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Master in Business Administration

Postgraduate Dissertation

The effect of the R&D department on organizational performance:

A post-pandemic study

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Supervisor: Lyda Kyrgidou

Patras, Greece, September 2021

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The effect of the R&D department on organizational performance

A post-pandemic study

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“Acknowledgments and / or Dedication”

Abstract

Ensuring sustainability is essential for organizations but achieving growth is equally -if not more- important for building the future. A main source of growth is innovation which has been key factor that allowed industries to move forward, evolve and improve. Organizations rely on their R&D departments to produce such innovation by coming up with the next generation of products designed and produced to deal with an unsolved or even undiscovered problems. Solving this kind of problems is one of the most demanding challenges a R&D department faces constantly, since the available data are usually insufficient or inconsistent and a lot of assumptions or trial are required before releasing a product for production. Based on that, quality of operation and the results produced by the R&D department of a company can directly and majorly impact the overall performance of the organization. In addition, by taking into account the still ongoing effect of the pandemic COVID-19 which has forced organizations to adapt to new working conditions, a great opportunity arises to analyze the performance measures that the R&D department affects and further examine if the currently used measures apply to the new era of business operation that imperatively was applied earlier due to the global pandemic.

Keywords

research, development, r&d, performance, covid19

Η επίδραση του τμήματος E&A στις επιδόσεις της οργάνωσης:

Μία μελέτη μετά την πανδημία

Ιωάννης Κίτσος

Περίληψη

Η διασφάλιση της βιωσιμότητας είναι απαραίτητη για τους οργανισμούς, αλλά η επίτευξη ανάπτυξης είναι εξίσου -αν όχι σημαντικότερη- για να διασφαλιστεί το μέλλον της επιχείρησης. Μια βασική πηγή ανάπτυξης είναι η καινοτομία και υπήρξε αλλά και υπάρχει βασικός παράγοντας στην εξέλιξη και βελτίωση των βιομηχανιών. Οι οργανισμοί βασίζονται στα τμήματα Έρευνας και Ανάπτυξης για να παράγουν καινοτόμα προϊόντα διασφαλίζοντας πως η επόμενη γενιά προϊόντων που σχεδιάζονται και παράγονται θα καταφέρουν να αντιμετωπίσουν ένα άλτο ή ακόμη και ανεξερεύνητο πρόβλημα. Η επίλυση αυτού του είδους των προβλημάτων είναι μια από τις πιο απαιτητικές προκλήσεις που αντιμετωπίζει συνεχώς ένα τμήμα E & A, καθώς τα διαθέσιμα δεδομένα είναι συνήθως ανεπαρκή ή ασυνεπή και απαιτούνται πολλές υποθέσεις ή δοκιμές πριν αποδεσμευτεί ένα προϊόν προς την παραγωγή του. Συνεπώς, η ποιότητα λειτουργίας και τα αποτελέσματα που παράγονται από το τμήμα E & A μιας εταιρείας μπορούν άμεσα και σε μεγάλο βαθμό να επηρεάσουν τη συνολική απόδοση του οργανισμού. Επιπλέον, λαμβάνοντας υπόψη την συνεχιζόμενη επίδραση της πανδημίας COVID-19 που ανάγκασε τους οργανισμούς να προσαρμοστούν σε νέες συνθήκες εργασίας, προσφέρεται μια μεγάλη ευκαιρία να αναλυθούν οι δείκτες απόδοσης που επηρεάζει το τμήμα E & A και να εξετάσουν περαιτέρω εάν οι δείκτες που χρησιμοποιούνται ισχύουν για τη νέα εποχή της επιχειρηματικής λειτουργίας που επιβλήθηκε σε πρώιμο στάδιο λόγω της πανδημίας.

Λέξεις – Κλειδιά

Mention 3 to 6 key words for the indexing of your thesis / dissertation in Greek.

Table of Contents

Abstract	v
Περίληψη.....	vi
Table of Contents	vii
List of Figures	viii
List of Tables.....	ix
List of Abbreviations & Acronyms	xii
1. Introduction	1
1.1 Historical References of Innovations	1
1.2 Innovation Nowadays	2
1.3 The Role of R&D	2
2. Literature Review	4
2.1 Organizational Performance Measurement	4
2.2 R&D Performance Measurement	4
2.3 The R&D Effectiveness Index	6
3. Methodology	6
3.1 R&D Performance Measures	7
3.2 Organizational Performance Measures	8
4. Data Analysis	10
4.1 Industry Related Data.....	10
4.2 Location Related Data.....	11
4.3 Company Size Related Data.....	11
4.4 Number of R&D Departments	13
4.5 R&D Activities.....	13
4.6 R&D Structure	14
4.7 R&D Performance.....	15
4.8 Organizational Performance.....	24
4.9 R&D Performance Linear Models	33
4.10 R&D Performance Linear Models	33
4.11 Organizational Performance Linear Models in Respect to R&D metrics	38
4.12 Organizational Performance Linear Models in Respect to company characteristics	47
5. Discussion of Findings	48
6. Theoretical and Managerial Implications.....	50
7. Conclusions	51
References	52
Articles	53

List of Figures

Figure 2 - 1: Balance Scorecard for R&D	5
Figure 4 - 1: Industry sector distribution.....	11
Figure 4 - 2: Company size distribution of participants.	12
Figure 4 - 3: R&D size of participants as percentage of company size.	13
Figure 4 - 4: Single vs multiple disciplines distribution.	15
Figure 4 - 5: Multiple disciplines R&D management structure.....	15
Figure 4 - 6: R&D spending as percentage of sales in 2020.	18
Figure 4 - 7: R&D Headcount in 2020.	18
Figure 4 - 8: R&D Headcount reduced performance in 2020.	19
Figure 4 - 9: R&D Headcount increased performance in 2020.....	19
Figure 4 - 10: Number of patents in 2020.	19
Figure 4 - 11: Number of new products' release in 2020.	20
Figure 4 - 12: Decreased number of products released in 2020.....	20
Figure 4 - 13: Increased number of products released in 2020.	20
Figure 4 - 14: Return of Investment performance in 2020.....	21
Figure 4 - 15: R&D overall performance graph in 2020.....	23

