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A PMS guide for research and development activities through the I-P-O framework.

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Abstract

In this thesis I will Analyse how companies present in the Italian context approach the research and development processes. I will develop a method to evaluate the performance obtained through these processes, trying to understand whether they bring added value to the company or not. In detail, an analysis of the literature was carried out, to which I then applied the I-P-O model where the process was fragmented and studied in its components to clearly grasp where and how improvements in the process can be implemented, thanks to indicators able to evaluate input, process and output variables. In detail, the part of the process has been differentiated into research processes and development processes, thus studying them, as suggested by the literature, respectively through variables of effectiveness and efficiency. In addition, the indicators obtained through this work have been implemented to the Balance Scorecard model, so that we can also consider the company strategy, which during the analysis of the literature appeared as a fundamental variable to effectively promote R&D processes within the companies themselves. All this was done by selecting indicators specific to each of the four aspects of it. Finally, I have found that qualitative indicators could help us understand the effectiveness of the process regardless of who is responsible for carrying it forward, focusing only on the result of the process, namely the creation of added value.

Keywords:

Research and development, R&D, R&D activity, R&D process, SME, performance, efficiency, effectiveness, PMS, design, KPI, BSC, input, process, output, IPO.

Abstract (italiano)

In questa tesi andrò ad analizzare come le aziende presenti nel contesto italiano si approcciano ai processi di ricerca e sviluppo. Cercherò di sviluppare un metodo per valutare le performance ottenute tramite processi di ricerca e sviluppo, cercando di capire se tali processi portano all'azienda valore aggiunto oppure no. In particolare, è stata eseguita un'analisi della letteratura alla quale ho poi applicato il modello I-P-O in cui il processo è stato frammentato e studiato nelle sue componenti in modo da cogliere chiaramente dove e come si possano attuare miglioramenti del processo, grazie ad indicatori in grado di poter valutare le variabili di input, processo ed output. La parte relativa all'analisi del processo è stata poi differenziata in processi di ricerca e processi di sviluppo, studiandoli rispettivamente, come suggerito dalla letteratura, tramite variabili di efficacia e di efficienza. Inoltre, gli indicatori ottenuti tramite questo lavoro sono stati uniti al modello della Balance Scorecard, in modo da poter considerare anche la strategia aziendale, che durante l'analisi della letteratura è apparsa come una variabile fondamentale per promuovere efficacemente i processi di R&S all'interno delle aziende stesse. Il tutto è stato fatto selezionando indicatori specifici per ognuno dei quattro aspetti di essa. Infine, è stato scoperto che gli indicatori qualitativi potrebbero aiutare a comprendere l'efficacia del processo, indipendentemente da chi sia responsabile del suo progresso, concentrandosi solo sul risultato del processo, vale a dire la creazione di valore aggiunto.

Parole chiave:

Ricerca e sviluppo, R&S, attività di ricerca e sviluppo, processo di ricerca e sviluppo, PMI, prestazioni, efficienza, efficacia, PMS, progettazione, KPI, BSC, input, processo, output, IPO.

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List of Abbreviations

BSC Balance Scorecard

DEA Data Envelopment Analysis

EBIT Earnings Before Interest and Tax

EBITDA Earnings Before Interest Tax Depreciation and Amortization

IPO Input Process Output

KPI Key Performance Indicators

NPD New Product Development

PMS Performance Management System

R&D Research and Development

ROA Return on Asset

ROE Return on Equity

ROI Return on Investment

RIS Research Information System

SME Small and Medium Enterprises

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Chapter 1: Introduction

Research and development generally refer to the activity of companies aimed at innovating**.** According to Shumpeter J., man has a propensity to research and solve the problems that surround him by generating new ideas and inventions. This interaction between inventions and entrepreneur gives rise to innovation. Also, Shumpeter J. calls the introduction of innovation into the economic system an entrepreneurial act and called the entrepreneur the one who innovates. The entrepreneur then assesses the economic importance of the invention by acting under the impetus of his own economic benefit, seizing its potential and appropriating its transformation into innovation to obtain *extra-gains*, defined as a competitive advantage. Innovations can concern both the techniques adopted to obtain a good, therefore a process innovation or a new product, but also concern changes in the organization such as to improve the efficiency of production or the quality of the product and services. In particular:

- Product: It can be both a new product and the improvement of an existing one already on the market; the degree of innovation depends on the reference that is assumed (subject, market, nation) a product may be new not in the absolute sense but may already be present in the economic system.
- Process: Change to a process increases performance and therefore improves factor productivity while not changing the characteristics of the product. It will reduce production costs by lowering either the price of the good or increasing its margin. Again, it can be a new or improved process. It can be considered as a product innovation depending on the perspective you take.
- Organizational: a special case of process organization, that takes place at the managerial level.

Moreover, the intensity of innovation can be radical or incremental depending on whether the improvements substantially change the good or whether they take place gradually.

As suggested by the two terms, the research and development activity includes two distinct moments: the research, aimed mainly at the conception and experimentation of new products or processes and conducted under laboratory conditions, and the development or applied research, in which research inventions are transformed into innovations.

To begin with, I would like to clarify why it is important to analyse the performance of R&D processes. Over decades, company management has been convinced that research and development activities could not be measured and that subjecting them to measurement and control would reduce the creativity and quality of the work of scientists; this led companies to refuse to ask for explanations about performance to research and development managers. These beliefs have changed to date and the trigger for this breakthrough is closely related to the evolution of the economic environment and the evolution of research and development activities. The fact that R&D activities have shifted from being a fixed expenditure in an annual budget to being considered a strategic variable for the growth and survival of many companies, has led to the need for R&D managers to measure the performance of research and development activities by also highlighting their concern not to know how to measure them effectively Kerssen-van Drongelen I.C. and Bilderbeek J., (1999).

Furthermore, the design of a PMS is much more demanding for research and development than for other activities due to the higher degree of uncertainty, isolation and secrecy that characterizes the innovative efforts of companies.

Despite the difficulty of managing these processes, the persistence of companies in research and development may be desirable. In fact, as seen in the Study Manez J.A. et al., (2014) it is related to high productivity growth and even greater profitability.

Chapter 2: Objectives

In this thesis I will analyse, how companies present in the Italian market, mainly small and medium-sized enterprises, approach such processes. This study should therefore both arouse interest as it is on the one hand closely linked to the Italian economic fabric, and because as pointed out by Baumol W. J., (2006) small enterprises contribute about two and a half times more innovations per employee than larger and more structured enterprises; in addition, SMEs tend to produce even more radical innovations than their counterparts. Although more precisely, Wang E.C. and Huang W., (2007), found that R&D performances are higher in small and large enterprises than in medium-sized ones.

