-sharing events were performed	1 – Very low
[20, 40[% of the planned result-sharing events were performed	2 – Low
[40, 60[% of the planned result-sharing events were performed	3 – Medium
[60, 80[% of the planned result-sharing events were performed	4 – High
≥ 80% of the planned result-sharing events were performed	5 – Very high

Table 22 – Criteria Table 13: planned innovation meetings that were performed

Criteria	Score
Not applicable	0 – N/A
[0, 20[% of the planned innovation meetings were performed	1 – Very low
[20, 40[% of the planned innovation meetings were performed	2 – Low
[40, 60[% of the planned innovation meetings were performed	3 – Medium
[60, 80[% of the planned innovation meetings were performed	4 – High
≥ 80% of the planned innovation meetings were performed	5 – Very high

Table 23 – Criteria Table 14: planned progress meetings that were performed

Criteria	Score
Not applicable	0 – N/A
[0, 20[% of the planned progress meetings were performed	1 – Very low
[20, 40[% of the planned progress meetings were performed	2 – Low
[40, 60[% of the planned progress meetings were performed	3 – Medium
[60, 80[% of the planned progress meetings were performed	4 – High
≥ 80% of the planned progress meetings were performed	5 – Very high

The logic represented by these criteria tables and their performance indicators is that the higher the performed/planned rate of meetings and events as the ones stated, the higher the collaboration intensity which, consequently, is expected to lead to higher performance of the university-industry R&D collaboration. Moreover, these criteria tables also contemplate the scenario in which the performed/planned rate of meetings and events is superior to 100% or, in other words, the scenario in which the number of meetings and events performed is superior to the number planned.

The next criteria table, Table 24, is related to performance indicator 15 of the MPUIC method: the percentage of researchers and industry collaborators satisfied about each other's effective dedication to the collaboration.

Table 24 – Criteria Table 15: researchers and industry collaborators satisfied about each other's effective dedication to the collaboration

Criteria	Score
Not applicable	0 – N/A
[0, 20[% of the researchers and industry collaborators are satisfied about each other's effective dedication to the collaboration	1 – Very low
[20, 40[% of the researchers and industry collaborators are satisfied about each other's effective dedication to the collaboration	2 – Low
[40, 60[% of the researchers and industry collaborators are satisfied about each other's effective dedication to the collaboration	3 – Medium
[60, 80[% of the researchers and industry collaborators are satisfied about each other's effective dedication to the collaboration	4 – High
[80, 100] % of the researchers and industry collaborators are satisfied about each other's effective dedication to the collaboration	5 – Very high

As well as some of the previous criteria tables, the criteria table here presented divides equally the possible values of its performance indicator into five intervals of equal range. The logic is that the higher the satisfaction of researchers and industry collaborators regarding each other's effective dedication to the collaboration, the higher the collaboration intensity which, consequently, is expected to lead to higher performance of the university-industry R&D collaboration.

Next, Table 25 is related to performance indicator 16 of the MPUIC method: the patent applications (submitted/planned). As for the performance indicator stated in this criteria table, the logic is that a higher submitted/planned rate of patent applications is expected to lead to a higher performance of the university-industry R&D collaboration.

Table 25 – Criteria Table 16: planned patent applications that were submitted

Criteria	Score
Not applicable	0 – N/A
[0, 25[% of the planned patent applications were submitted	1 – Very low
[25, 50[% of the planned patent applications were submitted	2 – Low
[50, 75[% of the planned patent applications were submitted	3 – Medium
[75, 100[% of the planned patent applications were submitted	4 – High
≥ 100% of the planned patent applications were submitted	5 – Very high

Given the nature of these numbers, the scenario in which the number patent applications submitted is superior to the number of patent applications planned is contemplated by the score “5 – Very high”.

Below, Table 26 is related to performance indicator 17 of the MPUIC method: the rate of publications (published/planned).

Table 26 – Criteria Table 17: planned publications that were published

Criteria	Score
Not applicable	0 – N/A
[0, 25[% of the planned publications were published	1 – Very low
[25, 50[% of the planned publications were published	2 – Low
[50, 75[% of the planned publications were published	3 – Medium
[75, 100[% of the planned publications were published	4 – High
≥ 100% of the planned publications were published	5 – Very high

The idea of this criteria table and its performance indicator is closely related to the one in the previous criteria table and, in this case, a higher published/planned rate of publications is expected to lead to a higher performance of the university-industry R&D collaboration. Likewise, the scenario where the number of publications published is superior to the number of publications planned is contemplated in score “5 – Very high”.

The following Table 27 is related to performance indicator 18 of the MPUIC method: the percentage of joint publications.

Table 27 – Criteria Table 18: publications that were jointly authored by university and industry members

Criteria	Score
Not applicable	0 – N/A
[0, 5[% of the publications were jointly authored by university and industry members	1 – Very low
[5, 10[% of the publications were jointly authored by university and industry members	2 – Low
[10, 15[% of the publications were jointly authored by university and industry members	3 – Medium
[15, 20[% of the publications were jointly authored by university and industry members	4 – High
≥ 20% of the publications were jointly authored by university and industry members	5 – Very high

Here, the performance indicator and its criteria table are closely related to performance indicator 17: the published/planned rate of publications (see Table 26). Additionally, the percentages established in each score are based on Tijssen's (Tijssen, 2011) research, as well as in the expert judgment and experience of the supervisors of this dissertation. The percentage of publications jointly authored by university and industry members among high ranked universities typically ranges from 10% to 15% (Tijssen, 2011), however, these percentages are adjusted in this criteria table, considering that university-industry R&D collaborations typically lead to a higher number of joint publications. Accordingly, the logic is that a higher number of joint publications is expected to lead to a higher performance of the university-industry R&D collaboration.

The next criteria table, Table 28, is related to performance indicator 19 of the MPUIC method: the rate of deliverables executed on time.

Table 28 – Criteria Table 19: deliverables that were executed on time

Criteria	Score
Not applicable	0 – N/A
[0, 20[% of the deliverables were executed on time	1 – Very low
[20, 40[% of the deliverables were executed on time	2 – Low
[40, 60[% of the deliverables were executed on time	3 – Medium
[60, 80[% of the deliverables were executed on time	4 – High
[80, 100] % of the deliverables were executed on time	5 – Very high

Regarding this criteria table, it is considered that a higher rate of deliverables executed on time is expected to lead to a higher performance of the university-industry R&D collaboration. Moreover, and in the same way as previous criteria tables, this criteria table divides equally the possible values of its performance indicator into five intervals of equal range. This performance indicator is also able to measure how well a governance model is embedded in a university-industry R&D collaboration, hence the removal of performance indicator 20 present in the Initial version of the MPUIC method, as explained previously in this Section.

The following Table 29 and Table 30 are related, respectively, to performance indicators 20 and 21 of the MPUIC method:

20. the rate of recruitment of PhDs researchers from the program by the industry partner (Table 29)
21. the rate of recruitment of research assistants from the program by the industry partner (Table 30)

Table 29 – Criteria Table 20: PhDs researchers from the program that were recruited by the industry partner

Criteria	Score
Not applicable	0 – N/A
[0, 20[% of the PhDs researchers from the program were recruited by the industry partner	1 – Very low
[20, 40[% of the PhDs researchers from the program were recruited by the industry partner	2 – Low
[40, 60[% of the PhDs researchers from the program were recruited by the industry partner	3 – Medium
[60, 80[% of the PhDs researchers from the program were recruited by the industry partner	4 – High
[80, 100] % of the PhDs researchers from the program were recruited by the industry partner	5 – Very high

Table 30 – Criteria Table 21: research assistants from the program that were recruited by the industry partner

Criteria	Score
Not applicable	0 – N/A
[0, 20[% of the research assistants from the program were recruited by the industry partner	1 – Very low
[20, 40[% of the research assistants from the program were recruited by the industry partner	2 – Low
[40, 60[% of the research assistants from the program were recruited by the industry partner	3 – Medium
[60, 80[% of the research assistants from the program were recruited by the industry partner	4 – High
[80, 100] % of the research assistants from the program were recruited by the industry partner	5 – Very high

Both these criteria tables are presented simultaneously, since their logic is exactly the same: a higher recruitment of PhDs researchers (performance indicator 20) or research assistants (performance indicator 21) by the industry partner is expected to lead to a higher performance of the university-industry R&D collaboration. Once again, the total of PhDs researchers or research assistants is divided equally into five intervals of equal range and each of these intervals corresponds to each score from the scale used.

The following Table 31 is related to performance indicator 22 of the MPUIC method: the variation in the percentage of collaborators with higher education qualifications. This performance indicator distinguishes between the collaborators of a company (all of them, not only the ones working in the university-industry R&D collaboration) that hold a higher education qualification, wherein bachelor's degree is the minimum considered, to the collaborators with no higher education qualification at all. This metric is not relevant to the university side, since university is totally composed by researchers with higher education qualifications.

Table 31 – Criteria Table 22: percentage points increase in the percentage of collaborators with higher education qualifications

Criteria	Score
Not applicable	0 – N/A
< 2,5 percentage points* increase in the percentage of collaborators with higher education qualifications	1 – Very low
[2,5; 5[percentage points increase in the percentage of collaborators with higher education qualifications	2 – Low
[5; 7,5[percentage points increase in the percentage of collaborators with higher education qualifications	3 – Medium
[7,5; 10[percentage points increase in the percentage of collaborators with higher education qualifications	4 – High
≥ 10 percentage points increase in the percentage of collaborators with higher education qualifications	5 – Very high

* Percentage point refers to the difference between two percentages. For example, an increase from 18% to 20% is a 2 percentage points increase.

Accordingly, the measurement of this performance indicator compares the difference between the percentage of collaborators holding a higher education qualification in an initial year to the percentage of collaborators holding a higher education qualification in a following and distinct year. Given this difference between two percentages, the concept of percentage point must be used.