List of Tables

Table 4 - 1: Industry sector information	10
Table 4 - 2: Size Related Summary.....	12
Table 4 - 3: R&D Involvement Index	14
Table 4 - 4: R&D Performance measures.	16
Table 4 - 5: R&D Performance in 2020.....	17
Table 4 - 6: Performance summary in 2020.....	21
Table 4 - 7: R&D overall performance in 2020.	22
Table 4 - 8: Remote work for R&D employees in 2020.	23
Table 4 - 9: Significance averages for Organizational Performance Metrics.	25
Table 4 - 10: Effect of R&D on each organizational performance metric.	26
Table 4 - 11: Actual revenues vs target revenues metric performance in 2020.	27
Table 4 - 12: Profit metric performance in 2020.....	27
Table 4 - 13: Sales metric in 2020.	28
Table 4 - 14: COGS metric in 2020.	28
Table 4 - 15: Expenses vs Budget metric in 2020.....	29
Table 4 - 16: Cash flow for financing activities metric performance in 2020.	29
Table 4 - 17: Innovation spending metric performance in 2020.	29
Table 4 - 18: Number of customers metric performance in 2020.	30
Table 4 - 19: Customer support tickets metric performance in 2020.....	30
Table 4 - 20: Percentage of products defects metric performance in 2020.....	30
Table 4 - 21: Average annual expenses to serve one customer metric performance in 2020.	31
Table 4 - 22: Employee satisfaction metric performance in 2020.	31
Table 4 - 23: Salary competitiveness ration metric performance in 2020.	31
Table 4 - 24: Accumulation of knowledge and expertise metric performance in 2020.	32
Table 4 - 25: Knowledge achieved with training metric performance in 2020.....	32
Table 4 - 26: Regression Analysis for R&D Involvement Index – Initial Model.....	33
Table 4 - 27: Regression Analysis for R&D Involvement Index – First Iteration.....	34
Table 4 - 28: Regression Analysis for R&D Involvement Index – Second Iteration	34
Table 4 - 29: Regression Analysis of R&D Spending as percentage of Sales – Initial Model	34
Table 4 - 30: Regression Analysis of R&D Spending as percentage of Sales – First Iteration	34
Table 4 - 31: Regression Analysis of R&D Spending as percentage of Sales – Second Iteration	34
Table 4 - 32: Regression Analysis of R&D Spending as percentage of Sales – Third Iteration	34
Table 4 - 33: Regression Analysis for R&D Headcount – Initial Model	35
Table 4 - 34: Regression Analysis for R&D Headcount – First Iteration	35
Table 4 - 35: Regression Analysis for R&D Headcount – Second Iteration.....	35
Table 4 - 36: Regression Analysis for Patents released per year – Initial Model	35
Table 4 - 37: Regression Analysis for Patents released per year – First Iteration	35
Table 4 - 38: Regression Analysis for Patents released per year – Second Iteration.....	36
Table 4 - 39: Regression Analysis for New Products per year – Initial Model	36

Table 4 - 40: Regression Analysis for New Products per Year – First Iteration.....	36
Table 4 - 41: Regression Analysis for New Products per Year – Second Iteration	36
Table 4 - 42: Regression Analysis for New Product per Year – Third Iteration	36
Table 4 - 43: Regression Analysis for Return of Investment – Initial Model.....	36
Table 4 - 44: Regression Analysis for Return of Investment – First Iteration.....	37
Table 4 - 45: Regression Analysis for Return of Investment – Second Iteration	37
Table 4 - 46: Regression Analysis for actual vs target revenues – Initial Model	38
Table 4 - 47: Regression Analysis for actual vs target revenues - First Iteration	38
Table 4 - 48: Regression Analysis for Profit – Initial Model.....	38
Table 4 - 49: Regression Analysis for Sales – Initial Model	39
Table 4 - 50: Regression Analysis for Sales – First Iteration	39
Table 4 - 51: Regression Analysis for COGS - Initial Model.....	39
Table 4 - 52: Regression Analysis for COGS – First Iteration	40
Table 4 - 53: Regression Analysis for Expenses vs Budget – Initial Model.....	40
Table 4 - 54: Regression Analysis for Expenses vs Budget – First Iteration.....	40
Table 4 - 55: Regression Analysis for Budget vs Expenses – Second Iteration	40
Table 4 - 56: Regression Analysis for Cash Flow for Financing Activities – Initial Model	41
Table 4 - 57: Regression Analysis for Cash Flow for Financing Activities – First Iteration	41
Table 4 - 58: Regression Analysis for Innovation Spending – Initial Model	41
Table 4 - 59: Regression Analysis for Innovation Spending – First Iteration	41
Table 4 - 60: Regression Analysis – Second Iteration	42
Table 4 - 61: Regression Analysis for the Number of Customers – Initial Model	42
Table 4 - 62: Regression Analysis for the Number of Customers – First Iteration	42
Table 4 - 63: Regression Analysis for Customer Support Tickets – Initial Model.....	43
Table 4 - 64: Regression Analysis for Customer Support Tickets – First Iteration	43
Table 4 - 65: Regression Analysis for Customer Support Tickets – Second Iteration.....	43
Table 4 - 66: Regression Analysis for Percentage of Product Defects – Initial Model	43
Table 4 - 67: Regression Analysis for Percentage of Product Defects – First Iteration	44
Table 4 - 68: Regression Analysis for Annual Expenses to serve one customer – Initial Model	44
Table 4 - 69: Regression Analysis for Annual Expenses to serve one customer – First Iteration	44
Table 4 - 70: Regression Analysis for Annual Expenses to serve one customer – Second Iteration	44
Table 4 - 71: Regression Analysis for Employee Satisfaction – Initial Model.....	45
Table 4 - 72: Regression Analysis for Employee Satisfaction – First Iteration.....	45
Table 4 - 73: Regression Analysis for Employee Satisfaction – Second Iteration	45
Table 4 - 74: Regression Analysis Salary competitiveness ratio – Initial Model	45
Table 4 - 75: Regression Analysis for Accumulation of Knowledge and Expertise – Initial Model	46
Table 4 - 76: Regression Analysis for Accumulation of Knowledge and Expertise – First Iteration	46
Table 4 - 77: Regression Analysis for Knowledge by training – Initial Model	46
Table 4 - 78: Regression Analysis for Knowledge by training – First Iteration	46

Table 4 - 79: Regression Analysis for Knowledge by training – Second Iteration.....47

List of Abbreviations & Acronyms

COGS: Cost of Goods Sold

C1: Variable used to describe Company Size

C2: Variable used to describe R&D Size as Percentage of Company Size

C3: Variable used to describe Number of R&D Departments

C4: Variable used to describe R&D Structure

P01: Variable used to describe Actual vs Target Revenues

P02: Variable used to describe Profit

P03: Variable used to describe Sales

P04: Variable used to describe Cost of Goods Sold

P05: Variable used to describe Actual Expenses vs Budget

P06: Variable used to describe Cash Flow for Financing Activities

P07: Variable used to describe Innovation Spending

P08: Variable used to describe Number of Customers

P09: Variable used to describe Customer Support Tickets

P10: Variable used to describe Percentage of Product Defects

P11: Variable used to describe Average annual expenses to serve one customer

P12: Variable used to describe Employee Satisfaction

P13: Variable used to describe Salary Competitiveness Ratio

P14: Variable used to describe Accumulation of knowledge and expertise

P15: Variable used to describe Knowledge achieved with training

RD1: Variable used to describe R&D Involvement Index

RD2: Variable used to describe R&D Spending as Percentage of Sales

RD3: Variable used to describe R&D Headcount

RD4: Variable used to describe number of patents released annually

RD5: Variable used to describe new products released annually

RD6: Variable used to describe Return on Investment for R&D

R&D: Research and Development

1. Introduction

1.1 Historical References of Innovations

Since the beginning of human history, people tried to become more efficient by developing tools to help them on their daily tasks the wheel for transportation of goods, hand-tools and weapons for hunting or defending themselves. In addition to simple tools, people started making use of natural elements like fire for cooking and warmth or air and water for moving mills naturally. Human curiosity also played an important role in early inventions resulting in building the first sea vessels in about 3000BC simultaneously in Asia and Mediterranean area.