The second objective I set myself is being able to evaluate and clearly understand whether is more performing a company with an employee, or a business unit dedicated exclusively to R&D processes, that follows a process described internally following clear and defined procedures; or whether companies of clearly smaller size, in which the research and development process remains entrusted to the entrepreneur, or to a foreman of a production line, who has years of experience behind him and feels the duty to innovate this process despite deviating his main task are equally effective.

Finally, I will try to develop an effective method to evaluate the performance obtained from these processes, making it clear whether they bring added value to the company or not.

In any case, if innovation occurs, it remains crucial to identify whether there is a person in the company entrusted with this task in the light of the possible tax relief and advantages offered to those carrying out research and development activities, processes defined as one of the engines of economic growth.

Chapter 3: Methodology

As far as the research methodology is concerned, systematic reviews of the literature are completed through an iterative process of defining the appropriate search keywords. Systematic reviews of the literature aim to reduce prejudices in the selection of studies and summarizing them objectively, a structured methodology for scanning resources, designing a mind map to structure the revision of the literature, describing the study and building the bibliography is recommended, Behnam Fahimniaa et al., (2015).

Starting from preliminary researches on Scopus, I began to define the line of searching review that I have personally carried out, using a methodology divided into several phases for the collection of data and a complete evaluation of the research field with the aim of identifying the most related studies and determining the areas of interest.

The first step is to define the appropriate search terms: I started looking for articles through keywords that aimed to satisfy a wide range of research terms to acquire as much knowledge as possible within the world of research and development, investigating all the areas related to it.

The focus was to measure their performance at the operational level, then going to see on what criteria these PMS were designed. Subsequently, I looked for articles related to the creation of new products and services, then to the new product and service development, finally going further and looking at how research and development processes brought added value to the company.

Another part of the initial research was focused not only on the study of processes, but also of research and development projects, topics subsequently discarded.

The keywords have therefore been maintained at a general level to cover a wider range of studies.

The research was carried out using the "title, abstract and keywords" search in the Scopus database, and led to a total of 3779 documents, then the identified items were collected and stored. I have also limited the search space to “Articles” documents written in English excluding conference documents, book series, commercial publications, and magazine articles. Furthermore, for ease of reading they have been limited to only open access items present in the Scopus library.

TITLE-ABS-KEY (("R&D activit*" OR "R&D process*") AND "performance") 1077 results. Of these 1035 date back to the last 25 years and only 635 were in English and coming from journals and 541 were articles. There were only 66 open access items.

The same procedures were also carried out for the following keyword searches, TITLE-ABS-KEY (("R&D process*") AND "performance" OR "PMS") 159 results, reduced to 11 articles.

TITLE-ABS-KEY (("R&D activit*") AND "performance" OR "PMS") 935 results, reduced to 32 articles.

TITLE-ABS-KEY (("R&D activit*") AND "design") 872 results, reduced to 29 articles.

TITLE-ABS-KEY (("R&D activit*") AND ("NPD" OR "NSD")) just 7 results.

TITLE-ABS-KEY (("R&D project*") AND "performance") 729 results, reduced to 46 articles.

After that, I switched to limiting articles released in the past 25 years, as they represented more than 90% of the articles present, this gave me the opportunity to reduce the raw dataset to 185 documents that will be used as the primary source for literature analysis. More importantly it led me to identify many keywords that I then went to decrease by better understanding of the objectives of this research thus excluding anything that was not directed exclusively on the processes. Search results were stored in RIS format to include all essential card information such as card title, author names, abstract affiliations, keywords, and references. The actual research began, once the area of study had been decided, I searched for other articles by inserting the previously selected keywords.

The first one was: TITLE-ABS-KEY (("R&D activit*" OR "R&D process*") AND "performance"), but unlike previously I selected only the articles concerning "business-management and accounting" which led me to a result of 139 results.

The second one: TITLE-ABS-KEY (("R&D activit*" OR "R&D process*") AND "SME"), this search, limited as the previous one led me to 64 results.

Subsequently, a search was carried out with the following keywords: TITLE-ABS-KEY (("R&D activit*" OR "R&D process*") AND ("performance" OR "PMS") AND "SME"), the result was 19 downloaded documents.

From this research it also emerged keywords such as "efficiency" and "effectiveness" which led me to perform a further research thus composed: TITLE-ABS-KEY ("R&D activit*" AND ("efficiency" OR "effectiveness")), which resulted in 533 articles that once filtered for articles from journals, in English and about business-management and accounting led me to 91 articles.

From the previous research it appeared as an additional keyword “DEA”, i.e., Data Envelopment Analysis, a linear programming model used to evaluate the efficiency of decisions in business units. Precisely, “DEA is a non-parametric method of relative efficiency evaluation suitable for multiple input and multiple output complex system analysis, proposed by the American operations research expert Chames A. et al., (1978).

This led me to a last research: TITLE-ABS-KEY ("R&D activit*" AND "DEA"), which resulted in 94 documents, among which there were 24 articles in English.

Considering the large number of documents received, I have begun a Bibliometry phase, which aimed to check the number of citations collected from these articles, to highlight the most relevant among them.

Reconsidering the first 139 research-derived articles (("R&D activit*" OR "R&D process*") AND "performance") we can see that they were cited 2323 times, so it carries an average of 16.71 citations per article, but of these 139, the top 50 (288 to 9 citations per article) have been cited 2108 times, collecting 90.74% of the total citations. Another 3 articles, published in the last two years, were also selected even if they do not have many citations.

As for the 64 articles from (("R&D activit*" OR "R&D process*") AND "SME"), there are 1578 citations, an average of 24.65 citations per article. The first 25 articles collect as many as 1429 citations, so 90.55% of the total citations. Another one was later on published, with few citations and dated back to 2019 which brought the total number to 26.

For what concerns the search (("R&D activit*" OR "R&D process*") AND ("performance" OR "PMS") AND "SME") the 19 documents that appeared as a result, after the opportune filters inserted, have 337 citations, an average of 17.73 citations per article. The top 10 articles in order of number of citations incorporate more than 96% of them, but I decided to also consider two articles with no citations given the recent publication: 2019 and 2020. Leading to a total of 12 articles.

The next research, ("R&D activit*" AND ("efficiency" OR "effectiveness")) once filtered to had resulted in 91 articles, featured 2475 total citations for an average of 27.95 citations per item. As previously done, I selected the study that encased more than 90% citations and other recent and relevant ones at the same time, leading me to consider 31 articles.

Finally, the latest research ("R&D activit*" AND "DEA") once filtered as the previous, had led me to 24 articles, that had been mentioned by another 542, with an average of 22.58 citations per article. Of these, 10 incorporated more than 95% citations, and another 6 were interesting despite the recent publication.