The logic of this criteria table is that a higher variation in the percentage of collaborators with higher education qualifications, between two distinct years, is positively related to a higher performance of the university-industry R&D collaboration. To reach the values considered in the criteria table, the data from PORDATA, the contemporary database of Portugal, is considered. According to this database ("PORDATA," 2018):

- In 2013, 14,99% of the population in Portugal had higher education qualifications
- In 2016, 17,80% of the population in Portugal had higher education qualifications

The above two percentages result in a 2,81 percentage points increase regarding the population of Portugal with higher education qualifications. Considering this data and the expert judgment and experience of the supervisors of this dissertation, the values in the criteria table are adjusted to the context of university-industry R&D collaborations.

Below, Table 32 is related to performance indicator 23 of the MPUIC method: the number of master's degree dissertations and PhD theses obtained under the program context.

Table 32 – Criteria Table 23: number of master's degree dissertations and PhD theses obtained under the program context

Criteria	Score
Not applicable	0 – N/A
The evaluator, with his expert judgment, perceives that the number of master's degree dissertations and PhD theses obtained under the program context is far below the expected	1 – Very low
The evaluator, with his expert judgment, perceives that the number of master's degree dissertations and PhD theses obtained under the program context is below the expected	2 – Low
The evaluator, with his expert judgment, perceives that the number of master's degree dissertations and PhD theses obtained under the program context meets the expected	3 – Medium
The evaluator, with his expert judgment, perceives that the number of master's degree dissertations and PhD theses obtained under the program context is above the expected	4 – High
The evaluator, with his expert judgment, perceives that the number of master's degree dissertations and PhD theses obtained under the program context is far above the expected	5 – Very high

The idea of this criteria table is overcome the subjectivism of measuring its performance indicator, thus the attribution of a score considering the expert judgment of a designated evaluator that must be carefully selected according to the specific context. In addition, the logic reflected through the criteria table of this performance indicator is that a higher number of master's degree dissertations and PhD theses obtained under the program context is expected to lead to a higher performance of the university-industry R&D collaboration.

Program Closure phase (performance indicators 24–28)

The next criteria tables, Tables 33–37, are related, respectively, to performance indicators 24–28 of the MPUIC method:

24. Number of new products and product improvements developed (Table 33)
25. Number of new processes and process improvements developed (Table 34)
26. Number of new solutions concepts generated (Table 35)
27. Increase of technology readiness levels (TRL), in comparison to the beginning of the projects within the program (Table 36)
28. Number of new project ideas generated from the program, which might result in a new R&D program (Table 37)

These criteria tables are presented simultaneously due to the need, in all of them, to overcome the subjectivism of measuring the performance indicators. Likewise, all of these criteria tables employ the expert judgment of a designated evaluator and, once again, this evaluator must be carefully chosen according to the context, so that the measurement of the performance indicators is credible and trustworthy. Moreover, the logic of these indicators is that the performance of a university-industry R&D collaboration is positively affected by a high number of new products and product improvements developed (performance indicator 24), a high number of new processes and process improvements developed (performance indicator 25), a high number of new solutions concepts generated (performance indicator 26), a high increase of technology readiness levels (performance indicator 27), and a high number of new project ideas generated from the program (performance indicator 28).

Table 33 – Criteria Table 24: number of new products and product improvements developed

Criteria	Score
Not applicable	0 – N/A
The evaluator, with his expert judgment, perceives that the number of new products and product improvements developed is far below the expected	1 – Very low
The evaluator, with his expert judgment, perceives that the number of new products and product improvements developed is below the expected	2 – Low
The evaluator, with his expert judgment, perceives that the number of new products and product improvements developed meets the expected	3 – Medium
The evaluator, with his expert judgment, perceives that the number of new products and product improvements developed is above the expected	4 – High
The evaluator, with his expert judgment, perceives that the number of new products and product improvements developed is far above the expected	5 – Very high

Table 34 – Criteria Table 25: number of new processes and process improvements developed

Criteria	Score
Not applicable	0 – N/A
The evaluator, with his expert judgment, perceives that the number of new processes and process improvements developed is far below the expected	1 – Very low
The evaluator, with his expert judgment, perceives that the number of new processes and process improvements developed is below the expected	2 – Low
The evaluator, with his expert judgment, perceives that the number of new processes and process improvements developed meets the expected	3 – Medium
The evaluator, with his expert judgment, perceives that the number of new processes and process improvements developed is above the expected	4 – High
The evaluator, with his expert judgment, perceives that the number of new processes and process improvements developed is far above the expected	5 – Very high

Table 35 – Criteria Table 26: number of new solutions concepts generated

Criteria	Score
Not applicable	0 – N/A
The evaluator, with his expert judgment, perceives that the number of new solutions concepts generated is far below the expected	1 – Very low
The evaluator, with his expert judgment, perceives that the number of new solutions concepts generated is below the expected	2 – Low
The evaluator, with his expert judgment, perceives that the number of new solutions concepts generated meets the expected	3 – Medium
The evaluator, with his expert judgment, perceives that the number of new solutions concepts generated is above the expected	4 – High
The evaluator, with his expert judgment, perceives that the number of new solutions concepts generated is far above the expected	5 – Very high

Table 36 – Criteria Table 27: increase of TRL

Criteria	Score
Not applicable	0 – N/A
The evaluator, with his expert judgment, perceives that the increase of TRL is far below the expected	1 – Very low
The evaluator, with his expert judgment, perceives that the increase of TRL is below the expected	2 – Low
The evaluator, with his expert judgment, perceives that the increase of TRL meets the expected	3 – Medium
The evaluator, with his expert judgment, perceives that the increase of TRL is above the expected	4 – High
The evaluator, with his expert judgment, perceives that the increase of TRL is far above the expected	5 – Very high

Table 37 – Criteria Table 28: number of new project ideas as a result of the collaboration

Criteria	Score
Not applicable	0 – N/A
The evaluator, with his expert judgment, perceives that the number of new project ideas as a result of the collaboration is far below the expected	1 – Very low
The evaluator, with his expert judgment, perceives that the number of new project ideas as a result of the collaboration is below the expected	2 – Low
The evaluator, with his expert judgment, perceives that the number of new project ideas as a result of the collaboration meets the expected	3 – Medium
The evaluator, with his expert judgment, perceives that the number of new project ideas as a result of the collaboration is above the expected	4 – High
The evaluator, with his expert judgment, perceives that the number of new project ideas as a result of the collaboration is far above the expected	5 – Very high

Post-Program phase (performance indicators 29–31)

Next, Table 38 is related to performance indicator 29 of the MPUIC method: the rate of patents granted (granted/submitted). This performance indicator is similar to performance indicator 16, in the Program Benefits Delivery phase: the rate of patent applications (submitted/planned).

Table 38 – Criteria Table 29: patent submitted that were granted

Criteria	Score
Not applicable	0 – N/A
[0, 20[% of the patent submitted were granted	1 – Very low
[20, 40[% of the patent submitted were granted	2 – Low
[40, 60[% of the patent submitted were granted	3 – Medium
[60, 80[% of the patent submitted were granted	4 – High
[80, 100] % of the patent submitted were granted	5 – Very high

In this case, the idea is a rate between the patents granted in function of the patents submitted. Thus, the logic is that a higher granted/submitted rate of patents granted is expected to lead to a higher performance of the university-industry R&D collaboration. Such as other performance indicators previously presented, this criteria table divides equally the total value of its performance indicator (100%) into five intervals of equal range.

The following Table 39 is related to performance indicator 30 of the MPUIC method: the variation of annual sales volume (net all discounts and taxes), from the program closing year to the year of the measuring. Regarding this criteria table, it is considered that a higher variation in the annual sales volume (net all discounts and taxes) is expected to lead to a higher performance of the university-industry R&D collaboration.

Table 39 – Criteria Table 30: variation in the annual sales volume (net all discounts and taxes), from the program closing year to the year of the measuring

Criteria	Score
Not applicable	0 – N/A
< 0% variation in the annual sales volume (net all discounts and taxes), from the program closing year to the year of the measuring	1 – Very low
[0; 2[% variation in the annual sales volume (net all discounts and taxes), from the program closing year to the year of the measuring	2 – Low
[2; 5[% variation in the annual sales volume (net all discounts and taxes), from the program closing year to the year of the measuring	3 – Medium
[5; 8[% variation in the annual sales volume (net all discounts and taxes), from the program closing year to the year of the measuring	4 – High
≥ 8% variation in the annual sales volume (net all discounts and taxes), from the program closing year to the year of the measuring	5 – Very high

In order to determine a score, the annual sales volume of the year of the measuring is compared with the closing year of the university-industry collaboration. This comparison allows to reach a percentage of increase or decrease in the annual sales volume between the two years and, therefore, to reach a score from the scale. Moreover, the percentages attributed in the criteria table consider the expert judgment and experience of the supervisors of this dissertation.

Lastly, Table 40 is related to performance indicator 31 of the MPUIC method: the investment value of new university-industry R&D projects/programs generated.

Table 40 – Criteria Table 31: investment value of the closing collaboration that is invested in new R&D projects/programs

Criteria	Score
Not applicable	0 – N/A
[0, 25[% of the investment value of the closing collaboration is invested in new R&D projects/programs	1 – Very low
[25, 50[% of the investment value of the closing collaboration is invested in new R&D projects/programs	2 – Low
[50, 75[% of the investment value of the closing collaboration is invested in new R&D projects/programs	3 – Medium
[75, 100[% of the investment value of the closing collaboration is invested in new R&D projects/programs	4 – High
≥ 100% of the investment value of the closing collaboration is invested in new R&D projects/programs	5 – Very high

The partnership sustainability is the last performance component analyzed. Here, it is considered that a higher investment value of new R&D projects/programs generated from a university-industry R&D collaboration is expected to lead to a higher performance of the initial university-industry R&D collaboration. The values in the criteria table acknowledge the difficulties in increasing the investment value of these collaborations and are in accordance with the expert judgment and experience of the supervisors of this dissertation.

The current Section, Section 4.3, meets Research Objective 2, stated in Section 1.2, that consists in improving the Initial version of the MPUIC method. After the modifications in the performance indicators used (Subsection 4.3.1) and the incorporation of the criteria tables in the weighted scoring approach (Subsection 4.3.2), the MPUIC method can now be applied in the case study adopted for this dissertation.