As humankind progressed, more needs arose demanding more advanced inventions such as the compass to assist navigation, railways and the steam engine to benefit various aspects of human life from transportation to electricity generation followed by even the first airplane invented by Wright brothers back in 1903. Of course, there were great achievement in other sectors, for example a great moment for healthcare was the identification of penicillin by prof. Alexander Fleming in 1928 which led to manufacturing antibiotics to fight infections. Great moments were also the extended use of steel alloys or cement which are used worldwide even today.

In 1927, General Electric made the first refrigerator, changing the way preserving foods, medicines or other sensitive substances forever. Late in 1947 the first transistor was developed by Bell Laboratories, a semiconductor used in the vast majority of electronics ever since. In 1969, Neil Armstrong was the first human walked on the moon. In 1993 the Web, which is known as the Internet, was made available to anyone and quickly became an integral part of people's lives.

It is clear that the list of human achievements exceeds by far the brief examples mentioned above and are taken for granted in our lives nowadays. The need of improving our lives persist, asking current generations to prepare a better future for the ones coming after.

1.2 Innovation Nowadays

Nowadays, all the innovations of the past have been integrated to people's life creating in their turn new needs to be met.

For example, fossil fuels have been part of people lives for years, but their reserve is limited and their extended use in order to meet the continuously increasing energy demands has already caused a serious environmental damage, that is why making use of renewable energy sources is becoming a trend of our times. Also, different energy sources, like nuclear power, are becoming more popular, which requires a delicate approach in their implementation.

In terms of technology, IoT services, artificial intelligence and 5G wireless communication are only a fraction of the new fields introduced recently in our lives with great potential but along with a lot of ethical considerations. In the same time, more and more companies and organization turn their eyes to space, preparing for space exploration, tourism or even inhabitation.

COVID-19, the pandemic affecting the whole world since the end of 2019, violently reshaped business reality, forcing a leap to the future by requiring the implementation of technologies before they reach maturity. Also, the development of multiple vaccines and medicines to fight and control the disease, in such a short time is one indicator of how far humanity can go when there is such large-scale need.

1.3 The Role of R&D

The R&D department of a company is responsible of producing innovation. Producing innovation can benefit companies by improving their reputation either as a result of their contribution in solving challenging problems or by providing unique solutions to specific groups of people by coming up with product or services to meet their specific needs. In both cases, revenue is generated for the company with potentially great amount of profit.

A successful R&D requires a level of expertise and a specific skill-set, hence a major responsibility for the R&D inside the company in order to ensure continuous operation is to produce, maintain and distribute knowledge and knowhow to its members, keeping them up-to-date with any new technology advancements that may be proven useful to them in producing innovation.

Operating an efficient R&D department is not an easy task and can lead to a lot of losses if it is not done properly. Conducting any type of Research requires a lot of expenses in order to acquire proper tools, specific knowledge or even knowledge regarding competition. A successful R&D must be ahead of the competition in order to produce innovation. But Research is only half the part of increased expenses, Development of new products may require a lot of prototypes, trials and tests in order to achieve expected results. It becomes clear that operating a R&D department comes with a great risk of losing the amount invested in its activities so a careful planning is required and even with it a successful operation cannot be always guaranteed.

Different industries have different requirements and even companies within the same industry does not operate their R&D departments in the same way, creating multiple ways of returning the investment and adding value to the organization. Additionally, in many cases R&D activities are expand to assist operation of different departments like Quality, Industrialization or Production Departments.

In this study, it is attempted to explore the connection of R&D operation with the performance of the organization reaching conclusions capable of providing valuable information for increasing performance as a result of R&D activities. The key outcome expected in the end of this research is a model summarizing this connection, allowing management to apply modifications to R&D operation in order to improve organizational performance by using the resulted model.

This study is divided in chapters. Chapter 2 is a brief summary of relevant literature; Chapter 3 describes in detail the method used for this research. In the fourth chapter, the collected data along with their analysis are presented while Chapter 5 and 6 discuss the findings and the implication of the resulted model respectively. Finally, in Chapter 7 some conclusions and opportunities for expanding this research in the future are presented.

2. Literature Review

There are numerous books and surveys written for both organizational performance and R&D performance. Both of them demand multidimensional approach, adapted to the unique needs and operation of each corporation. For this reason, coming up with a generic yet effective approach is both complex and difficult, in order to do so, a large number of books and papers was studied in order to decide the proper course of action.

2.1 Organizational Performance Measurement

Organizational Performance is the most commonly studied aspect of business operation. Since the performance is the most vital part of a healthy operation and growth, the number of studies already conducted on the matter cannot be determined. For the needs of this study, a modern approach for Performance Measurement Systems is taken into account. With the assist of the evolution of technology, nowadays Performance Measurement Systems are becoming more and more popular while successful Performance Measurement Systems take into account the following attributes:

- Important features for each organization
- Roles within the organization
- Processes happening in the organization

By effectively deciding the parameters above, a Performance Measurement System is defined and allows its users to extract useful results representing their unique needs.

Converging to a well-defined Performance Measurement System requires continuous planning and frequent reviews in order to be kept aligned with the organizational goals and may require some iterations before the initial definition is completed.

For the needs of this study, performance is attempted to be measured by various attributes trying to approach the matter in a complete and a multi-level way.

2.2 R&D Performance Measurement

R&D department is the one responsible for producing new products and it is the only common ground it can be found between different organizations. Even in the case of products, they can have significant differences between them with too diverse success and failure criteria. For these reasons, there is also a great number of studies attempting to define a successful R&D model, but due to the diversity in terms of R&D function and the products

developed, it is also extremely high to come up with a generic model, hence most of the studies are industry-oriented or product-oriented. Of course, there also numerous studies attempting to achieve a generic approach and this exactly is the target of this study as well. An effective way to evaluate R&D performance is a Balanced Scorecard.

With a Balanced scorecards the different perceptive forming both the course of action and the relative success of failure criteria for an R&D department are defined. The perceptive are:

- Customer perceptive is looking at the product or service produced by the point of view of the customer and their satisfaction
- Financial perceptive is looking at the product in terms of profit and cash flow generation
- Internal business perceptive is looking at the R&D performance by the eyes of organization's employees and focuses on issues like employees' relationships in the workplace and satisfaction
- Innovation and learning perceptive is essential for the R&D to sustain itself and keep growing and deals with matters like training, building new skills and building cooperation

A visual representation of a Balanced Scorecard for R&D is presented below.