Once downloaded all the articles of interest they were grouped thus defining where intersections are, which were present in all the groups of keywords I wanted. As easy to imagine, the first three searches were more similar, just as there was an affinity between the last two.

Combining the results of all the research carried out, I came to 27 articles incorporating all the keywords I searched for, plus 12 other articles belonging to the first three searches, and 6 belonging to the last two, which, although they did not contain all the keywords, were similar as content to my research needs. To these were added another 19, which incorporated the first brick of specific knowledge that I acquired and other articles among the most mentioned in those I read. Thus, bringing the final number of articles read for the literature review to 64.

Chapter 4: Literature Review

A literature review was carried out to address the problem from a broader and more relevant perspective to build the thesis on a solid knowledge base. In fact, the first part basically summarizes how research and development processes have been analysed over the last twenty years, starting from being considered as an expenditure in the budget, to being recognized as a strategic variable. Thus, bringing a great interest in the study of this subject. In the second part I studied in more detail in the analysis based on framework I-P-O.

4.1 Why measure performance?

It was noted by Lazzarotti V. et al., (2011) that the reasons why companies measure results effectively are: the increasingly dynamic market, changes in customer needs from year to year, the growing number of competitors, as well as the number of knowledge and alternative products and services.

The costs for these activities are also continuing to grow year after year, but without any on revenues, moreover, the dependence of companies on technology continues to go on in order to establish a solid competitive advantage, both causes lead to a single solution, measuring the performance of research and development.

Most companies working in this sector adopt a business strategy and operate in a competitive environment that gives to R&D activities a fundamental role in cultivating and supporting the competitive advantage of the company.

In case of heavy dependence on competitive advantage, for a company that carries out R&D activities, the need to control them becomes primary as they also have to face important costs to implement control systems to monitor the most critical performance for their business strategy.

Finally, a company may need to measure the performance of its research and development activities monitoring its ability to meet certain requirements defined by regulatory bodies, or to meet deadlines and cost targets. Therefore, to maintain a competitive advantage, it is crucial to have an efficient and at the same time effective R&D department.

Contributions to performance measurement have so far focused mainly on defining a set of performance sizes to be monitored and on the indicators to be used to measure them. It is also important to not leave out that part of the literature that deals with the definition of an entire performance measurement system that is an integrated system not only able to measure a specific set of performance, but also to explain the managerial and organizational meaning of each measure, to suggest the most appropriate use of them and to analyse the performance of R&D regarding the company strategy.

In other words, for Chiesa V. et al., (2007), a systemic perspective should be adopted, that allows us to examine research and development performance in terms of "system", which should consist of a set of integrated and internally coherent elements, i.e. objectives of a PMS, as performance dimensions, metrics and indicators, control objects and measurement process.

By adopting this perspective to measure performance, managers in R&D department among their current tasks, have to measure their performance through appropriate models, reflecting the meaning and the motivation of the measures. Later on, Chiesa V. et al., (2009), indicated that companies measure research and development performance for different purposes, such as motivating researchers and engineers, for example by directing their efforts towards long-term objectives, overcoming the lack of commitment that determines the increasingly intangible results of research and development, monitoring the progress of activities, assessing the profitability of projects, promoting coordination and communication, in particular by stimulating rapid and effective organizational learning that can reduce the level of uncertainty surrounding critical decisions on research and development.

Another interesting aspect brought to light by their analysis is that companies with large research and development units are more involved in using PMS for "diagnostic" purposes than SMEs that tend to use it more for "motivational" purposes.

As already mentioned, not only measuring the performance and contribution of research and development become a key concern for the managers of these departments in recent decades, but this issue should be addressed systemically, which is why the number of texts in the literature seeking models for measuring the performance of these processes has been growing considerably over the last 20 years.

Both for Pearson A.W. et al., (2000) and for Chiesa et al., (2007), the measurement of research and development performance has increasingly become a strategic issue that must be aligned with the company strategy itself. To encourage such alignment, a performance measurement system is needed, in which are concerned both the size of the performance to be monitored and its indicators, but also the structure of the system and the process aspects to be defined for the proper functioning of it, i.e. the rules to be implemented for the operation of the PMS (e.g. the timing and frequency of measurement, the role and tasks of the people involved in the system).

Chiesa V. and Masella C., (1996) have suggested a Research and Development Performance Measurement System that includes successful technical measures and efficiency measures.

Lee K. et al., (2017) aimed to develop a system that can evaluate companies' research and development processes and improve those that are problematic. This system in their opinion can help managers improve research and development performance by highlighting even the necessary improvements on the most critical processes.

Salimi N. and Rezaei J., (2018) with the aim of measuring R&D results considering the different levels of importance of the measures, show how the allocation of different weights to different R&D measures results in a different classification that allows those responsible for these activities to formulate more effective strategies to improve their company's R&D performance.

Thanks to these works we can prove that companies, depending on the context in which they operate, have different needs to measure such performance, and that therefore there are no special and unique indicators.

It is also interesting to observe from the literature what can influence measurement. According to a study by Chiesa V. et al., (2009) all these objectives are influenced both by the context (type of research and development, industry membership, size) in which a PMS is designed and subsequent measurement, and by the same objectives pursued by the company.

For Wang E.C. and Huang W., (2007) the efficiency of a research and development unit to turn inputs into output is affected by its technical skills, which are controllable variables, and by the external operating environment, which is usually beyond its control.

In addition, R&D activities are not performed with immediate profit expectation. Instead, it is expected to contribute to the long-term viability of a company. According to Beneito P. et al., (2014), we obtain that the number of years of commitment to research and development has a positive effect on the expected results of innovation since the investments do not lead to immediate tangible results as there are delays in both the development and marketing of a project, stretching the time needed to assess how profitable the investment has been. In more detail, a lag of time between input and output should be considered when making a precise assessment (Wang E.C. and Huang W., (2007); Hashimoto A. and Haneda S., (2008)). It is therefore essential to effectively measure the economic value of improving these operations often after a considerable period.

Finally, for Pearson A.W. et al., (2000) it is necessary to be able to monitor R&D performance in the best way possible, without imposing too many rules within the process, measurements defined too restrictively to map such a complex concept, without remaining too much focused on the short term and considering above all the people affected by the introduction of performance measurement systems.