5. Results: Demonstration of the MPUIC Method's Application

The current Chapter consists in applying the MPUIC method in the IC-HMI program, the university-industry R&D collaboration adopted in this dissertation and presented in Section 3.2. This application corresponds to the fourth activity of the DSRM that implies a demonstration of the resulting artifact as a solution to the initial problem. Specifically, the initial problem of this dissertation is the inexistence of a tool capable of measuring the performance of university-industry R&D collaborations.

Moreover, not all six steps of the MPUIC method presented in Section 4.1 are going to be applied, due to the fact that the IC-HMI program was already in the Program Closure phase by the time of this application. Thus, this application only applies until the third step of application of the MPUIC method, namely until measurement data is used to score each performance indicator. However, no performance indicators are selected and prioritized (fourth step), and no actions are defined to improve the low scoring performance indicators (fifth step), since applying these steps by the time of this application would have very little to none impact in the performance of the IC-HMI program.

Due to the same reason presented above, not all results with respect to the performance indicators of the Program Closure phase are yet available. Thus, this application of the MPUIC method in the IC-HMI program only considers the first three phases of the method (and the correspondent performance indicators), namely: Program Preparation, Program Initiation, and Program Benefits Delivery. Therefore, the weights of the Program Closure phase (15%) and Post-Program phase (5%) are attributed to the Program Benefits Delivery phase that is now weighted with 70%. All the remaining weights are the ones from the initial version, which result from the experience of the authors in university-industry R&D collaborations.

In order to demonstrate this application, the MPUIC method is divided per its first three phases in which the performance indicators are actually measured.

Program Preparation phase (performance indicators 1–9)

Table 41 illustrates the measurement, at the date of this application of the MPUIC method, of the performance indicators constituting this phase.

The average h-index of the UMinho academic researchers that worked in the IC-HMI program is approximately 139% above average. This value is the arithmetic mean of the h-index, per engineering sub-discipline, of the UMinho academic researchers compared against the point of reference[3]. As stated in Subsection 4.3.2, the point of reference considered is the mean h-index of polish engineering sub-disciplines (see Annex), due to the closeness of Portugal and Poland in terms of h-index. Thus, **performance indicator 1 is scored as "5 – Very high"**, according to Criteria Table 1 (see Table 10, in Subsection 4.3.2).

Table 41 – The MPUIC method's application in the IC-HMI program: program preparation phase

Related to	Performance Component	Performance Indicator	Result	Score
UMinho	Researchers' capability	1. Average h-index of the academic researchers (excluding research assistants)	139%	5 – Very high
		2. Percentage of researchers with past experience in university-industry R&D collaborations	65,22%	4 – High
		3. Percentage of researchers involved that are not research assistants	31,50%	4 – High
UMinho	Researchers' motivation	4. Percentage of researchers satisfied with the contribution of their participation in a collaboration with industry to the development of their academic careers	80,92%	5 – Very high
Bosch	Industry collaborators' capability	5. Percentage of industry collaborators with a post-graduation or a higher education qualification	60%	4 – High
		6. Percentage of industry collaborators with past experience in university-industry R&D collaborations	86,15%	5 – Very high
Bosch	Industry collaborators' motivation	7. Percentage of industry collaborators satisfied with the contribution of their participation in a collaboration with university to the development of their professional careers	78,46%	4 – High
UMinho & Bosch	Opportunities/ challenges	8. Number of project ideas to be studied	41	5 – Very high
UMinho & Bosch	Applied research	9. Percentage of initial project ideas in which the detailing of objectives and potential solutions is jointly determined by university and industry members	100%	5 – Very high

The data collected through the questionnaire mentioned in Section 3.2, for the Demonstration activity, reveals that 65,22% (90 of 138) of the UMinho researchers that worked in the IC-HMI

[3] All data used to this calculation can be consulted in Appendix II.

program have, at least, one year of experience in university-industry R&D collaborations[4]. Likewise, 86,15% (56 of 65) of the Bosch collaborators that worked in the IC-HMI program have one year or more of experience in university-industry R&D collaborations[5]. Therefore, according to Criteria Tables 2 and 6, **performance indicator 2 is scored as "4 – High"** (see Table 11, in Subsection 4.3.2), and **performance indicator 6 is scored as "5 – Very high"** (see Table 15, in Subsection 4.3.2).

The same questionnaire shows that 31,50% (40 of 127) of the UMinho researchers that worked in the IC-HMI program are not research assistants or, in other words, are academic researchers[6]. Thus, **performance indicator 3 is scored as "4 – High"**, according to Criteria Table 3 (see Table 12, in Subsection 4.3.2).

Moreover, the questionnaire reveals that 80,92% (106 of 131) of the UMinho researchers that worked in the IC-HMI program are satisfied, very satisfied, or extremely satisfied, with the contribution of their participation in a collaboration with Bosch to the development of their academic careers[7]. Therefore, according to Criteria Table 4 (see Table 13, in Subsection 4.3.2), **performance indicator 4 is scored as "5 – Very high"**. Similarly, 78,46% (51 of 65) of the Bosch collaborators that worked in the IC-HMI program are satisfied, very satisfied, or extremely satisfied, with the contribution of their participation in a collaboration with UMinho to the development of their professional careers[8]. So, according to Criteria Table 7 (see Table 16, in Subsection 4.3.2), **performance indicator 7 is scored as "4 – High"**.

As for the percentage of industry collaborators with a post-graduation or a higher education qualification, the questionnaire reveals that exactly 60% (39 of 65) of the Bosch collaborators that worked in the IC-HMI program hold, at least, a post-graduation[9]. Thus, **performance indicator 5 is scored as "4 – High"**, according to Criteria Table 5 (see Table 14, in Subsection 4.3.2).

The documents analyzed reveal that the IC-HMI program presented 41 project ideas to be studied throughout the program. To attribute a meaning to this number, the Program

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[4] The data used to this calculation can be consulted in Appendix III.
[5] The data used to this calculation can be consulted in Appendix III.
[6] The data used to this calculation can be consulted in Appendix IV.
[7] The data used to this calculation can be consulted in Appendix V.
[8] The data used to this calculation can be consulted in Appendix V.
[9] The data used to this calculation can be consulted in Appendix VI.

Coordination of IC-HMI was indicated as the evaluator of this performance indicator and perceives, according to its expert judgment, that the 41 project ideas studied in the IC-HMI program are far above the expected. Therefore, **performance indicator 8 is scored as "5 – Very high"**, according to Criteria Table 8 (see Table 17, in Subsection 4.3.2).

Lastly, all (100%) of those 41 project ideas had their objectives and potential solutions jointly determined by UMinho and Bosch, as indicated in the documents analyzed. So, according to Criteria Table 9 (see Table 18, in Subsection 4.3.2), **performance indicator 9 is scored as "5 – Very high"**.

Program Initiation phase (performance indicator 10)

Next, Table 42 presents the measurement of the single performance indicator that constitutes this phase.

Table 42 – The MPUIC method's application in the IC-HMI program: program initiation phase

Related to	Performance Component	Performance Indicator	Result	Score
UMinho & Bosch	Established governance	10. Degree of establishment of a joint governance model	–	4 – High

Once more indicated as the evaluator of a performance indicator, the Program Coordination perceives, according to its expert judgment, that the establishment of a joint governance model in the IC-HMI program is above the expected. Thus, **performance indicator 10 is scored as "4 – High"**, according to Criteria Table 10 (see Table 19, in Subsection 4.3.2).

Program Benefits Delivery phase (performance indicators 11–23)

Finally, Table 43 shows the measurement of the performance indicators composing this phase, at the date of this application of the MPUIC method. Most of the following data was collected using document analysis, as indicated in Section 3.2.

In terms of the rate of Steering Committee meetings, 111,11% (11 of 10) of the planned meetings were performed. So, as defined in Criteria Table 11 (see Table 20, in Subsection 4.3.2), **performance indicator 11 is scored as "5 – Very high"**. Likewise, 100% (5 of 5) of the planned result-sharing events were performed, which means that **performance indicator 12 is scored as "5 – Very high"**, as defined in Criteria Table 12 (see Table 21, in Subsection 4.3.2).

Regarding the rate of innovation meetings, 65,83% (79 of 120) of the planned meetings were performed. Thus, **performance indicator 13 is scored as "4 – High"**, according to Criteria Table 13 (see Table 22, in Subsection 4.3.2). As for the rate of progress meetings, 61,81% (445 of 720) of the planned meetings were performed. So, according to Criteria Table 14 (see Table 23, in Subsection 4.3.2), **performance indicator 14 is scored as "4 – High"**.

Table 43 – The MPUIC method's application in the IC-HMI program: program benefits delivery phase

Related to	Performance Component	Performance Indicator	Result	Score
UMinho & Bosch	Collaboration intensity	11. Rate of Steering Committee meetings (performed/planned)	$\frac{11}{10}$ = 111,11%	5 – Very high
		12. Rate of result-sharing events (performed/planned)	$\frac{5}{5}$ = 100%	5 – Very high
		13. Rate of innovation meetings (performed/planned)	$\frac{79}{120}$ = 65,83%	4 – High
		14. Rate of progress meetings (performed/planned)	$\frac{445}{720}$ = 61,81%	4 – High
		15. Percentage of researchers and industry collaborators satisfied about each other's effective dedication to the collaboration	75,51%	4 – High
UMinho & Bosch	Technology	16. Rate of patent applications (submitted/planned)	$\frac{23}{22}$ = 104,55%	5 – Very high
UMinho & Bosch	New knowledge	17. Rate of publications (published/planned)	$\frac{77}{72}$ = 106,94%	5 – Very high
		18. Percentage of joint publications	$\frac{23}{68}$ = 33,82%	5 – Very high
UMinho & Bosch	Management and organizational quality	19. Rate of deliverables executed on time	$\frac{226}{307}$ = 73,62%	4 – High
UMinho & Bosch	Human capital	20. Rate of recruitment of PhDs researchers from the program by the industry partner	$\frac{3}{13}$ = 23,08%	2 – Low
		21. Rate of recruitment of research assistants from the program by the industry partner	$\frac{45}{134}$ = 33,58%	2 – Low
		22. Variation in the percentage of collaborators with higher education qualifications	12,26 percentage points	5 – Very high
		23. Number of master's degree dissertations and PhD theses obtained under the program context	54 master's degree dissertations and 6 PhDs theses	5 – Very high

Moreover, the data collected through the questionnaire mentioned in Section 3.2 was analyzed using SPSS in order to indicate:

- The number of UMinho researchers satisfied, very satisfied, or extremely satisfied, about the effective dedication of Bosch collaborators to the IC-HMI program: 71,32% (92 of 129)[10];
- The number of Bosch collaborators satisfied, very satisfied, or extremely satisfied, about the effective dedication of UMinho researchers to the IC-HMI program: 79,69% (51 of 64)[11].