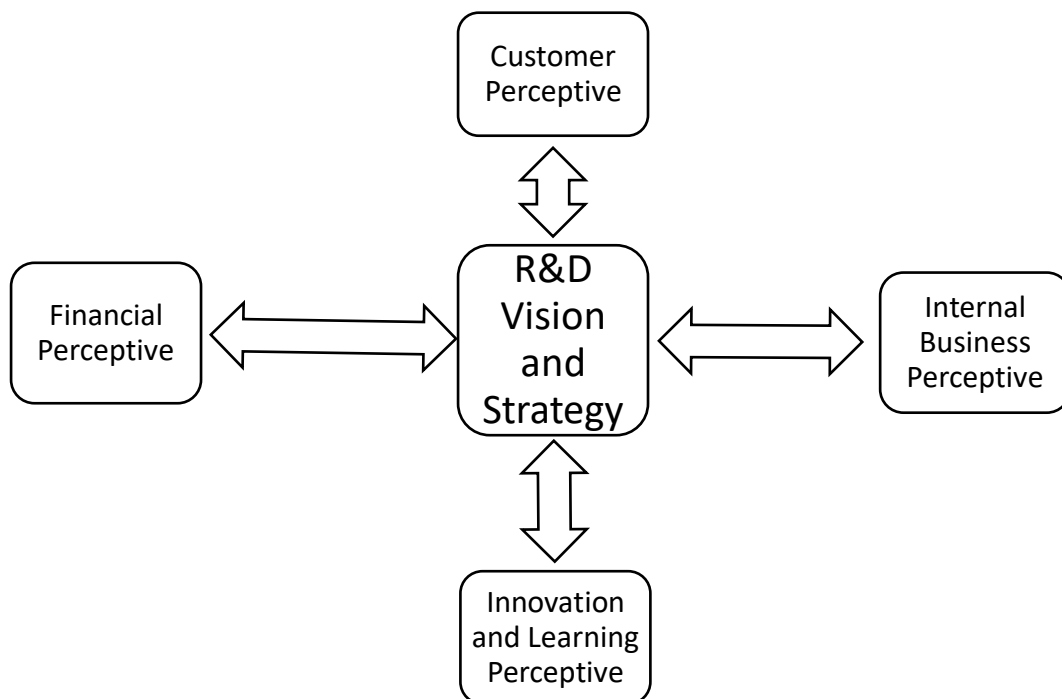


Figure 2 - 1: Balance Scorecard for R&D

2.3 The R&D Effectiveness Index

An quantitate and effective tool to evaluate R&D performance is the empirical R&D Effectiveness Index, first referred by McGrath and Romeri in 1994. This index requires some percentages in order to evaluate annual R&D effectiveness in a specific scale. This index will be contrasted against the answers of specific companies in a case study.

This index is effective enough for different industries and can be used as a measurement Return on Investment, hence a R&D Effectiveness Index less than 1.0 implies that the organization does not receive sufficient return of R&D activities, similarly to ROI.

The formula for computing the R&D Effectiveness Index (EI) follows.

$$EI = \frac{\frac{\text{New Product Revenue}}{\text{Revenue}} \cdot \frac{(\text{Net Profit}) + (\text{R\&D Investment})}{\text{Revenue}}}{\frac{\text{R\&D Investment}}{\text{Revenue}}}$$

All quantities above refer to the same accounting period, normally a year. Another advantage of this index is that it is not project oriented and can evaluate R&D operation regardless of the project completion within the accounting period, since it is not uncommon for R&D to work on a project for more than one accounting periods. This tool specifically is not going to be implemented in the data analysis but studying it helped in defining the process of analysis and in general choosing how to approach the research and to choose some of the data collected.

3. Methodology

The methodology used to obtain data for this thesis was primary research with questionnaires. Coming up with both accurate and generic performance measures in order to cover all different aspects attempted to be studied is not possible.

In terms of R&D performance, it is difficult to measure performance directly due to the nature of the work, for this reason five of the most popular metrics were chosen based on research on literature and in the public practices of world-known professionals. For this metrics, companies participated in the research are asked to answer if they are applicable to their organization and they are encouraged to provide additional metrics they may use.

In some cases, when the organization size is large, it may have multiple R&D departments or in case an organization produces different products, may have separate departments focus

on each product family. This information is also collected in order to evaluate if it is somehow possible.

On the other hand, there are numerous of organizational performance measures, the challenge in this part was to choose metrics that may be affected by the R&D activities. For this reason, eighteen metrics were chosen and their application on each firm is explored. Same as in R&D performance metrics, research participants are encouraged to add more metrics they deem necessary.

3.1 R&D Performance Measures

In this section, the most common R&D performance metric are presented with a short description. For this metrics, the research tried to identify if they are applicable to the companies participated.

1. R&D spending as percentage sales: This metric is mainly applicable in companies with commercial activities whose products are intended to be used in large quantities and are expected to generate annual sales. An indicative example of a firm that this metric may apply is the firms of commercial electronics like for example smartphone manufacturers.
2. R&D Headcount: The number of people working in a department is a generic enough metric in order to estimate its performance. Since this number is affected by various other parameters like the size of whole organization or the nature of R&D activities, this information is also collected in order to take them into account.
3. Number of patents per year: Not all the organizations need to patent their products and not all the products can be patented. Number of patents per year is an indicator of how innovative is the company and may be applicable to pharmaceutical companies or companies developing new technologies.
4. Number of products released per year: Number of products released must not be confused with the products sold, for example, a company mainly doing business with governmental organizations cannot always sell directly its products, but may require to participate in a tender beforehand, in such cases a wider portfolio can be helpful to pursue different leads.

5. Return of Investment: Return of investment is also a simple metric. It requires the investment period to be defined in order to effectively make use of it, but it is a pretty straightforward metric, evaluating a project after its end.

Even though these metrics are all quantitative, their qualitative data are collected in order to keep the research generic and approachable to participators, instead of asking them for specific numbers.

3.2 Organizational Performance Measures

As mentioned above, there are numerous measures for organizational performance. Some of them expected to be affected by the R&D are presented below with a brief description.

1. Actual Revenues vs Target Revenues: When developing a new product, it is expected to generate a certain revenue and it is usually important for firms to monitor if the actual revenues met their expectations.
2. Profit: Profit is the key element for all firms, but it is not only associated with R&D activities, hence there is interesting in exploring the connection of between them.
3. Sales: Sales is another attribute that is not always affected by the R&D activities but in a lot of companies is crucial to increase revenues.
4. Cost of Goods Sold: One of the biggest challenges in producing innovation is to keep the production cost as low as possible. In cases that COGS is considered as a performance metric for the organization it is expected to align with R&D activities.
5. Expenses vs Budget: In all aspects of business operation a budget is made and is expected to be followed as close as possible, but when developing new products, it is not uncommon that certain situations arise requiring deviation from the defined budget. It is useful for a company to have a R&D department capable of successfully predicting such situations and limit budget exceeds to minimum.
6. Cash flow for financing activities: R&D is a department always requiring new finance for its activities. In case a company evaluates this metric as important it is expected to set high expectations for its R&D as well.