4.2 Types of indicators:

I consider it is fundamental to introduce in detail the types of indicators that can be used for a research and development PMS through the study of the literature, Brown M.G. and Svenson R., (1988), indicated that a PMS for research and development can be defined effective if it is constructed around a limited number of indicators that measure results unequivocally, and thus favour objective metrics over subjective ones. In addition, Nixon B., (1998), suggested that the parameters needed to make the measurements should be quantitative and objective. As seen by Chiesa V. et al., (2007), however, the most effective measurement approaches for research and development are those that balance both quantitative and qualitative metrics. The main types of indicators that can be used to measure the size of performance in research and development contexts are:

1. Quantitative objective indicators, i.e. numerical metrics obtained by Algorithms leading to the same assessment independently of measurement variables (e.g. percentage of projects completed on time, number of citations from company researchers' publications).

2. Quantitative subjective indicators, which as defined by Chiesa V. et al., (2007) are numerical metrics based on the personal judgment of an expert, whose subjective assessment is, however, translated into a numerical score through alternative techniques.
3. Qualitative subjective indicators, which are not expressed numerically, but through the personal judgment of an expert in charge of the analysis.

Each of the three indicator categories, according to Chiesa V et al., (2007), can also be used to measure any size of performance, be it the efficiency, effectiveness, time or the contribution to value creation.

This study also reveals a clear diversification of performance indicator classes throughout the research and development process. In detail, quantitative objective metrics are much more widespread in development than in research, while qualitative subjective metrics are typical of research activities.

A further study of the types of measures comes from Landström A. et al., (2016) which through a study of seven companies state that based on the need for use, indicators can also be identified as "lagging" or "leading". The first indicator is typically output-oriented, such as revenue or costs, and is also easier to measure as they are variable that can be easily obtained, while the second indicator is input-oriented. Therfore we can define the "leading" indicators as independent variables, while the "lagging" indicators are dependent on the input variables and also on the process itself.

The main indicators should, however, be chosen to promote change and generally improvements.

Remaining on the concept of input and output, García-Valderrama T. et al., (2009) by seeking to broaden the concept of efficiency measurement for research and development activities, have tried to link it to the four perspectives of the Norton and Kaplan BSC. According to their study, the best practice for doing this is to consider on the one hand the financial and client perspective with drivers, or inputs, since it is the prospects more closely related to financial and commercial results. On the other hand, considers internal processes, learning and growth processes as perspectives more related to process output. Although it is more widespread as a measure of outputs a proxy of commercial results derived from innovation however, this does not remain an isolated attempt. Chiesa V. et al., (2009) demonstrated in a study how the companies they studied measure research and development performance considering: the economic and financial aspects associated with research and development (financial perspective); the client's perspective, i.e. how research and development meet their demands; the efficiency with which specific tasks and processes are carried out (perspective of the business process); and finally, how much research and development contribute to generating new opportunities for knowledge and innovation (innovation and learning perspective). The analysis also shows that each performance dimension requires a correct estimation of specific indicators as shown later, analysing the literature relating to the I-P-O framework.

These are two well-described cases in the literature, but many other scholars have attempted to apply the Balance Scorecard (BSC) approach to R&D by maturing an approach to measuring research and development performance that, by integrating financial perspectives, customers, internal companies, innovation and learning, i.e. the four perspectives of a BSC, is easily allowed to implement the R&D strategy and therefore also the company's competitive strategy.

It is clear from other research that this strategy needs to be linked to the company's one. Nixon B., (1998), anticipated that performance indicators for research and development should have a strategic orientation and reflect the company's critical success factors. In fact, the basis of a good performance measurement system must be a common strategy and the objectives must be set according to those of the other business units. Moreover, as research and development are a core component for companies, a close integration of research and development activities with the company strategy itself is increasingly necessary. It must therefore be understood that while the task of the company strategy is to suggest to managers how research and development activities should be managed, the staff undertaking such activities should collaborate in defining it to aspire to the achievement of the results coveted by the company.

To return to the concept of the Balanced Scorecard (Kaplan R.S. and Norton D.P. (1992), it is basically a dashboard, that is, a visual tool that allows us to "squeeze" and "surf" indicators of different kinds. The balance scorecard allows us to associate a set of four indicators related to the four different perspectives, the financial one, the prospect of customers, the perspective of internal processes, and the one of growth and learning.

It can also be described as a performance measurement system that, starting from the vision and the company strategy, allows to identify the most important aspects of the business: the aim is to organize the activities of all parts of the company around a common understanding of the objectives of the organization.

These frameworks focus mainly on the design of a set of balanced key performance indicators (KPIs), integrating financial and non-financial dimensions and also considering internal and external stakeholders. KPIs specifically are a set of objectively quantifiable measures that a company uses to evaluate its performance over time, in fact, they have the advantage over other metrics of being specific, measurable and stable over time.

These metrics are mainly used to determine a company's progress in achieving its strategic and operational goals, but also to compare its performance relating to other companies within its industry through benchmarking.

The literature on this subject suggests many studies based on the use of specific KPIs for research and development. Flipse S.M. et al., (2013) identified several key performance indicators with an amended version of Wageningen's innovation assessment tool, through which they analysed 72 projects. In this study they could demonstrate that relevant social aspects, such as communication, cooperation, sustainability and health, are important performance indicators in food technology research projects.

Wiktorsson M. et al., (2018) through a case study they have shown that KPIs are not essential during the development phases of the product and production system. This document introduces enabling indicators that can be analysed and evaluated in the early stages of development.

Tadic J. et al., (2020) tried to verify through a sample of 196 companies whether the research and development KPIs they assumed were related to a company's performance, demonstrating that all the KPIs analysed have a significant impact on business performance calculated with financial indicators such as ROA, ROE, and EBITDA margin.

R&D activities are also involved in learning and innovation measures and in internal process improvement measures. KPIs can now be defined in three large classes: Costs, Project Quality, and People.

Not only have the studies listed investigated and studied so far the reasons why there is a strong need to monitor and measure research and development processes, the advantages of adopting a systemic view of the entire process, what types of indicators to use and the importance of tying all this with visual tools such as a balance scorecard, through which it is possible to tie indicators to different business aspects; but it has also been shown that it would be even more appropriate to differentiate a PMS itself from those capable of measuring the performance of research activities to those for development activities, also defined as new product or process development activities. In fact, some companies are engaged only in research or development activities. Small companies rarely deal with both, given the organizational complexities and costs to be incurred. For these reasons, proposing only general models in which PMS is shown for research and development could be problematic since companies and managers could adopt indicators or measurement frequencies that are unknown on the other hand if the companies in question were carrying out both research and development activities, organizational complexities could arise for having two different PMS in the same organizational unit.