The arithmetic mean of these two values reveals that 75,51% of UMinho researchers and Bosch collaborators are satisfied about each other's effective dedication to the IC-HMI program. Therefore, **performance indicator 15 is scored as "4 – High"**, according to Criteria Table 15 (see Table 24, in Subsection 4.3.2).

The rate of patent applications within the IC-HMI program indicates a result of 104,55%, given the 23 applications submitted from a total of 22 applications. Thus, according to Criteria Table 16 (see Table 25, in Subsection 4.3.2), **performance indicator 16 is scored as "5 – Very high"**.

In the same way, the rate of publications within the IC-HMI program indicates a result of 106,94% or, in other words, 77 publications published from a total of 72 publications planned. So, in function of Criteria Table 17 (see Table 26, in Subsection 4.3.2), **performance indicator 17 is scored as "5 – Very high"**. Moreover, out of the publications published and publicly available to be consulted, 33,82% (23 of 68) were jointly authored by UMinho and Bosch members. Therefore, in function of Criteria Table 18 (see Table 27, in Subsection 4.3.2), **performance indicator 18 is scored as "5 – Very high"**.

As for the deliverables within the IC-HMI program, the documents analyzed reveal that 73,62% (226 of 307) were of the deliverables were executed on time. Thus, **performance indicator 19 is scored as "4 – High"**, according to Criteria Table 19 (see Table 28, in Subsection 4.3.2).

The rate of recruitment, by Bosch, of UMinho PhDs that worked in the IC-HMI program is 23,08% (3 of 13), hence **performance indicator 20 is scored as "2 – Low"**, according to Criteria Table 20 (see Table 29, in Subsection 4.3.2). As for the UMinho research assistants that worked in the IC-HMI program and were recruited by Bosch, the value is 33,58% (45 of 134). Thus,

[10] The data used to this calculation can be consulted in Appendix VII.
[11] The data used to this calculation can be consulted in Appendix VIII.

according to Criteria Table 21 (see Table 30, in Subsection 4.3.2), **performance indicator 21 is scored as “2 – Low”**.

Regarding the Bosch collaborators with higher education qualifications, a difference is established between the two following years:

- 2013, wherein 23,63% (444 of 1879) of Bosch collaborators held higher education qualifications;
- 2016, wherein 35,89% (865 of 2410) of Bosch collaborators held higher education qualifications.

Given the concept of percentage point, explained in Subsection 4.3.2, the previous values indicate a 12,26 (35,89% minus 23,63%) percentage points increase in the percentage of Bosch collaborators with higher education qualifications. So, in function of Criteria Table 22 (see Table 31, in Subsection 4.3.2), **performance indicator 22 is scored as “5 – Very high”**. As can be noted, there is a limitation in the years of the data used, which are not the most recent.

Last of all, 54 master’s degree dissertations and 6 PhDs theses are set to be obtained under the IC-HMI program context. Indicated to evaluate this performance indicator and attribute a meaning to the previous numbers, the Program Coordination perceives, according to its expert judgment, that this number of master's degree dissertations and PhD theses obtained under the program context is far above the expected. Therefore, **performance indicator 23 is scored as “5 – Very high”**, in function of Criteria Table 23 (see Table 32, in Subsection 4.3.2).

Considering all these results, Table 44 summarizes the application of the MPUIC method in the IC-HMI program and displays the respective scores per program phase.

Table 44 – The MPUIC method's application in the IC-HMI program: score per phase

Program Phase	Weight	Related to	Performance Component	Weight	Performance Indicator	Weight (1)	Score (2)	Weighted Score [(1) × (2)]
Program Preparation	25%	UMinho	Researchers' capability	15%	1. Average h-index of the academic researchers (excluding research assistants)	40%	5	2
					2. Percentage of researchers with past experience in university-industry R&D collaborations	30%	4	1,2
					3. Percentage of researchers involved that are not research assistants	30%	4	1,2
		UMinho	Researchers' motivation	15%	4. Percentage of researchers satisfied with the contribution of their participation in a collaboration with industry to the development of their academic careers	100%	5	5
		Bosch	Industry collaborators' capability	15%	5. Percentage of industry collaborators with a post-graduation or a higher education qualification	50%	4	2
					6. Percentage of industry collaborators with past experience in university-industry R&D collaborations	50%	5	2,5
		Bosch	Industry collaborators' motivation	15%	7. Percentage of industry collaborators satisfied with the contribution of their participation in a collaboration with university to the development of their professional careers	100%	4	4
		UMinho and Bosch	Opportunities/challenges	20%	8. Number of project ideas to be studied	100%	5	5
		UMinho and Bosch	Applied research	20%	9. Percentage of initial project ideas in which the detailing of objectives and potential solutions is jointly determined by university and industry members	100%	5	5
					Program Preparation phase score: 4,7			
Program Initiation	5%	UMinho and Bosch	Established governance	100%	10. Degree of establishment of a joint governance model	100%	4	4
					Program Initiation phase score: 4			

Table 44 (continued) – The MPUIC method's application in the IC-HMI program: score per phase

Program Phase	Weight	Related to	Performance Component	Weight	Performance Indicator	Weight (1)	Score (2)	Weighted Score [(1) × (2)]
Program Benefits Delivery	70%	UMinho and Bosch	Collaboration intensity	25%	11. Rate of Steering Committee meetings (performed/planned)	15%	5	0,75
					12. Rate of result-sharing events (performed/planned)	20%	5	1
					13. Rate of innovation meetings (performed/planned)	25%	4	1
					14. Rate of progress meetings (performed/planned)	20%	4	0,8
					15. Percentage of researchers and industry collaborators satisfied about each other's effective dedication to the collaboration	20%	4	0,8
		UMinho and Bosch	Technology	15%	16. Rate of patent applications (submitted/planned)	100%	5	5
		UMinho and Bosch	New knowledge	15%	17. Rate of publications (published/planned)	50%	5	2,5
					18. Percentage of joint publications	50%	5	2,5
		UMinho and Bosch	Management and organizational quality	20%	19. Rate of deliverables executed on time	100%	4	4
		UMinho and Bosch	Human capital	25%	20. Rate of recruitment of PhDs researchers from the program by the industry partner	25%	2	0,5
					21. Rate of recruitment of research assistants from the program by the industry partner	25%	2	0,5
					22. Variation in the percentage of collaborators with higher education qualifications	25%	5	1,25
					23. Number of master's degree dissertations and PhD theses obtained under the program context	25%	5	1,25
					Program Benefits Delivery phase score: 4,3			

In order to reach the overall score of performance of the IC-HMI program, the scores per program phase are first calculated by multiplying the weights of the performance components by the sum of the weighted scores of the performance indicators that constitute each performance component. Specifically, the calculation in the **Program Preparation phase** performed is:

[15% × (2+1,2+1,2)] + (15% × 5) + [15% × (2+2,5)] + (15% × 4) + (20% × 5) + (20% × 5) = **4,7**

As for the **Program Initiation phase**, there is a single multiplication:

[100% × 4] = **4**

Lastly, for the **Program Benefits Delivery phase**, the calculation is:

[25% × (0,75+1+1+0,8+0,8)] + (15% × 5) + [15% × (2,5+2,5)] + (20% × 4) + [25% × (0,5+0,5+1,25+1,25)] = **4,3**

Having calculated the previous values, it is now possible to reach **the overall score of performance of the IC-HMI program**, simply by multiplying the weight of each phase by their respective score as follows:

[25% × 4,7] + [5% × 4] + [70% × 4,3] = **4,4**

Therefore, 4,4 out of 5 is the overall score of performance of this first application of the MPUIC method in the IC-HMI program.

Throughout the demonstration in this Chapter of the application of the MPUIC method in the IC-HMI program, an example of a university-industry R&D collaboration, the Research Objective 3, identified in Section 1.2, is achieved.

6. DISCUSSION: EVALUATION OF THE MPUIC METHOD

In this Chapter, an evaluation of the MPUIC method is going to be conducted. This evaluation corresponds to the fifth activity of the DSRM and has the objective of observe and measure how well the MPUIC method, the artifact developed, constitutes a solution to the inexistence of a tool capable of measuring the performance of university-industry R&D collaborations. Accordingly, the objectives of a solution, defined in the second activity of DSRM (Section 3.1), are considered and compared to the actual results obtained from the application of the MPUIC method (Chapter 5).

The evaluation of the MPUIC method is performed through the conduction of a questionnaire (see Appendix I) to university members acquainted with the context of university-industry R&D collaborations, as the characterization of the respondents in Table 45 indicates.

Table 45 – Characterization of the respondents

Respondent	Role	Relation	Experience (years)	Gender	Age (years)
Respondent #1	Program Manager	University	> 15	Male	]40 – 50]
Respondent #2	PgPMO Officer	University	< 1	Male	]30 – 40]
Respondent #3	PgPMO Officer	University	[1 – 3]	Male	]40 – 50]
Respondent #4	PgPMO Officer	University	[1 – 3]	Male	[25 – 30[
Respondent #5	PgPMO Officer	University	[3 – 5]	Female	[25 – 30[
Respondent #6	PgPMO Officer	University	[1 – 3]	Female	]30 – 40]
Respondent #7	PgPMO Officer	University	[3 – 5]	Male	]30 – 40]
Respondent #8	PgPMO Officer	University	[1 – 3]	Male	]30 – 40]
Respondent #9	Project Responsible	University	> 15	Male	]40 – 50]
Respondent #10	Project Responsible	University	]10 – 15]	Male	]40 – 50]
Respondent #11	Project Responsible	University	> 15	Male	]40 – 50]
Respondent #12	Project Responsible	University	[3 – 5]	Female	> 50
Respondent #13	Project Responsible	University	> 15	Male	> 50

It is worth noting that a Program Manager and several members of the PgPMO team answered this questionnaire. This is a relevant aspect since the responsibility of applying the MPUIC method is suggested to lie with the Program Manager, supported by a PgPMO team (Fernandes, Pinto, Araújo, Magalhães, et al., 2017).