7. Innovation spending: Financing activities are not only limited to R&D activities, but innovation spending is, hence it is interesting to see how companies evaluate these two metrics in comparison.
8. Number of customers: Similarly, to Sales, this is not a metric applicable to all organizations, it is possible a company two have all its revenues generated by a single customer, but in cases the company depends on this number of customers it is expected to have a fast-paced R&D department, ready to deliver new products.
9. Customer support tickets: Customers requiring support is an additional cost for the companies. Successful products have minimum defects, straight forward operation and instructions lead to happy customers. Building a successful product and test properly before its release for production is important to have an effective R&D department.
10. Percentage of products defects: This metrics can be used both as an evaluation of released products and as an addition to the previous metric to examine how many of the support tickets are due to defect product or for other reason. With both this metrics it is easy for an organization to evaluate how its products are perceived by its customers.
11. Average annual expenses to serve one customer: Serving one customer is not only limited to problems related with the products, it may be a service provided by the firm. R&D may be involved when it comes to installing equipment for example or by producing equipment easy to install with as less as possible special tools and procedures that may increase the cost.
12. Employee satisfaction: It is critical for a healthy firm to have employees happy to work there and ready to give their best for company's prosperity. In order to have such loyalty be the employees, it is essential that they are satisfied by their job. Organizations evaluating this metric as important are expected to perform better both in R&D and in total.
13. Salary competitiveness ratio: R&D operation requires employees with special skills in order to produce innovation, hence a competitive salary policy would attract the best talents in their field. Companies treating a competitive salary policy are expected to perform good continuously.

14. Accumulation of knowledge and expertise: This is a non-monetary metric, but in developing new products it is important to work with skilled professionals who can make use of accumulated knowledge in future projects, reducing development time and resources, practically reducing development cost.
15. Knowledge achieved with training: In addition to accumulation of knowledge through experience, companies with high expectations tend to train their staff in new technologies in order to achieve better results. Companies investing in training their employees are expected to have more satisfied and loyal employees.

4. Data Analysis

In total, 61 companies participated in the research regarding the effect of the R&D on organizational performance. A summary for the collected results along with the proposed analysis follows.

4.1 Industry Related Data

The industry sectors of the research participant companies are shown on the following table.

Table 4 - 1: Industry sector information	
Industry Sector	Number of Companies Participated
Additive Manufacturing	4
Agricultural Equipment	2
Chemicals	1
Commercial Equipment	2
Construction	7
Consumer Goods	2
Defense	2
Education	1
Electronics	1
Energy	6
Informatics	1
Machinery	5
Medical Devices	1

Oil and Energy	2
Pharmaceutical	4
Robotics	6
Security Products	1
Software	5
Space	2
Telecoms	5
Telecommunication Equipment	1

It is clear from the Table 4 – 1 that the collected data do not suffice to draw industry-based conclusions since the number of representatives in same cases is a single company, but it could be interesting to compare the companies with the most representatives in the research data. The following figure is used to effectively summarize Table 1 – 1.

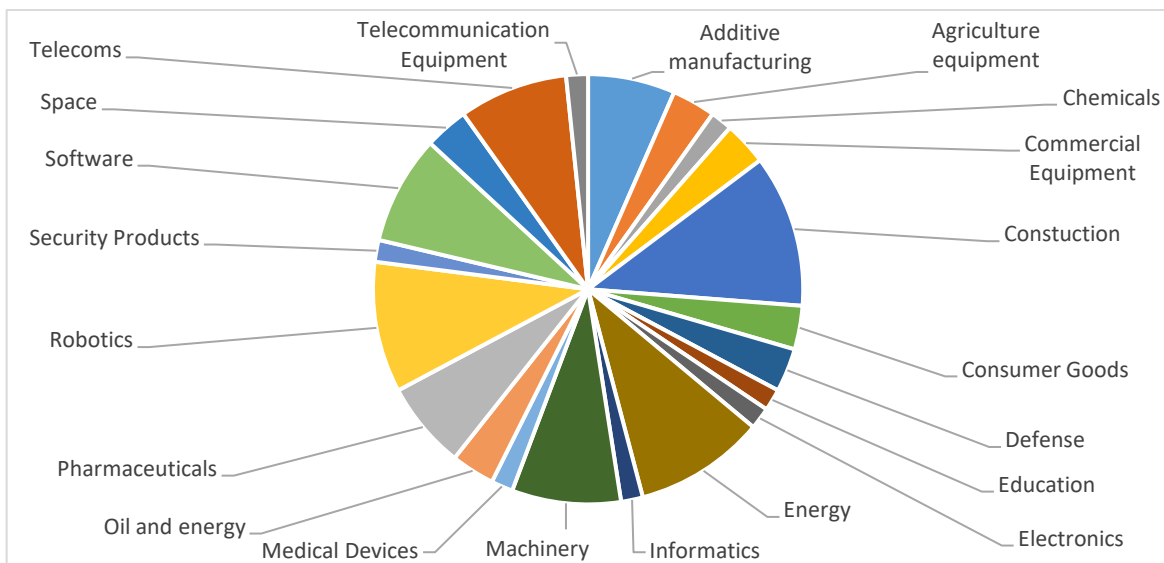


Figure 4 - 1: Industry sector distribution.

4.2 Location Related Data

From the collected data, 58 companies are located in Greece, 1 in Italy, 1 in Australia and 1 in United Kingdom. With this available data it is not possible to study region specific effect, hence this variable it will be omitted from the research. Specifically in the case of the UK company, it is significantly large, hence the analysis will be performed with and without it in order to remove any bias from data.

4.3 Company Size Related Data

In terms of the size, companies participated in the research fall into the following categories.

Table 4 - 2: Size Related Summary

Number of Employees	Participants Count	Participants Percentage	Min R&D Size as Percentage	Max R&D as Percentage
1 - 10	8	13.11%	50.00%	100.00%
11 - 50	14	22.95%	10.00%	93.33%
51 - 200	20	32.79%	2.50%	81.82%
201 - 500	1	1.64%	15.91%	15.91%
501 - 1000	8	13.11%	2.18%	80.00%
1001 - 5000	9	14.75%	3.64%	77.27%
5001 - 10000	0	0.00%	0.00%	0.00%
10001+	1	1.64%	3.77%	3.77%

A quick insight based on the data presented in the Table 4 – 2 is that the smaller a company is, the more it counts on its R&D judging by the size of the R&D department in respect to the company size. The following figures are offered for additional clarity and further analysis will be performed after the data summary is completed.