In any case, as written by Chiesa V. et al., (2007), the literature proposed up to that time on the measurement of research and development performance, tended to regard R&D as a homogeneous process. During their study they assessed whether and how the design of a PMS is influenced by the type of activity to be evaluated, be it research or development of new products (NPD). According to what has been read, a contextual approach should be adopted to the measurement of research and development performance by suggesting to those responsible to identify priorly which of the two activities measurement is necessary and to design an appropriate PMS. To proceed managers have to start from the purpose of PMS, for example for research they may need to motivate staff, for development instead they could try to encourage organizational learning. The next steps are well explained in the figure by as Chiesa V. et al., (2007) which provide us with some practical guidelines to adapt the PMS to the type of activity that will be measured.

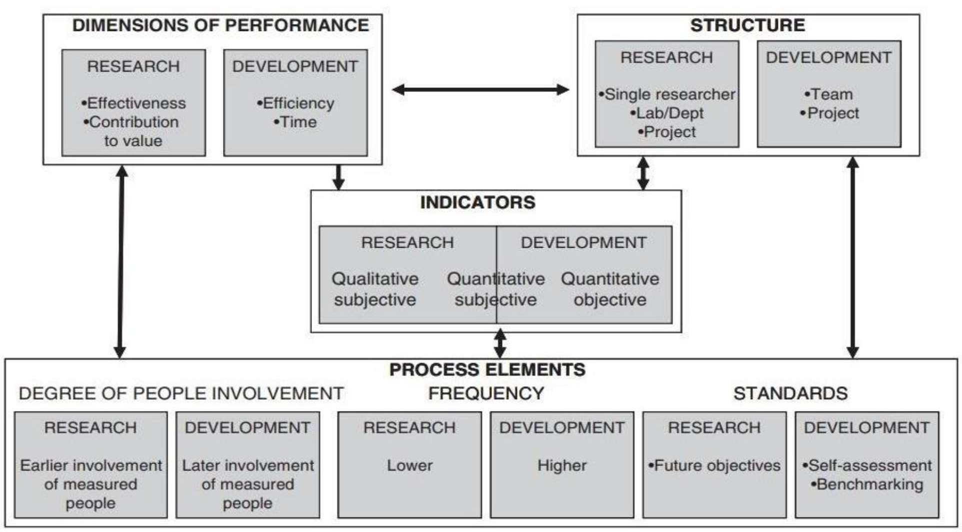

Figure 1: PMS Guideline (Source: Chiesa V. et al, 2007)

Thanks to this work, carried out as a multiple case study, we are told that research PMS tend to monitor performance sizes other than development performance. To support this, according to García-Valderrama T. et al., (2009) the main focus should be on efficiency (i.e. costs) and time spent, variables influenced both by factors under the control of the company such as technical expertise and its growth prospects and by the external operating environment, which is usually outside its control.

While as far as research activities are concerned, the critical performance dimensions are related to effectiveness. It was then demonstrated by Mulero-Mendigorri E. et al., (2016) that the four factors that most influence the effectiveness of research are: obtaining the results deriving from these activities, a close integration with the company strategy, proper planning and the existence of close relationships and cooperation between the research and development, and lastly the production and marketing functions of the company; all issues previously found by the study carried out by Chiesa V. et al., (2009) in which they were linked to the objectives to be aspired to for the creation of a PMS.

4.3 I-P-O

Another way in which R&D processes can be schematized and decomposed into easier-to-control problems is through the I-P-O model. This framework has recently been used as a base for other studies in the field of management for example by Ghezzi A. et al., (2018) because it can help distinguish the main components and results of the process under examination. The components which form the following framework for evaluating R&D processes with a view to the I-P-O model have been taken from studies based on this process: as Garcia-Manjón J.V. et al., (2018) and Chiesa V. et al., (2007). However, the main components of our framework for measuring the level of innovation refer mainly to Garcia-Manjón J.V. et al., (2018), who hypothesized that the most common measures used in the literature to analyse these processes are as follows:

1. A measure of inputs into the innovation process, such as R&D expenditure or the number of scientists and engineers.
2. A study of the process, i.e. how all management areas related to it are managed, which can in the same way be measured in terms of efficiency.
3. A direct measure of innovative outputs, such as the number of patented inventions, new products or new processes.

A similar taxonomy was adopted by Brown M.G. and Svenson R., (1988), which tried to measure every performance dimension by combining input, process and output indicators. Finally, as mentioned by Chiesa V. et al., (2009) for a correct performance measurement system it would be necessary to analyse the relationships that occur between the inputs, the resources necessary for the research and development process and then compare them with the outputs, i.e. the results obtained, being able to trace the process evaluating whether there has been an increase regarding the ratio of input to output or not, highlighting whether the performance has improved.

4.3.1 Input measures:

Research and development activities absorb different resources such as human capital, physical capital, support services and infrastructure. These resources will have a cost that the company will have to sustain and that therefore represent the amount of input necessary to carry out R&D projects. Instead of the overall R&D expenditure they can be used as input indicators of R&D components and the literature offers numerous ideas about it. Garcia-Manjón J.V. et al., (2018) have built a theoretical model that helps determine these factors. In their case, examples of input measures were:

Input variables:
% graduates/total number of employees
of project heads in the company
Specific budget in writing for R&D and innovations
of R&D and innovtion projects detailed in writing
Technological level of the company
Staff exclusively dedicated to R&D and innovation
Research assistants in R&D and innovation
Carries out technical training without subsidies

Table 1: Input Indicators 1 (Source: Garica-Manjón J.V. et al, 2018)

Li R. et al., (2014) in another study have sought to evaluate through the DEA method of measuring and analysing production efficiency, input redundancy and output deficiency of regional research and development institutes in China. The input variables considered were:

1. Research and development staff
2. Intramural expenditure on research and development
3. Production index
4. Scientific Papers Issued

D'Angelo A., (2012) with the aim of examining the influence of innovation measures on the intensity of exports of Italian high-tech small and medium-sized enterprises, as a proxy to measure inputs in R&D processes within companies, he used total domestic spending on research and development for total sales and R&D employees on total employees.

Hashimoto A. and Haneda S., (2008), using the DEA model to measure research and development efficiency at both company and industrial levels, as input variables, have measured the efficiency of the activities indicated as research and development expenditure, such as the number of research and development researchers.

Chen K. et al., (2018) defining a systemic measurement for the efficiency of investment activities in research and development have hypothesized different inputs, one is related to research and development staff, that is a measure of the time spent by research and development staff to carry out such activities. The other one is spending on research and development, including paying the salaries of research and development employees and purchasing research and development equipment and facilities.

Mulero-Mendigorri E. et al., (2016) to measure the effectiveness of R&D activities, used as input variables the resources and infrastructure available for human processes and resources.

Liu H.-H. et al., (2020) investigating the efficiency of research and development through a DEA approach, used research and development expenses and the number of people involved in the process as input.