Next, the answers of the respondents to Parts 2, 3, and 4 of the questionnaire are analyzed.

Level of Relevance of the Performance Indicators

Following the questions of characterization in Part 1 of the questionnaire, Part 2 asked to the respondents to indicate, in a five-point scale (wherein 1 is very low, 2 is low, 3 is medium, 4 is high, and 5 is very high), the level of relevance of each performance indicator constituting the MPUIC method to the measurement of university-industry R&D collaborations. Additionally, it was given the possibility to the respondents to suggest other performance indicators which, from their point of view, could be included in the MPUIC method.

Table 46 shows the descriptive statistics of the responses in relation to the level of relevance of the performance indicators, divided by the program phases.

It is possible to see that all performance indicators of the MPUIC method have, in average, a level of relevance above 3, considering the values of the mean, median, and mode. The only exceptions are the values of the mean of performance indicator 3 (percentage of researchers involved that are not research assistants) and performance indicator 8 (number of project ideas to be studied). Moreover, in relation to the Program Closure and Post-Program phases, all the performance indicators have, in average, a high level of relevance, since they all display values above 4 in their mean, median, and mode.

As suggestions, the number of patents registered by researchers was indicated as a performance indicator that could be included in the Program Initiation phase. In addition, a performance indicator suggested to be included in the Post-Program phase was the investment value of new university-industry R&D collaborations generated with different industrial partners, instead of the perspective of continuity between partners that performance indicator 31 displays.

Table 46 – Level of relevance of the performance indicators

Program Phase	Performance Indicator	Observations	Mean	Median	Mode	Standard Deviation	Min.	Max.
Program Preparation	1. Average h-index of the academic researchers (excluding research assistants)	13	3,2	3	3	0,90	2	5
	2. Percentage of researchers with past experience in university-industry R&D collaborations	13	4,4	4	4	0,51	4	5
	3. Percentage of researchers involved that are not research assistants	13	2,6	3	3	0,96	1	4
	4. Percentage of researchers satisfied with the contribution of their participation in a collaboration with industry to the development of their academic careers	13	3,8	4	4	0,55	3	5
	5. Percentage of industry collaborators with a post-graduation or a higher education qualification	13	3,6	4	3 and 4	0,87	2	5
	6. Percentage of industry collaborators with past experience in university-industry R&D collaborations	13	4,0	4	4	0,58	3	5
	7. Percentage of industry collaborators satisfied with the contribution of their participation in a collaboration with university to the development of their professional careers	13	4,0	4	4	0,58	3	5
	8. Number of project ideas to be studied	13	2,6	3	3	0,51	2	3
	9. Percentage of initial project ideas in which the detailing of objectives and potential solutions is jointly determined by university and industry members	13	4,2	4	4	0,80	2	5
*	10. Degree of establishment of a joint governance model	12	4,5	5	5	0,67	3	5
Program Benefits Delivery	11. Rate of Steering Committee meetings (performed/planned)	13	3,7	4	4	0,75	2	5
	12. Rate of result-sharing events (performed/planned)	13	4,1	4	4	0,76	3	5
	13. Rate of innovation meetings (performed/planned)	13	3,9	4	4	1,04	1	5
	14. Rate of progress meetings (performed/planned)	13	4,1	4	4	0,76	3	5
	15. Percentage of researchers and industry collaborators satisfied about each other's effective dedication to the collaboration	13	4,5	5	5	0,66	3	5
	16. Rate of patent applications (submitted/planned)	13	3,9	4	4	0,64	3	5
	17. Rate of publications (published/planned)	13	3,8	4	4	0,69	3	5
	18. Percentage of joint publications	13	3,8	4	4	0,90	2	5
	19. Rate of deliverables executed on time	13	3,9	4	4	0,64	3	5
	20. Rate of recruitment of PhDs researchers from the program by the industry partner	13	4,1	4	4	0,64	3	5
	21. Rate of recruitment of research assistants from the program by the industry partner	13	4,2	4	4	0,55	3	5
	22. Variation in the percentage of collaborators with higher education qualifications	13	3,8	4	4	0,73	2	5
	23. Number of master's degree dissertations and PhD theses obtained under the program context	13	4,1	4	4	0,64	3	5

Table 46 (continued) – Level of relevance of the performance indicators

Program Phase		Performance Indicator	Observations	Mean	Median	Mode	Standard Deviation	Min.	Max.
Program Closure	24.	Number of new products and product improvements developed	13	4,5	4	4	0,52	4	5
	25.	Number of new processes and process improvements developed	13	4,4	4	4	0,51	4	5
	26.	Number of new solutions concepts generated	13	4,5	4	4	0,52	4	5
	27.	Increase of technology readiness levels (TRL), in comparison to the beginning of the projects within the program	13	4,2	5	5	1,17	1	5
	28.	Number of new project ideas generated from the program, which might result in a new R&D program	13	4,2	4	4	0,55	3	5
Post-Program	29.	Rate of patents granted (granted/submitted)	13	4,4	4	4 and 5	0,65	3	5
	30.	Variation of annual sales volume (net all discounts and taxes), from the program closing year to the year of the measuring	13	4,2	4	4	0,69	3	5
	31.	Investment value of new university-industry R&D projects/programs generated	13	4,5	4	4	0,52	4	5

*Program Initiation

Weight of the Different Elements

Given that the weights used in the application of the MPUIC method in the IC-HMI program were the ones present in the initial version of the method, the questionnaire also aimed to identify a new proposal for the weights of importance of each program phase, each process component, and each performance indicator. Therefore, it was asked to the respondents to attribute a weight to all these elements, in Part 3 of the questionnaire. The mean of the weights attributed by the participants are presented in Table 47.

Table 47 – Means of the weights attributed

Program Phase	Initial Weight	Mean Weight	Performance Component	Initial Weight	Mean Weight	PI	Initial Weight	Mean Weight
Program Preparation	25%	23%	Researchers' capability	15 %	20%	1.	40 %	24%
						2.	30 %	54%
						3.	30 %	22%
			Researchers' motivation	15 %	17%	4.	100%	**100%**
			Industry collaborators' capability	15 %	19%	5.	50 %	45%
						6.	50 %	55%
			Industry collaborators' motivation	15 %	15%	7.	100%	**100%**
			Opportunities/challenges	20 %	13%	8.	100%	**100%**
			Applied research	20 %	15%	9.	100%	**100%**
Program Initiation	5 %	13%	Established governance	100%	**100%**	10.	100%	**100%**
Program Benefits Delivery	50 %	35%	Collaboration intensity	25 %	25%	11.	15 %	14%
						12.	20 %	18%
						13.	25 %	15%
						14.	20 %	20%
						15.	20 %	32%
			Technology	15 %	19%	16.	100%	**100%**
			New knowledge	15 %	18%	17.	50 %	47%
						18.	50 %	53%
			Management and organizational quality	20 %	14%	19.	100%	**100%**
			Human capital	25 %	24%	20.	25 %	28%
						21.	25 %	30%
						22.	25 %	21%
						23.	25 %	21%
Program Closure	15%	15%	Innovations	50%	36%	24.	50%	52%
						25.	50%	48%
			Solution concepts	35%	38%	26.	50%	52%
						27.	50%	48%
			New ideas	15%	26%	28.	100%	**100%**
Post-Program	5%	14%	Technology achievement	30%	33%	29.	100%	**100%**
			Sales growth	40%	35%	30.	100%	**100%**
			Partnership sustainability	30%	32%	31.	100%	**100%**

The highlights in bold indicate the weights pre-defined with 100% due to a single performance component constituting a program phase or a single performance indicator constituting a performance component. Also, the performance indicators are represented by their numbers because of space limitations.

Additionally, all performance indicators have 13 observations, while the performance components have 12 observations and the program phases have 11 observations. This is due to two questionnaires in which the respondents did not attributed all the weights, namely the weights of the program phases and performance components, possibly because they did not saw the respective empty spaces that were meant to be answered.

Furthermore, regarding the program phases, it is possible to see that the only relevant variations between the initial weights and the mean weights obtained from the questionnaire are:

- The mean weight of the Program Benefits Delivery phase (35%), compared to its initial weight (50%);
- The mean weight of the Program Initiation phase (13%), compared to its initial weight (5%);
- The mean weight of the Post-Program phase (14%), compared to its initial weight (5%).

As for the performance components, the main variations between the initial weights and the mean weights obtained from the questionnaire are in the Innovations component (50% as initial weight and 36% as mean weight) and New Ideas component (15% as initial weight and 26% as mean weight). For all the other performance components, the variation is not superior to 6% and, in some of them, the initial weight and the mean result obtained from the questionnaire are equal.

Lastly, for the performance indicators, the main variations between the initial weights and the mean weights obtained from the questionnaire are in the following performance indicators:

1. Average h-index of the academic researchers (excluding research assistants);
2. Percentage of researchers with past experience in university-industry R&D collaborations;
3. Percentage of researchers involved that are not research assistants;

13. Rate of innovation meetings (performed/planned);
15. Percentage of researchers and industry collaborators satisfied about each other's effective dedication to the collaboration.

For all the other performance indicators, the variation is ≤ 5% and, in some cases, there is no variation at all.

Level of Simplicity and Ease of Use of Criteria Tables

Lastly, Part 4 of the questionnaire asked to the respondents to indicate the level of simplicity and ease of use of each criteria table constituting the MPUIC method, in a five-point scale (wherein 1 is very complex, 2 is complex, 3 is normal, 4 is simple, and 5 is very simple). The respondents could also suggest modifications to the criteria tables by answering an open question associated to each criteria table. Table 48 shows the descriptive statistics of the responses regarding the level of simplicity and ease of use of the criteria tables.