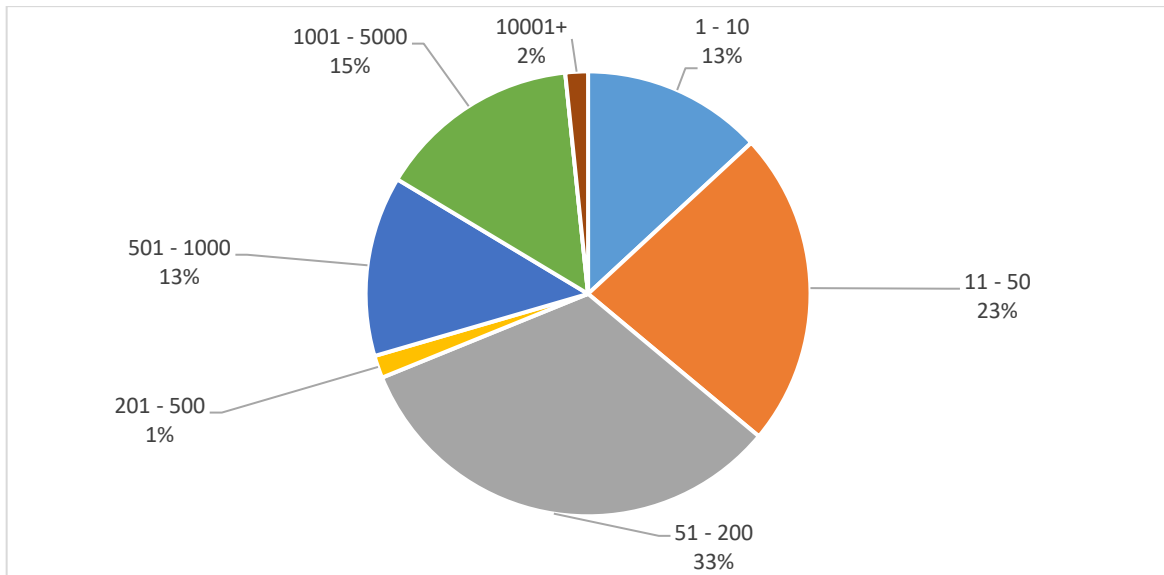


Figure 4 - 2: Company size distribution of participants.

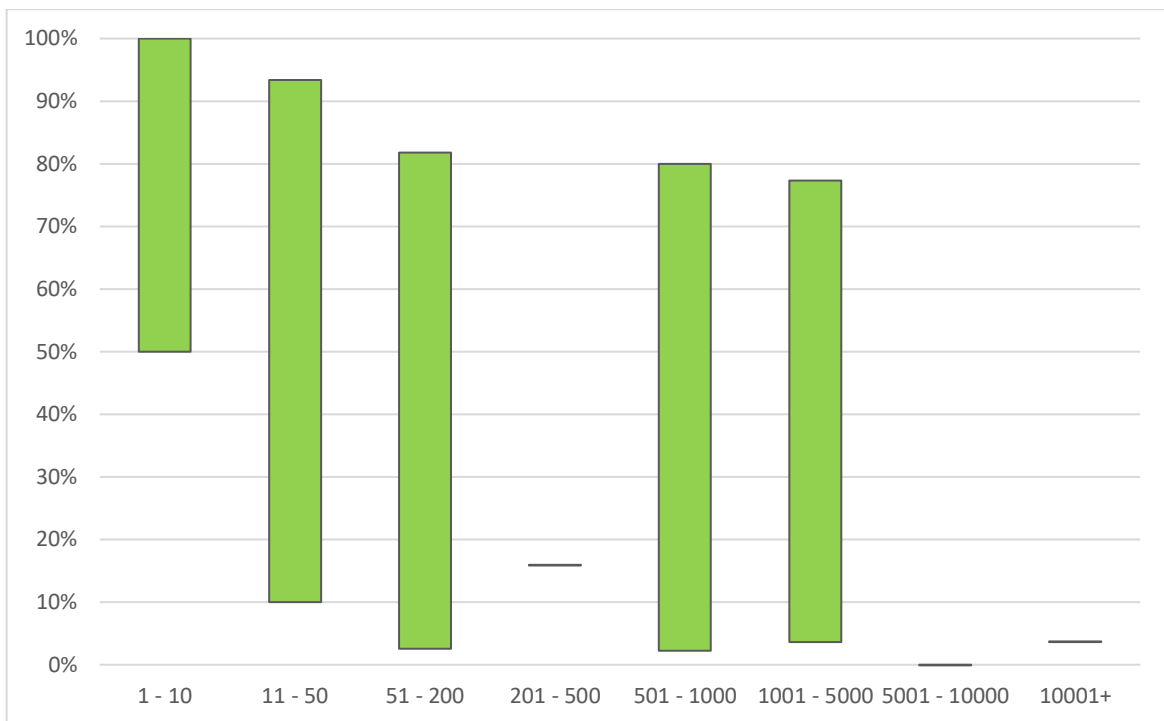


Figure 4 - 3: R&D size of participants as percentage of company size.

4.4 Number of R&D Departments

Some of the companies operate multiple R&D departments, specifically for the research participants, 9 of them or the approximately 14.52% of the participants operate multiple R&D departments. As expected, all the companies that operate multiple R&D departments are larger than 1000 employees in terms of company size. In order to determine if it has a significant effect, this is one of the variables to study. In most of the cases, 7 out of 9 the extra R&D departments are also located on different countries.

4.5 R&D Activities

In order to determine the involvement of the R&D to the full life-cycle of the product, the participants were asked to answer the involvement of the R&D of their companies to the following activities:

- Product documentation
- Prototype testing
- Product certification
- Product industrialization
- Production support
- After-sales support
- Commercial documentation

The question was a close-type one with the following possible answers:

- There is a dedicated team, part of the R&D, working for this task
- R&D is responsible for the task, but with no dedicated team
- Another department is responsible for this task
- Not applicable for my business

In order to reach quantitative results, the applicable answers were replaced by a number:

- There is a dedicated team, part of the R&D, working for this task, was replaced by the number 2, indicating the importance of the R&D in this activity
- R&D is responsible for the task, but with no dedicated team, was replaced by the number 1, indicating the involvement of R&D with the activity, but with half significance compared to the case of a dedicated team
- Another department is responsible for this task, was replaced by the number 0, indicating that the activity is performed by the company, but R&D has no part in it.

With these quantitative data, a R&D Involvement Index is defined attempting to summarize the inputs. This Index is computed by summing up the involvement numbers from the answers and the divide them by the number of applicable activities. Based on this, the closer this index goes to 0, the less R&D is involved to business activities regarding product life-cycle and the more it goes close to 2 the, more R&D is involved. For the research participants, the following table contains a summary of the answers.

Table 4 - 3: R&D Involvement Index

R&D Involvement Index Value	Number of Companies
0.00 – 0.50	1
0.51 – 1.00	37
1.01 – 1.50	18
1.51 – 2.00	5

As expected for most of the cases R&D is involved critically in the life cycle of the products with the level of involvement depending of various parameters that will be further studied.

4.6 R&D Structure

In order to determine if the structure of the department affect its performance and the effect it has in organizational performance, data relevant to R&D composition and structure were collected. It is not a surprise that in the majority of cases, specifically 49 out of 61, R&D

departments consists of different disciplines. Managing cross-discipline teams especially when the number of people rises is difficult, hence in 16 of these 49 cases the R&D is broken into discipline sub-departments with a discipline specialist as a manager of each division.