Finally, as previously anticipated García-Valderrama T. et al., (2009) and Chiesa V. et al., (2009) tried to integrate the design of a PMS for research and development with the balance scorecard.

In fact, in their studies they tried to connect different performance proxies to each of the four areas of the BSC. Particularly, in the work of García-Valderrama T. et al., (2009) the BSC perspective linked to learning and growth is exclusively related to inputs, while the financial perspective as we will Analyse later is closely linked to outputs thus leaving the perspective of customers, the perspective of innovation and the internal processes perspective both related to outputs and inputs depending on the measure selected. Anyway, a measure was sought that would estimate the effectiveness of the processes through different proxies obtained such as the ratio between output and input. In the following table shows some indicators hypothesized in the document mentioned.

Financial perspective:	**Customer perspective:**
Increased financial profitability	Increase of sales
Increased Profits	Increase in market share
	Improved positioning in the market
Innovation and learning perspective:	**Perspective of business processes:**
# of patents	Quality
Innovation achieved	% annual expenditure in R&D
Ability of R&D personnel	Success in achieving objective
Experience of R&D personnel	Match with budget

Table 2: Input Indicators 2 (Source: Garcia-Valderrama T. et al, 2009)

In the work of Chiesa V. et al., (2009) a different approach has been adopted, indeed indicators related to input, process and output measures were sought for each perspective of the BSC. Among the measures related to input, for example, we can find:

Financial perspective:	**Customer perspective:**
Total cost of each R&D project	# customer interactions during the project
Annual expenditure on research and development	% of the budget dedicated to customer analysis
Annual research and development investments	% of customer-led projects
Innovation and learning perspective:	**Perspective of business processes:**
# in % of people with managerial experience	Knowledge of advanced managerial tools
# of employees in research and development	Knowledge of advanced IT support tools
	Experience of research and development employees

Table 3: Input Indicators 3 (Source: Chiesa V. et al, 2009)

Generally, we can say that in the literature there is not a single way in which inputs related to research and development processes can be represented, but there is a multiplicity of them, each valid according to the research objectives in which it has been applied. Although the most common measures concern the expenditure incurred for the activities and the number of researchers involved.

4.3.2 Process measures:

By definition, *a process is the place where the work is performed*. A process generally consists of a series of steps or operations that are performed in part by human operator, a robot, a computer or a machine. There are many processes to perform different functions in the organizations and research and development are one of them, carried out by several sub-processes. According to the literature, research and development is considered as a multiplicity of activities and processes whose performance must be monitored, especially since in many technological contexts they are considered the best resource of competitive advantage. The part concerning processes is precisely related to this set of individual activities that needs to be monitored. Moreover processes, such as inputs, generate variables that we have to consider in evaluating their performance. A research and development process can basically lead to two different outputs, on the one hand we have the creation of a new process, on the other the creation of a new product. In both cases, however, the implementation is similar.

Considering the literature, García-Manjón J.V. et al., (2018) for example, in their study as variables related to the process they have:

Process variables:	Human resource variables:
Use of project management methodology	The increase in research and development staff
Incentive-based remuneration systems	The aptitude in human resources
Introduction of changes in organizational structure	
Presence of staff with a technical and engineering profile	
Receive public grants for R&D and innovation	
Carry out R&D activities on an ongoing basis	
Collaborate with external entities in R&D	

Table 4: Process Indicators 1 (Source: Garica-Manjón J.V. et al, 2018)

Chiesa V. et al., (2009) again connecting to the BSC he hypothesized as measures of the process the following:

Financial perspective:	Customer perspective:
Cost of acquiring a new technology	Time-to-market
Present value of R&D achievements	Design hours on projects/design hours on projects and troubleshooting
Research and development expenditure	# of analysis reports of the problems requested and delivered
Innovation and learning perspective:	**Perspective of business processes:**
# of hours of staff training	% of projects meeting costs and budget
Time spent analyzing the failure of previous projects	Quality of development documentation
% of suggestions implemented	Average annual improvement of process parameters
Ability to acquire new bodies of expertise	Sum of durations/sum of the revised planned durations

Table 5: Process Indicators 2 (Source: Chiesa V. et al, 2009)

Subsequently, in the study led by Chiesa V. et al., (2009) it can be interesting to have two PMS dedicated one to the research phases and one to the development. Taking a look for example at the structure of the Double Diamond used in Design Thinking we can see that the first part of the diamond looks like research activities, while the second part has affinity with development. In fact, a research and development process tend to be like a design thinking process; in both cases the goal is to create a new product or process.

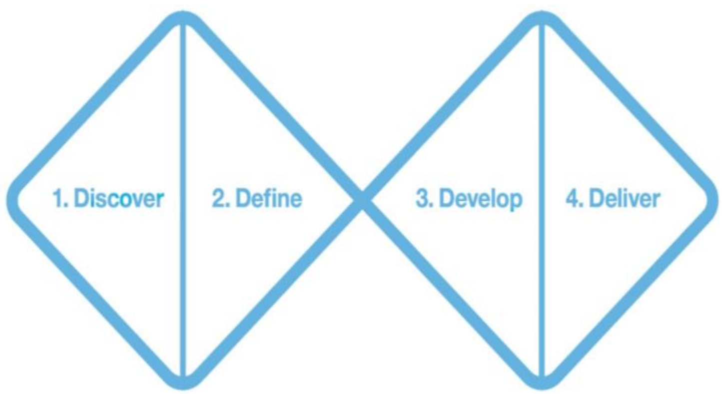

Figure 2: Double Diamond (Source: Design Council)

In general, a search process can be represented as follows:

Figure 3: Research Process

It is crucial to collect different types of data through different methods, to obtain evidence and inspirations for the following conception phase and then select and analyse the collected data, then transform them into insights, which will lead to the formation of possible solutions and further developments.

As seen in the study of Mulero-Mendigorri E. et al., (2016) the research tends to be measured with efficiency-related parameters that can generally be measured with indicators such as:

1. Total cost of the activity.
2. Perceived quality.
3. Time invested.

However, a certain degree of "measurable" performance is expected due to the intrinsic nature of the company's activity, i.e., basic and applied research, and therefore highly creative, uncertain and completely unstructured.

As for a process dedicated to development, we can represent it as in this figure:

Figure 4: Development Process (Source: Ulrich & Eppinger)

In the study of Mulero-Mendigorri E. et al., (2016) the process part was simply enclosed in such pair of indicators: Research and Development Plan and Implementation of the Research and Development Plan.

It is more understandable at this point, that there is a need for a well-structured plan to carry out all the stages of the process which is according to this scheme, the first fundamental point of the process.