It is possible to see that there are several criteria tables which are considered, in average, complex to use with a mean below 3. A set of relevant suggestions were made, namely:

- The use of an evaluation committee instead of a single evaluator in the criteria tables of the performance indicators that use these type of measurement;
- Increase the values used in the intervals of percentages corresponding to each score (1 – Very low, 2 – Low, 3 – Medium, 4 – High, and 5 – Very high) of Criteria Table 1 (see Table 9, in Section 4.3.2);
- Increase the values used in the intervals of percentages corresponding to each score (1 – Very low, 2 – Low, 3 – Medium, 4 – High, and 5 – Very high) of Criteria Table 11 (see Table 19, in Section 4.3.2), in order to distinguish between a rate of 80% and a rate of 110%, for instance;
- Specify a time period in Criteria Tables 20–21 (see Tables 28–29, in Section 4.3.2).

The previous analysis of the questionnaire observes and measures how well the MPUIC method constitutes an effective solution to the inexistence of a tool capable of measuring the performance of university-industry R&D collaborations. Thus, this Chapter meets Research Objective 4, identified in Section 1.2, that consists in evaluating the developed MPUIC method as an effective solution to the initial problem.

Table 48 – Level of simplicity and ease of use of the criteria tables

Criteria Table	Observations	Mean	Median	Mode	Standard Deviation	Min.	Max.
Criteria Table 1: h-index of the academic researchers	13	3,5	4	3 and 4	1,2	1	5
Criteria Table 2: researchers with past experience in university-industry R&D collaborations	13	3,3	3	3	0,9	2	5
Criteria Table 3: researchers involved are not research assistants	13	4	4	4	0,9	2	5
Criteria Table 4: researchers satisfied with the contribution of their participation in a collaboration with industry to the development of their academic careers	13	2,9	3	2	0,9	2	4
Criteria Table 5: industry collaborators with a post-graduation or a higher education qualification	13	3,9	4	4	0,9	2	5
Criteria Table 6: industry collaborators with past experience in university-industry R&D collaborations	13	3,5	3	3	0,9	2	5
Criteria Table 7: industry collaborators satisfied with the contribution of their participation in a collaboration with university to the development of their professional careers	13	2,8	3	2	0,9	2	4
Criteria Table 8: number of project ideas to be studied in the university-industry R&D collaboration	13	3,1	3	3 and 4	1,1	1	5
Criteria Table 9: initial project ideas with their objectives and potential solutions jointly determined by university and industry members	13	3	3	3	0,6	2	4
Criteria Table 10: establishment of a joint governance model	13	2,3	2	2	0,9	1	4
Criteria Table 11: planned Steering Committee meetings that were performed	13	3,8	4	4	0,8	2	5
Criteria Table 12: planned result-sharing events that were performed	13	4,2	4	4	0,7	3	5
Criteria Table 13: planned innovation meetings that were performed	13	4,2	4	4	0,7	3	5
Criteria Table 14: planned progress meetings that were performed	13	4,1	4	4	0,6	3	5
Criteria Table 15: researchers and industry collaborators satisfied about each other's effective dedication to the collaboration	13	2,2	2	2	1	1	4
Criteria Table 16: planned patent applications that were submitted	13	3,9	4	4	0,8	3	5
Criteria Table 17: planned publications that were published	13	3,8	4	3 and 4	0,8	3	5
Criteria Table 18: publications that were jointly authored by university and industry members	13	3,5	4	3 and 4	1,1	1	5
Criteria Table 19: deliverables that were executed on time	13	3,4	3	3 and 4	0,7	2	4
Criteria Table 20: PhDs researchers from the program that were recruited by the industry partner	13	3	3	2 and 3	0,9	2	4
Criteria Table 21: research assistants from the program that were recruited by the industry partner	13	3,2	4	4	1	1	4
Criteria Table 22: percentage points increase in the percentage of collaborators with higher education qualifications	13	2,9	3	2 and 3	1	2	5
Criteria Table 23: number of master's degree dissertations and PhD theses obtained under the program context	13	3,7	4	4	1	2	5
Criteria Table 24: number of new products and product improvements developed	13	2,8	3	3	0,7	2	4
Criteria Table 25: number of new processes and process improvements developed	13	2,7	3	2	0,8	2	4
Criteria Table 26: number of new solutions concepts generated	13	2,5	2	2	0,8	1	4

Table 48 (continued) – Level of simplicity and ease of use of the criteria tables

Criteria Table	Observations	Mean	Median	Mode	Standard Deviation	Min.	Max.
Criteria Table 27: increase of TRL	13	2,5	2	2	1,1	1	5
Criteria Table 28: number of new project ideas as a result of the collaboration	13	3	3	3	0,8	2	4
Criteria Table 29: patent submitted that were granted	13	4,1	4	4	0,6	3	5
Criteria Table 30: variation in the annual sales volume (net all discounts and taxes), from the program closing year to the year of the measuring	13	2,4	2	2	1,2	1	5
Criteria Table 31: investment value of the closing collaboration that is invested in new R&D projects/programs	13	3	3	3	1,1	1	5

7. CONCLUSIONS

University-industry R&D collaborations have been increasing (Perkmann, Neely, et al., 2011). However, few attempts have been made to measure the performance of these collaborations. The present dissertation aims to develop a method capable of measuring the performance of university-industry R&D collaborations. Achieving this objective would provide an answer to the research question: *how to measure the performance of university-industry R&D collaborations?*

This dissertation focused on a specific method, the MPUIC method, and in its development, namely through the achievement of the following research objectives:

1. Identify the difficulties in applying the initial version of the method for measuring the performance of university-industry R&D collaborations (MPUIC method).
2. Improve the method for measuring the performance of university-industry R&D collaborations (MPUIC method).
3. Demonstrate the application of the method for measuring the performance of university-industry R&D collaborations (MPUIC method) in a university-industry R&D collaboration.
4. Evaluate the developed method for measuring the performance of university-industry R&D collaborations (MPUIC method) as an effective solution.

The initial version of the MPUIC method was provided by a previous research in which the supervisors of this dissertation were involved (Fernandes, Pinto, Araújo, Magalhães, et al., 2017).

However, the identified difficulties in applying this initial version had to be addressed before proceeding to an actual application in a university-industry R&D collaboration. These difficulties were considered throughout the development of the MPUIC method as a proposed improvement and, afterwards, an application of the MPUIC method in the IC-HMI program led to an overall score of 4,4 in a scale from 0 to 5, regarding the performance of this university-industry R&D collaboration by the time of the application.

An evaluation of the MPUIC method was performed through the questionnaire administered to a sample of 13 different university members with experience in university-industry R&D collaborations. It was concluded that, from the thirty-one performance indicators constituting the MPUIC method, twenty-nine of them have, in average, a level of relevance above 3 (medium) and nineteen of these have, in average, a level of relevance equal or above 4 (high). Also, a new proposal for the weights used in the weighted scoring approach underpinning the MPUIC method was achieved. However, several of the criteria tables incorporated in this approach are considered to have, in average, a complex level of simplicity and ease of use. This is an issue that should be addressed in future research, with the objective of turning the level of simplicity and ease of use simpler to members experienced in university-industry R&D collaborations.

A cycle of the DSRM, the research design used throughout this dissertation, was performed. Ideally, an iteration of activities should be established and more cycles should have been performed, specifically cycles that would continue the design and development, the demonstration and the evaluation of the MPUIC method.

Furthermore, it should be noted that the results of the evaluation performed to the MPUIC method suffer from some limitations. The sample of respondents to the questionnaire of evaluation is small and it is does not have representatives of the industry side. In order to better evaluate the MPUIC method, a larger sample formed by members from both university and industry sides should be used in further research. Another limitation is that, in the development of the MPUIC method, the performance indicators of the phases of Program Preparation and Program Initiation, as well as these phases, could have been opted to not being included. The reason is that the performance indicators of these phases can be considered as success factors instead of success criteria, given that they influence the success or failure, but do not necessarily determine the respective success or failure. If a further application considers not to include the phases of Program Preparation and Program Initiation, a superior weight would necessarily need to be attributed to the phases of Program Benefits Delivery, Program Closure, and Post-Program.

As for future work, an actual objective established between the researcher and the supervisors of the dissertation is to publish an article regarding the MPUIC method developed throughout this dissertation.

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ANNEX – H-INDEX VALUES USED AS POINT OF REFERENCE

No.	Engineering sub-discipline	Observation number, n	H						Standard deviation σ	Variation coeff. σ/H	Skewnes coeff.
			min	max	range	mean	median	mode			
1.	Architecture and Urban Planning, A	29	1	5	4	2.07	2	2	1.13	0.55	1.13
2.	Production Engineering, PE	22	0	9	9	2.82	2	2	2.28	0.81	1.54
3.	Transport, T	30	0	10	10	3.07	3	3	1.80	0.59	1.95
4.	Mining, M	39	0	12	12	3.30	3	2v4	2.72	0.82	1.49
5.	Management of Mineral Resources, MM	30	0	9	9	3.53	3	3	2.03	0.57	0.82
6.	Machine Building, MB	37	0	12	12	4.14	4	4	2.50	0.60	1.06
7.	Civil Engineering and Hydroengineering, CEH	43	1	18	17	4.56	3	3	3.25	0.71	2.17
8.	Geodesy, G	33	2	12	10	4.79	4	4	2.34	0.49	1.33
9.	Environmental Engineering, EE	38	1	32	31	5.08	3	1v3	5.50	1.08	3.42
10.	Metallurgy, Met	30	0	16	16	5.40	4	2	4.14	0.76	1.11
11.	Metrology and Scientific Instrumentation, MSI	33	0	24	24	5.85	4	1v2	5.84	1.00	1.80
12.	Electrical Engineering, E	46	1	28	27	5.89	5	2v3	5.69	0.97	2.41
13.	Acoustics, Ac	31	1	17	16	5.97	6	6	4.14	0.69	1.05
14.	Thermodynamics & Combustion, TC	28	1	19	18	6.39	6	5v6	3.92	0.61	1.85
15.	Electronics & Telecommunication, E&T	46	0	29	29	7.13	6	4	6.33	0.89	1.63
16.	Informatics,I	43	0	33	33	7.67	5	0v3	7.7	1	1.43
17.	Automatic Control and Robotics, A&R	37	1	46	45	8.3	5	4	8.52	1.02	2.81
18.	Biocybernetics & Biomedical Engineering B&B	32	2	38	36	9.97	8	4v10	7.35	0.74	2.06
19.	Chemical and Process Engineering, ChE	29	3	27	24	10.14	9	4	5.95	0.59	0.89
20.	Mechanics, Mech	44	3	36	33	11.66	10	6	7.33	0.63	1.33
20a	Mechanics, Mech (Scopus)*	44	1	23	22	7.07	6	4	5.19	0.73	1.12
21.	Materials Science, MS	37	1	34	33	11.78	10	6	8.51	0.72	1.30

Retrieved from Czarnecki et al. (2013).