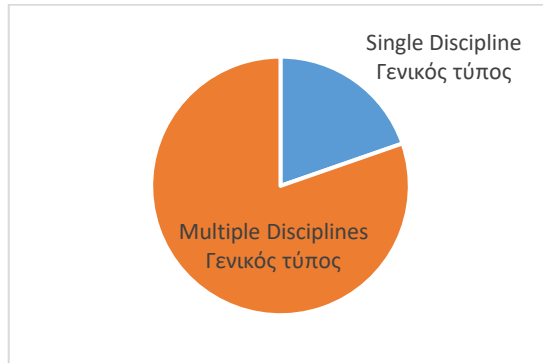


Figure 4 - 4: Single vs multiple disciplines distribution.

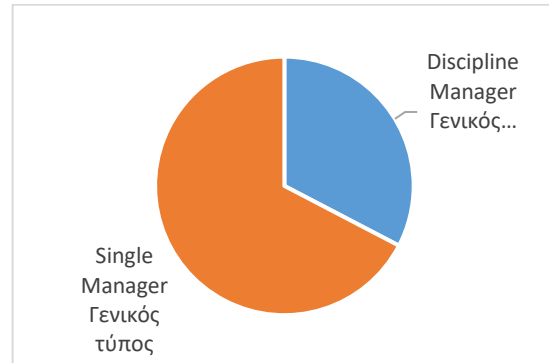


Figure 4 - 5: Multiple disciplines R&D management structure.

4.7 R&D Performance

In order to link the performance of the R&D department with the whole performance of the organizations, it is initially attempted to gather information relevant with the R&D performance measures described in Section 1. The possible answers were limited to the following options:

- Not applicable to my company
- Minor Significance
- Average Significance
- Major Significance

Similar to the analysis regarding the involvement of the R&D, the applicable qualitative answers are replaced by numerical values as follows:

- Minor Significance was replaced by the number 1
- Average Significance was replaced by the number 2
- Major Significance was replaced by the number 3

Using the values described above, a simple average and a weighted average are calculated. All the results are shown in Table 4 – 4. For the weighted average, the following formula was used.

$$\text{Weighted Average} = \frac{\text{Number of companies considering metric significant}}{\text{Total Number of Companies}} (\text{Simple Average})$$

Table 4 - 4: R&D Performance measures.

	Number of companies considering metric significant	Simple Average	Weighted Average
R&D spending as a percentage of sales	49	1.35	1.08
R&D headcount	61	1.38	1.38
Number of patents per year	40	1.23	0.80
Number of new products released per year	52	2.04	1.74
Return of Investment	49	1.94	1.56

Based on the collected data, all the participants find R&D headcount significant performance measure for their R&D departments while the number of patents, as expected, is the less applicable performance measure. Number of new products follows the R&D number of employees as the second most applicable measure, followed closely by both R&D spending as percentage of annual sales and the return on investment, both used by 49 companies.

In terms of significance, number of new products found as the most important measure to evaluate R&D performance, followed closely by return of investment. The third most significant measure was R&D headcount, even though it was the metrics used by all companies participated in this research, it was not considered the most important. Really close to the third metric was the spending for R&D as percentage of sales and the least important measure, was the number of patents released. It is interesting to observe that computing the weight average do not change the order of significance hinting the accuracy of the collected data.

The participants were requested to specify if they consider any other performance measures for their R&D departments and two additional measures were specified:

- Success rate in bids: It is a metric that similarly to the number of patents is not applicable to all companies, but can also have an effect on the whole organizational performance for companies taking it into account. In such cases, companies often

rely their sustainability and growth on the outcome of various tenders they participate, hence a R&D department capable of producing products that win the most bid is essential.

- **Product profitability:** Profit is a key for companies' growth regardless of their activities, hence product profitability, regardless if it is about a physical item or service, is a metric can also play an important role in a prosperous organization and can be related with various organizational performance measures, such as COGS or annual expenses for the need of one customer.

In order to also study if COVID-19 affected the R&D activities and determine if the same effect was extended to the whole organization, it was requested to provide an evaluation of these metrics in 2020 and a comment if the pandemic played a role in their performance. The answers are summarized in the following table.

Table 4 - 5: R&D Performance in 2020.

	Same Performance	Worse Performance	Better Performance
R&D spending as a percentage of sales	30	19	0
R&D headcount	40	16	5
Number of patents per year	18	18	4
Number of new products released per year	25	18	9
Return of Investment	21	17	11

R&D spending, was either kept in the same levels in 2020 for 30 companies and the rest 19 spent less for R&D activities, all due to the effect of COVID-19. Since COVID-19 outbreak created uncertainty, it was expected for companies to choose a more conservative approach in order to maintain their operation, with none of the companies choosing to increase the spending on their R&D activities compared to their sales.

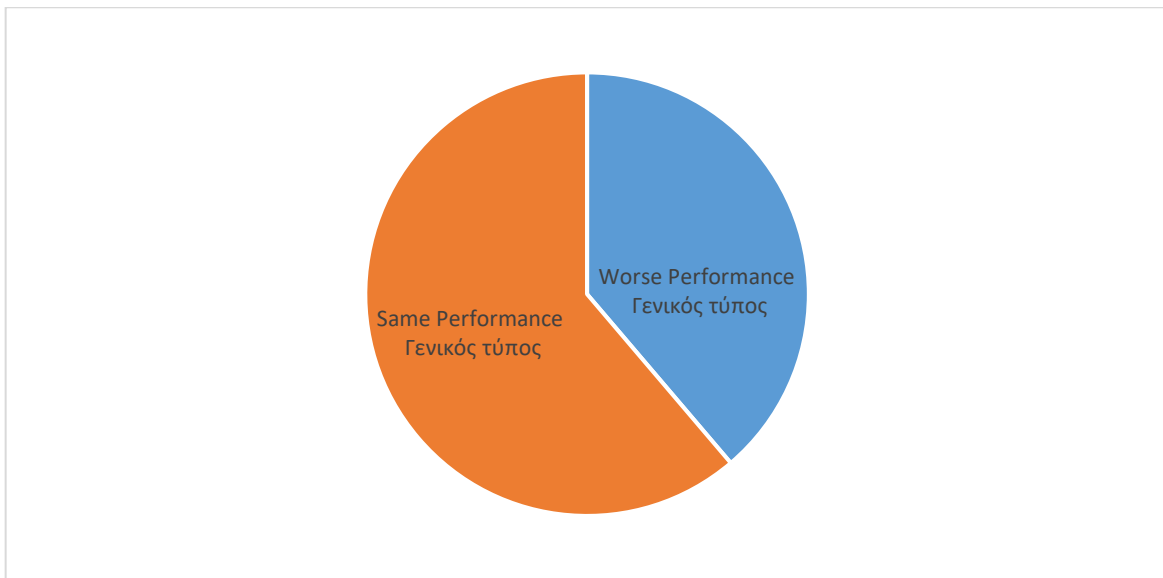


Figure 4 - 6: R&D spending as percentage of sales in 2020.

Opposing spending, there were a few cases in terms of number of employees in R&D that companies hired new people. Unfortunately, the number of companies that faced a decrease on their R&D staff was almost triple, but the majority of the companies managed to maintain the number of its R&D employees.