The second point is to develop a concept and then design it first in a general way and then in every detail then arriving at a test phase before being able to introduce it into the market.

The key points to be respected for a correct development PMS are the following:

- Product quality. Does the product meet the customer's needs? Is it robust and reliable? The quality of the product reflects the market share and how much the customer is willing to pay.
- The cost of the product. What is the cost of producing the product? This includes both the fixed cost of the equipment and the cost of production of the individual unit. This cost affects the profit that the company can have from a specific sales volume to a specific sales price.
- Development time. How quickly did the team complete the product development effort? It determines how responsive the company is to the competitive market and how quickly the company receives returns from the team's efforts.
- Development cost. How much does the company have to spend to develop the product? The cost of development is usually a high percentage of the investment needed to achieve high profits.
- Development capacity. Are the team and company more able to develop future products thanks to their experience with a product development project? Development capabilities are a resource that the company can use to develop the product more effectively and efficiently in the future.

Other criteria can also serve to measure the success of product development, such as innovation, sustainability/green products, emotion and safety.

According to Chiesa V. et al., (2007) the structure of development PMS generally includes a multifunctional team and therefore there is also a need to incorporate variables that can measure this aspect, such as: time spent for group work / total time.

As already highlighted by Chiesa V. et al., (2007), in research PMS, the typical control objects are the individual researcher, the scientific (or technical) office and the research project. People involvement also tends to appear during the early stages of the measurement process and continues throughout the process. In the case of development, engineers participating in development projects tend to be involved later on, usually during the analysis of results and in the design of corrective actions. This means that for the development of a PMS to measure the performance of research activities the human factor is more expensive and more resource-consuming than development activities. Therefore, there is a need to monitor human resources as well to implement a correct PMS.

Indeed, the actors of equal importance and perhaps even greater than the influence of financial and technological resources on research and development activities are quality, experience and training of human resources and, finally, motivation for innovation of the staff.

A rich literature shows the importance of human resources in the effectiveness of research and development activities. (Eva Mulero-Mendigorri E. et al., (2016); Chiesa V. et al., (2009); García-Valderrama T. et al., (2009)). These studies are particularly similar as regards the positive effects on the effectiveness of research and development of the know-how, and staff skills of the research and development department.

But how to monitor human capital? Proved to be a pillar of R&D processes.

Basically, there are three key measures and they are based on the quality, quantity and accessibility of these resources.

Quality:	**Quantity:**	**Accessibility:**
# of employees with a specific education	# of employees by role	Educational level in accessible areas

Table 6: Human Capital

Finally, to reduce the risk of uncertainty, development PMS tend to adopt higher measurement frequencies than research frequencies, looking at the process more closely, since an error during a process of developing a new product, if not found in a timely manner, risks entailing much higher costs for the company to take corrective action. In fact, as shown in the figure, the longer you wait to make changes or correct errors, the higher costs go up.

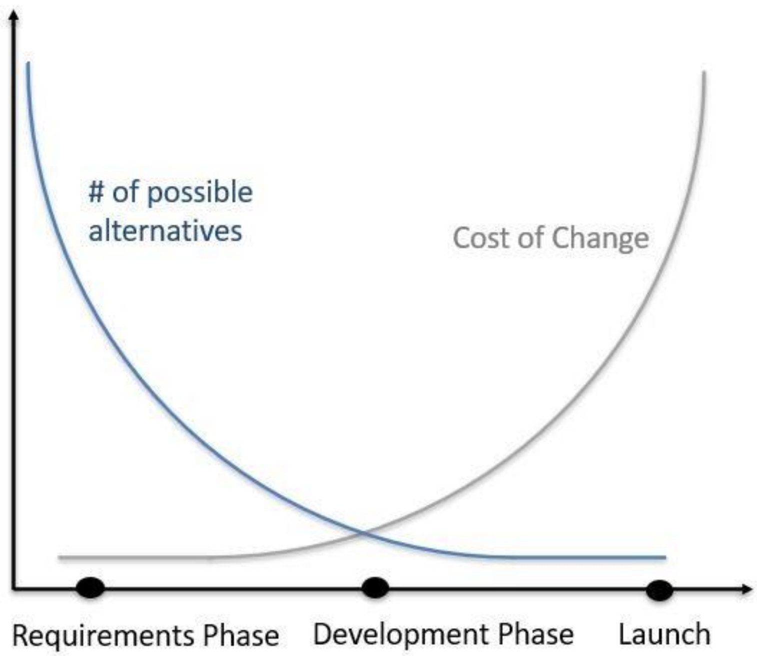

Figure 5: Graphic of Costs

4.3.3 Output measures:

After the analysis of the process, we are faced with the last element of the I-P-O model, namely output, which can be mainly distinguished in product and/or process innovation. Although at a glance it seems simple to identify its performance, it is actually a problematic task. In fact, taking as an example a study mentioned above, input indicators can be defined as leading indicators while output indicators can be defined as lagging indicators, this highlights that they can be influenced by inputs, but not only, indeed, the results are also influenced by the processes carried out in the research and development activity, increasing the variability of these indicators.

The aim is to quantify innovation in the market context by measuring the number of patents, the number of scientific publications and citations or the share of turnover due to innovation. However, the number of patents is not indicative of the effectiveness of innovation in terms of added value and degree of innovation because the aim of patenting research and development results is to try to create barriers to protect competitive advantage.

Other examples of output measurement are provided to us quite exhaustively by the literature, which speculates on the input part is rich.

As seen by Tadic J. et al., (20-20), the KPIs they analyse for the development of research and development products have a significant impact on business performance, but new product versions and patent production have the strongest.

Also, García-Manjón J.V. et al., (2018) in their study used as output variables, one with variables related to business performance: Product Innovation, Process Innovation, Sales in the reference period, Profits in the reference period, Reference Markets and Customer Type.

Li R. et al., (2014) already mentioned above have used multiple output measures such as: Published scientific articles, Publications on science and technology, Number of accepted patents and the national or industry standard.

D'Angelo A., (2012) also included two innovation output measures: one that measures whether companies have undertaken product innovations and another that measures whether companies have undertaken process innovations. In addition, we considered another variable that reflects the output of the process, i.e. the percentage of turnover resulting from a company's innovative activities.

Hashimoto A. and Haneda S., (2008), as output, have proposed the following dimensions: the number of patent applications published publicly in a year used as an invention proxy, that is, an indicator that directly reflects the level of research and development results. Subsequently, they broke down the output for research and development activities in enterprises into two components: one aims at "product innovation" and the other at "process innovation". The former contributes to increased sales and the latter increases profits by reducing costs. Considering two proxies for product and process innovations, they used sales and EBIT (earnings before interest and taxes).