Appendix I – Questionnaire of Evaluation

Measuring the Performance of University-Industry R&D Collaborations

Esta investigação, que está a ser desenvolvida em inglês, está inserida no âmbito de uma dissertação do Mestrado em Gestão de Projetos em Engenharia.

Deste modo, a investigação consiste no desenvolvimento de um método que é composto por diversos indicadores de desempenho, de forma a que estes, conjuntamente, permitam medir o desempenho das colaborações em I&D entre universidade e indústria.

Este método procura atribuir uma ponderação aos diferentes indicadores de desempenho, de forma a refletir o peso que cada um tem no desempenho das colaborações em I&D entre universidade e indústria.

Para tornar esta medição o mais objetiva possível, também foram desenvolvidos diferentes intervalos para os desempenhos possíveis de ser obtidos em cada indicador de desempenho. Tal representa-se sob a forma de tabelas de critério, que são associadas de forma individual a cada indicador de desempenho e nas quais o desempenho é medido de uma escala quantitativa.

De forma a avaliar o método desenvolvido e sujeitar o mesmo a possíveis melhorias, é de extrema importância poder contar com a vossa experiência e visão acerca desta investigação. Agradeço, desta forma, a vossa preciosa ajuda.

Parte 1

Caracterização do Participante

1. Indique a sua idade.
   - ☐ < 25 anos
   - ☐ [25-30] anos
   - ☐]30-40] anos
   - ☐]40-50] anos
   - ☐ > 50 anos

2. Indique o seu género.
   - ☐ Feminino
   - ☐ Masculino

3. Indique a instituição com quem tem vínculo contratual principal.
   - ☐ Indústria
   - ☐ Universidade

4. Indique a sua função na colaboração em I&D entre universidade e indústria que está inserido.
   - ☐ Gestor de Programa
   - ☐ Gestor de Projeto
   - ☐ PgMO Officer
   - ☐ Responsável de Projeto

5. Indique o número de anos de experiência em colaborações em I&D entre universidade e indústria.
   - ☐ < 1 ano
   - ☐ [1-3] anos
   - ☐]3-5] anos
   - ☐]5-10] anos
   - ☐]10-15] anos
   - ☐ > 15 anos

Parte 2

Relevância dos Indicadores de Desempenho

Os diversos indicadores de desempenho (*performance indicators*) que constituem o método final distribuem-se por componentes de desempenho (*performance components*), que contam com pelo menos um indicador. Adicionalmente, conforme a natureza distinta de cada um dos componentes de desempenho (e, consequentemente, dos indicadores de desempenho), estes estão alocados às diferentes fases existentes em colaborações em I&D entre universidade e indústria (*program phases*).

Sempre considerando esta distribuição (fases do programa > componentes de desempenho > indicadores de desempenho), pede-se que indique o **nível de relevância** que considera que cada indicador tem para a medição do desempenho das colaborações em I&D entre universidade e indústria.

Para tal, por favor, assinale o nível de relevância que considera adequado para cada indicador de desempenho individualmente, nos espaços da tabela que se segue, conforme a escala.

Program Phase	Performance Component	Performance Indicator	Level of Relevance				
			Very low	Low	Medium	High	Very high
Program Preparation	Researchers’ capability	Average *h*-index of the academic researchers (excluding research assistants)	☐	☐	☐	☐	☐
		Percentage of researchers with past experience in university-industry R&D collaborations	☐	☐	☐	☐	☐
		Percentage of researchers involved that are not research assistants	☐	☐	☐	☐	☐
	Researchers’ motivation	Percentage of researchers satisfied with the contribution of their participation in a collaboration with industry to the development of their academic careers	☐	☐	☐	☐	☐
	Industry collaborators’ capability	Percentage of industry collaborators with a post-graduation or a higher education qualification	☐	☐	☐	☐	☐
		Percentage of industry collaborators with past experience in university-industry R&D collaborations	☐	☐	☐	☐	☐
	Industry collaborators’ motivation	Percentage of industry collaborators satisfied with the contribution of their participation in a collaboration with university to the development of their professional careers	☐	☐	☐	☐	☐
	Opportunities/challenges	Number of project ideas to be studied	☐	☐	☐	☐	☐
	Applied research	Percentage of initial project ideas in which the detailing of objectives and potential solutions is jointly determined by university and industry members	☐	☐	☐	☐	☐

Na sua ótica, podem ser incluídos outros indicadores de desempenho? Se sim, indique quais, referindo a componente de desempenho na qual o(s) insere e se seria por troca com algum já existente.

Resposta: ____

Program Initiation	Established governance	Degree of establishment of a joint governance model	☐	☐	☐	☐	☐

Na sua ótica, podem ser incluídos outros indicadores de desempenho? Se sim, indique quais, referindo a componente de desempenho na qual o(s) insere e se seria por troca com algum já existente.

Resposta: ____

Program Benefits Delivery	Collaboration intensity	Rate of Steering Committee meetings (performed/planned)	☐	☐	☐	☐	☐
		Rate of result-sharing events (performed/planned)	☐	☐	☐	☐	☐
		Rate of innovation meetings (performed/planned)	☐	☐	☐	☐	☐
		Rate of progress meetings (performed/planned)	☐	☐	☐	☐	☐
		Percentage of academic researchers and industry collaborators satisfied about each other’s effective dedication to the collaboration	☐	☐	☐	☐	☐
	Technology	Rate of patent applications (submitted/planned)	☐	☐	☐	☐	☐
	New knowledge	Rate of publications (published/planned)	☐	☐	☐	☐	☐
		Percentage of joint publications	☐	☐	☐	☐	☐
	Management and organizational quality	Rate of deliverables executed on time	☐	☐	☐	☐	☐
	Human capital	Rate of recruitment of PhDs researchers from the program by the industry partner	☐	☐	☐	☐	☐
		Rate of recruitment of research assistants from the program by the industry partner	☐	☐	☐	☐	☐
		Variation in the percentage of collaborators with higher education qualifications	☐	☐	☐	☐	☐
		Number of master's degree dissertations and PhD theses obtained under the program context	☐	☐	☐	☐	☐

Na sua ótica, podem ser incluídos outros indicadores de desempenho? Se sim, indique quais, referindo a componente de desempenho na qual o(s) insere e se seria por troca com algum já existente.

Resposta: ____

(continuação)

Program Phase	Performance Component	Performance Indicator	Level of Relevance				
			Very low	Low	Medium	High	Very high
Program Closure	Innovations	Number of new products and product improvements developed	☐	☐	☐	☐	☐
		Number of new processes and process improvements developed	☐	☐	☐	☐	☐
	Solution concepts	Number of new solutions concepts generated	☐	☐	☐	☐	☐
		Increase of technology readiness levels (TRL), in comparison to the beginning of the projects within the program	☐	☐	☐	☐	☐
	New ideas	Number of new project ideas generated from the program, which might result in a new R&D program	☐	☐	☐	☐	☐

Na sua ótica, podem ser incluídos outros indicadores de desempenho? Se sim, indique quais, referindo a componente de desempenho na qual o(s) insere e se seria por troca com algum já existente.

Resposta: ____

Post-program	Technology achievement	Rate of patents granted (granted/submitted)	☐	☐	☐	☐	☐
	Sales growth	Variation of annual sales volume (net all discounts and taxes), from the program closing year to the year of the measuring	☐	☐	☐	☐	☐
	Partnership sustainability	Investment value of new university-industry R&D projects/programs generated	☐	☐	☐	☐	☐

Na sua ótica, podem ser incluídos outros indicadores de desempenho? Se sim, indique quais, referindo a componente de desempenho na qual o(s) insere e se seria por troca com algum já existente.

Resposta: ____

Parte 3

Ponderação da Importância dos Diferentes Elementos

Para ser possível aplicar o método em questão e medir o desempenho das colaborações em I&D entre universidade e indústria, é necessário quantificar a devida importância dos diferentes elementos – fases do programa, componentes de desempenho, e, por fim, indicadores de desempenho.

Deste modo, pede-se que atribua uma **ponderação relativamente à importância** dos diferentes elementos, sob a forma de percentagem. Para tal, por favor, preencha as linhas indicadas para o efeito, nas colunas *Weight* destacadas na tabela que de seguida se apresenta. Note que, em alguns casos nos quais apenas existe um elemento, as ponderações estão automaticamente definidas.

	Program Phase	Weight		Performance Component	Weight		Performance Indicator	Weight
100%	Program Preparation	_____ %	100%	Researchers’ capability	_____ %	100%	Average *h*-index of the academic researchers (excluding research assistants)	_____ %
							Percentage of researchers with past experience in university-industry R&D collaborations	_____ %
							Percentage of researchers involved that are not research assistants	_____ %
				Researchers’ motivation	_____ %	100%	Percentage of researchers satisfied with the contribution of their participation in a collaboration with industry to the development of their academic careers	100%
				Industry collaborators’ capability	_____ %	100%	Percentage of industry collaborators with a post-graduation or a higher education qualification	_____ %
							Percentage of industry collaborators with past experience in university-industry R&D collaborations	_____ %
				Industry collaborators’ motivation	_____ %	100%	Percentage of industry collaborators satisfied with the contribution of their participation in a collaboration with university to the development of their professional careers	100%
				Opportunities/challenges	_____ %	100%	Number of project ideas to be studied	100%
				Applied research	_____ %	100%	Percentage of initial project ideas in which the detailing of objectives and potential solutions is jointly determined by university and industry members	100%
	Program Initiation	_____ %	100%	Established governance	100%	100%	Degree of establishment of a joint governance model	100%
	Program Benefits Delivery	_____ %	100%	Collaboration intensity	_____ %	100%	Rate of Steering Committee meetings (performed/planned)	_____ %
							Rate of result-sharing events (performed/planned)	_____ %
							Rate of innovation meetings (performed/planned)	_____ %
							Rate of progress meetings (performed/planned)	_____ %
							Percentage of academic researchers and industry collaborators satisfied about each other’s effective dedication to the collaboration	_____ %
				Technology	_____ %	100%	Rate of patent applications (submitted/planned)	100%
				New knowledge	_____ %	100%	Rate of publications (published/planned)	_____ %
							Percentage of joint publications	_____ %
				Management and organizational quality	_____ %	100%	Rate of deliverables executed on time	100%
				Human capital	_____ %	100%	Rate of recruitment of PhDs researchers from the program by the industry partner	_____ %
							Rate of recruitment of research assistants from the program by the industry partner	_____ %
							Variation in the percentage of collaborators with higher education qualifications	_____ %
							Number of master's degree dissertations and PhD theses obtained under the program context	_____ %
	Program Closure	_____ %	100%	Innovations	_____ %	100%	Number of new products and product improvements developed	_____ %
							Number of new processes and process improvements developed	_____ %
				Solution concepts	_____ %	100%	Number of new solutions concepts generated	_____ %
							Increase of technology readiness levels (TRL), in comparison to the beginning of the projects within the program	_____ %
				New ideas	_____ %	100%	Number of new project ideas generated from the program, which might result in a new R&D program	100 %
	Post-program	_____ %	100%	Technology achievement	_____ %	100%	Rate of patents granted (granted/submitted)	100%
				Sales growth	_____ %	100%	Variation of annual sales volume (net all discounts and taxes), from the program closing year to the year of the measuring	100%
				Partnership sustainability	_____ %	100%	Investment value of new university-industry R&D projects/programs generated	100%

Parte 4

Simplicidade e Facilidade de Uso das Tabelas de Critério

Tendo definidas todas as métricas deste método para medir o desempenho das colaborações em I&D entre universidade e indústria, é necessário tornar o processo de medição o mais objetivo possível.

Para isso, a cada indicador de desempenho foi associado uma tabela de critério. Estas tabelas definem os critérios para a medição de cada indicador e abrangem os possíveis desempenhos que cada um pode obter.

Assim, pede-se, por favor, que analise cada tabela de critério associada a cada indicador de desempenho individualmente e que indique o nível de simplicidade e facilidade de uso de cada uma delas, assinalando o nível que considera adequado na escala. Caso tenha sugestões de possíveis alterações nas tabelas de critério, por favor indique-as.

Average *h*-index of the academic researchers (excluding research assistants)

Criteria	Score
Not applicable	0 – N/A
h-index of the academic researchers (excluding research assistants) is < 50% of the average	1 – Very low
h-index of the academic researchers (excluding research assistants) is [50, 70[% of the average	2 – Low
h-index of the academic researchers (excluding research assistants) is [70, 90[% of the average	3 – Medium
h-index of the academic researchers (excluding research assistants) is [90, 110[% of the average	4 – High
h-index of the academic researchers (excluding research assistants) is ≥ 110% of the average	5 – Very high

Level of Simplicity and Ease of Use

- ☐ Very complex
- ☐ Complex
- ☐ Normal
- ☐ Simple
- ☐ Very simple

Suggestions:

Percentage of researchers with past experience in university-industry R&D collaborations

Criteria	Score
Not applicable	0 – N/A
[0, 20[% of the researchers have past experience in university-industry R&D collaborations	1 – Very low
[20, 40[% of the researchers have past experience in university-industry R&D collaborations	2 – Low
[40, 60[% of the researchers have past experience in university-industry R&D collaborations	3 – Medium
[60, 80[% of the researchers have past experience in university-industry R&D collaborations	4 – High
[80, 100] % of the researchers have past experience in university-industry R&D collaborations	5 – Very high

Level of Simplicity and Ease of Use

- ☐ Very complex
- ☐ Complex
- ☐ Normal
- ☐ Simple
- ☐ Very simple

Suggestions:

Percentage of researchers involved that are not research assistants

Criteria	Score
Not applicable	0 – N/A
[0, 10[% of the researchers involved are not research assistants	1 – Very low
[10, 20[% of the researchers involved are not research assistants	2 – Low
[20, 30[% of the researchers involved are not research assistants	3 – Medium
[30, 35[% of the researchers involved are not research assistants	4 – High
≥ 35% or more of the researchers involved are not research assistants	5 – Very high

Level of Simplicity and Ease of Use

- ☐ Very complex
- ☐ Complex
- ☐ Normal
- ☐ Simple
- ☐ Very simple

Suggestions:

Given the excessive number of pages it would occupy, this part of the questionnaire is not all presented. The above example exemplifies how it was asked to the respondents to indicate the level of simplicity and ease of use of each criteria table.

APPENDIX II – H-INDEX OF THE UMINHO ACADEMIC RESEARCHERS THAT WORKED IN THE IC-HMI PROGRAM

Academic Researcher	H-index*	Engineering sub-discipline	Average h-index per engineering sub-discipline (1)	Point of reference (2)	Average h-index compared against the point of reference $\left[\frac{(1)}{(2)}\right]$
Academic Researcher #1	4	Electrical Engineering	6	5,89	101,87%
Academic Researcher #2	10				
Academic Researcher #3	4				
Academic Researcher #4	14	Electronics & Telecommunication	10,14	7,13	142,26%
Academic Researcher #5	9				
Academic Researcher #6	7				
Academic Researcher #7	8				
Academic Researcher #8	16				
Academic Researcher #9	6				
Academic Researcher #10	14				
Academic Researcher #11	11				
Academic Researcher #12	8	Informatics	9,53	7,67	124,24%
Academic Researcher #13	12				
Academic Researcher #14	5				
Academic Researcher #15	8				
Academic Researcher #16	13				
Academic Researcher #17	6				
Academic Researcher #18	13				
Academic Researcher #19	17				
Academic Researcher #20	19				
Academic Researcher #21	5				
Academic Researcher #22	3				
Academic Researcher #23	7				
Academic Researcher #24	10				
Academic Researcher #25	10				
Academic Researcher #26	16				
Academic Researcher #27	5				
Academic Researcher #28	5				

(continued)

Academic Researcher	H-index*	Engineering sub-discipline	Average h-index per engineering sub-discipline (1)	Point of reference (2)	Average h-index compared against point of reference $\left[\frac{(1)}{(2)}\right]$
Academic Researcher #29	9	Materials Science	12,58	11,78	106,82%
Academic Researcher #30	5				
Academic Researcher #31	10				
Academic Researcher #32	17				
Academic Researcher #33	5				
Academic Researcher #34	20				
Academic Researcher #35	17				
Academic Researcher #36	8				
Academic Researcher #37	4				
Academic Researcher #38	1				
Academic Researcher #39	7				
Academic Researcher #40	34				
Academic Researcher #41	21				
Academic Researcher #42	3	Mechanics	15	11,66	128,64%
Academic Researcher #43	14				
Academic Researcher #44	12				
Academic Researcher #45	40				
Academic Researcher #46	18				
Academic Researcher #47	3				
Academic Researcher #48	15	Production Engineering	6,5	2,82	203,50%
Academic Researcher #49	13				
Academic Researcher #50	6				
Academic Researcher #51	2				
Academic Researcher #52	8				
Academic Researcher #53	6				
Academic Researcher #54	5				
Academic Researcher #55	9				
Academic Researcher #56	8				
Academic Researcher #57	7				
Academic Researcher #58	4				
Academic Researcher #59	5				
Academic Researcher #60	2				
Academic Researcher #61	4				
Academic Researcher #62	5				
Academic Researcher #63	5				

* Values retrieved from Scopus and updated until 23/10/2018

APPENDIX III – YEARS OF EXPERIENCE OF IC-HMI MEMBERS IN UNIVERSITY-INDUSTRY R&D COLLABORATIONS

Years of Experience	Number of UMinho Researchers	Number of Bosch Collaborators
No experience	30	9
< 1 year	18	0
1-3 years	31	16
3-5 years	17	15
5-10 years	16	12
> 10 years	26	13
Total	138	65

APPENDIX IV – POSITION OF UMINHO RESEARCHERS THAT WORKED IN THE IC-HMI PROGRAM

Position	Number of UMinho Researchers
Full Professor	4
Associate Professor	15
Assistant Professor	21
Research Assistants	87
Total	127

APPENDIX V – DEGREE OF SATISFACTION OF IC-HMI MEMBERS ABOUT THE CONTRIBUTION OF THEIR PARTICIPATION IN THE IC-HMI PROGRAM TO A CAREER DEVELOPMENT

Degree of Satisfaction	Number of UMinho Researchers	Number of Bosch Collaborators
Dissatisfied	5	3
Not very satisfied	20	11
Satisfied	33	19
Very satisfied	45	18
Exceptionally satisfied	28	14
Total	131	65

Appendix VI – Education Qualifications of the Bosch Collaborators that worked in the IC-HMI Program

Education Qualification	Number of Bosch Collaborators
High school/vocational education	1
Bachelor's degree	25
Post-graduation	5
Master's degree	27
PhD	7
Total	65

Appendix VII – UMinho Researchers' Satisfaction about the Effective Dedication of the Bosch Collaborators to the IC-HMI Program

Degree of Satisfaction	Number of UMinho Researchers
Dissatisfied	13
Not very satisfied	24
Satisfied	21
Very satisfied	45
Exceptionally satisfied	26
Total	129

APPENDIX VIII – BOSCH COLLABORATORS' SATISFACTION ABOUT THE EFFECTIVE DEDICATION OF THE UMINHO RESEARCHERS TO THE IC-HMI PROGRAM

Degree of Satisfaction	Number of Bosch Collaborators
Dissatisfied	3
Not very satisfied	10
Satisfied	18
Very satisfied	25
Exceptionally satisfied	8
Total	64