Chen K. et al., (2018) considered two types of output to measure the output of the research and development process. One is the result of scientific knowledge, and the other is the production of technological inventions. Documents published on the scientific citation index and the patents granted are used as proxies. In addition, in the output of scientific research and development activities, documents should be the most appropriate choice in terms of data availability and measurement accuracy. Although in terms of output of technological research and development activities, patents have so far been the most appropriate indicator to date.

Liu H.-H. et al., (2020) used as output the main Operating Revenues to highlight the income of the primary activities of companies engaged in commercial activities and the sales revenues of new products as a proxy for the revenues obtained from the sales of new products that adopt new technologies, develop new design and production concepts, indicating the product's capacity for innovation.

As mentioned above, in the work of García-Valderrama T. et al., (2009) the BSC's perspective linked to the financial one is closely refers to outputs, while the customers, the innovation and the internal processes perspective are linked to both outputs and inputs. In any case, within the financial perspective as indicators we can find increased financial profitability and increased profits.

While in Chiesa V. et al., (2009) approach to implement the concept of balance scorecards and inputs, process and output, as output variables related to the different perspectives, the following were used:

Financial perspective:	Customer perspective:
Profits from research and development	# output of customer complaints
Reduction of costs (or % of costs)	Customer satisfaction
Market share due to research and development and innovations	Number of new customers
Innovation and learning perspective:	**Perspective of business processes:**
# of new ideas per year	Average project delay
% of patent applications that gave rise to registered patents	% of projects delayed or cancelled due to lack of resources
# of citations from researchers' publications	Total product development time
# improvement suggestions per employee	Success rate of projects, i.e. achieving time, cost, quality…

Table 7: Output Indicators (Source: Chiesa V. et al, 2009)

In general, it has been used parameters that can measure:

1. The existence of higher sales revenues (due to product innovations)
2. Lower production costs (tend to be due to process innovations)
3. The number of scientific articles published or the number of patents submitted.

A second-best solution for assessing the value provided is to evaluate the applications of the innovative output; for example it can be the number of times the patent is mentioned, increasing its relevance however, it is not indicative of the effectiveness of innovation in terms of added value and degree of innovation, in fact, companies can often decide not to patent since it is a long and expensive procedure compared to what are the life cycles of the product.

For the counting of scientific publications and citations, on the other hand, Bibliometry can be used, where the number of citations for the importance of newspapers is weighed, it is a discipline based on statistics. The limitations are that only published information can be analysed when it happens that it is preferred to keep it hidden to maintain competitive advantage, the basis of the ownership of innovation.

Chapter 5: Results

The reasons why measuring the performance of R&D processes, as well as the company's purposes to do so are manifold: motivational or diagnostic. Different models of PMS were presented in the literature and among them, the I-P-O model allows us to evaluate whether there has been an increase in performance during the entire course of the research and development process proposing improvements in each of its sub-part, thus also highlighting how and where value is created during the process. There are also different types of indicators, quantitative objective indicators, qualitative objective indicators and qualitative subjective indicators, each suggested to measure certain aspects of the process. As follows, these types of indicators have been taken up and incorporated by the studies analysed.

As far as input as we have seen is concerned, it tends to be measured by indicators that can extrapolate the number of researchers involved, or the expenditure incurred by the company to support the process. Examples can be the total cost of the R&D department, the costs for staff salaries, investments in new assets... considering the staff, indicators such as the percentage of graduate workers, the skill and experience of R&D workers can be considered.

As far as outputs are concerned, they were defined as "lagging indicators", as they were influenced by previous stages of the process. In general, however, it has been seen that there are several methods, useful in quantifying it. As the best alternative, indicators have frequently been used in the literature to measure costs such as the percentage of costs not incurred on initial costs or the delta of time spent, mainly due to improvements in business processes and therefore defined as process innovations. Some indicators are used to measure the increase in profits, such as EBIT or ROI, these can be linked both to process improvements and to new products launched on the market, which results with higher sales. Finally, metrics were also used to analyse the increase in market share, or the types of new customers, useful to monitor through market surveys whether the initial strategy has been respected, as well as the positioning of the company itself. As second-best solutions, techniques such as the counting of patent citations were used, even if companies do not always patent, especially in contexts where the life of the product is relatively short.

In conclusion, the process part has been analysed since it is also the most complex. We can mainly differentiate the research processes from the development processes, not only because they have different outputs, since studying them individually shows that the output of the research is in a certain way equivalent to the input of the development process, but also because they have micro processes and different control objects. In the research process, for example, the cost of the activity, the time invested and the perceived quality of the stakeholders are measured. As far as development is concerned, quality, costs and time are always measured, but spread over several factors, for example, both the cost of the product and the cost of the development process occur. Other metrics should consider development time, product quality, and team development capacity. In addition, to further monitor the multifunctional team it can also be observed the relationship between the time spent working in a group on total working time. For development projects, the frequency of measurements must be higher than the research, as in case of errors the costs increase exponentially the further you go in the process; while for research activities the measurements are less frequent and rigid, as researchers need certain autonomy to be able to give vent to their creativity. In any case, there is a big point that unites the *modus* *operandi* to monitor these processes, namely human resources. They have proved to be a key aspect of both processes and are predominantly measured by management according to three criteria: quality, quantity and accessibility.

To sum up, all the indicators from the results analysis have been incorporated in a balance scorecard where it is easy to visualize them.

Financial Perspective	**Customer Perspective**	**Inn. and Learning Perspective**	**Business process Perspective**
Total cost for R&D	Market share	% of employee with a degree	R&D employee capabilities
Costs for employees wage	New customers	# of employee with a degree	Time for R&D process
ROI	Quality perceived	Delta cost after R&D activity	Cost for production
EBIT			

Table 8: IPO Balance scorecard

This subtle differentiation in designing a PMS depending on whether the process is research or development, is also interesting from the point of view of the Italian economic context, in fact not all companies in our territory deal with both research and development, since they are mainly small and medium-sized and do not have large capital provisions to be able to support both research and development activities. This differentiation of PMS therefore helps the companies in question with even more specific indications given their activities.

Finally, regarding the last objective I have proposed to identify which figure is continuing the R&D process within companies, it would be appropriate to study all this through a multi-case study or interviews, to have direct feedback, given that the literature has always focused on companies with an already existent structured department. Indeed, in the articles I read, the authors in many cases measured R&D staff with specific indicators both quantitative objective, such as the number of R&D employees or the percentage of graduates, and with qualitative indicators, such as the skill and experience of the staff. These latter qualitative indicators could, however, help us understand the effectiveness of the process regardless by who it is carried out, focusing only on the result of the process, namely the creation of added value.

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