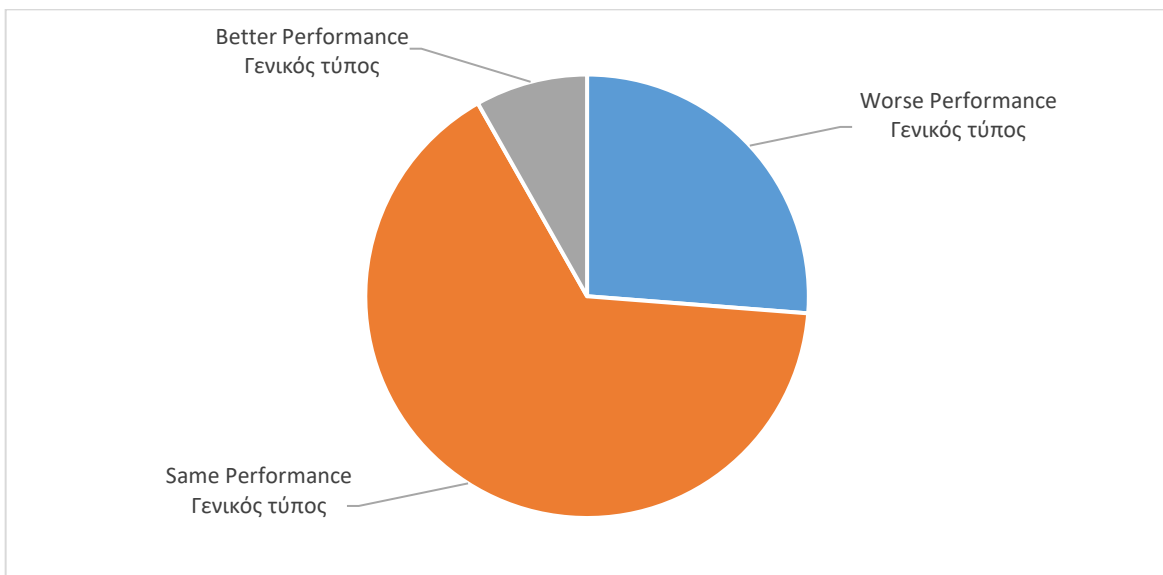


Figure 4 - 7: R&D Headcount in 2020.

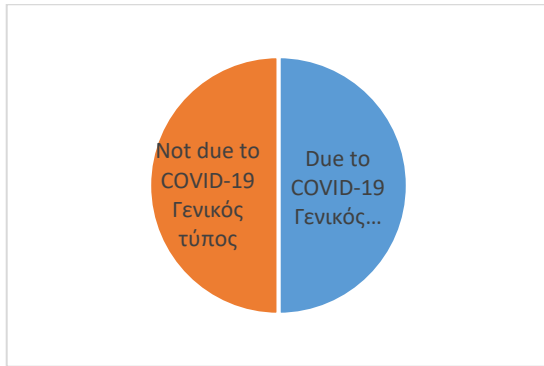


Figure 4 - 8: R&D Headcount reduced performance in 2020.

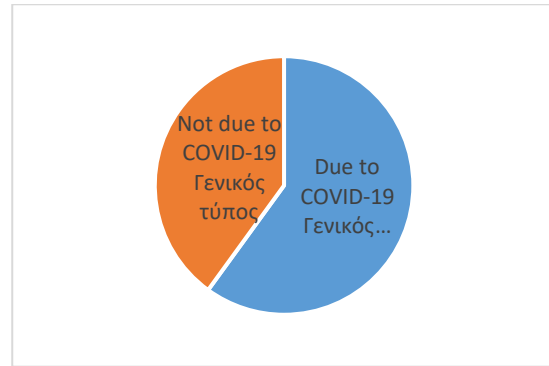


Figure 4 - 9: R&D Headcount increased performance in 2020.

Regarding the cases the R&D staff was reduced in 2020, half of them were due to the pandemic outbreak, while the rest had to do with the business operation regardless of COVID-19. It is interesting that the number of companies increased their staff due to COVID-19 was larger than the number that were to increase their staff either way, but still they overall evaluation of the metric for 2020 had a decreasing tendency.

Regarding the number of patents in 2020, the situation is a little different. The number of companies maintained the same patents in 2020 was equal to the number of companies that issued less patents in 2020. Preparing a product in order to qualify patent protection is usually a process requiring time, hence it is safe to assume that the companies that issued fewer patents in 2020 were supposed to do so regardless of the pandemic. By studying the answers, the assumption is confirmed since COVID-19 was not the reason in not a single one of them, on the contrary, in the cases that the number of patents increased in 2020, COVID-19 was the reason behind 3 out of the total 4 of them.

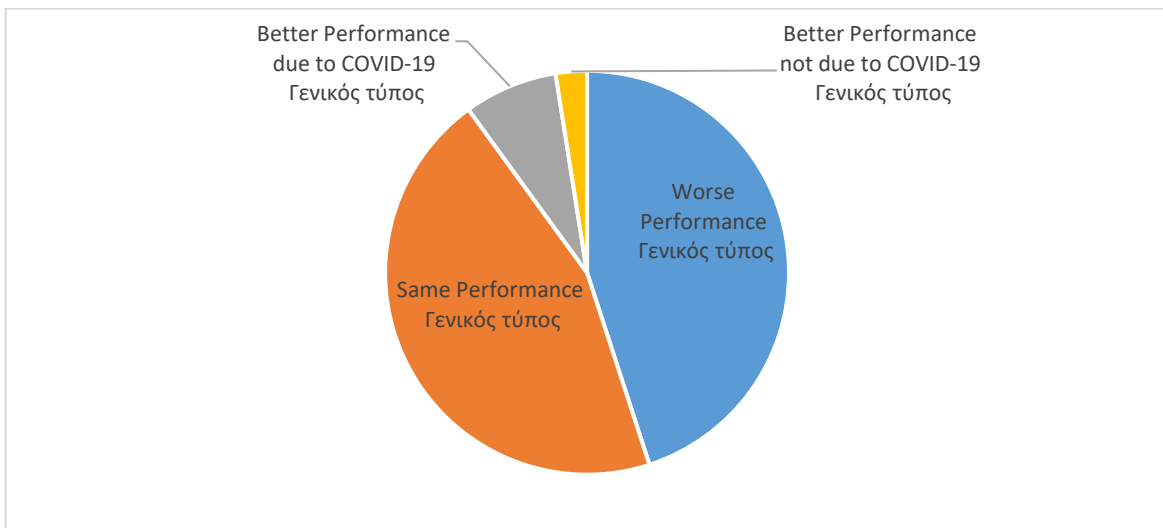


Figure 4 - 10: Number of patents in 2020.

In the case of releasing new products, the number of companies released in 2020 the same number of products as in previous years was observed in almost half of the answers, while the number of the companies released less products in 2020 was double compared to those who released more. The following figures summarize the answers.

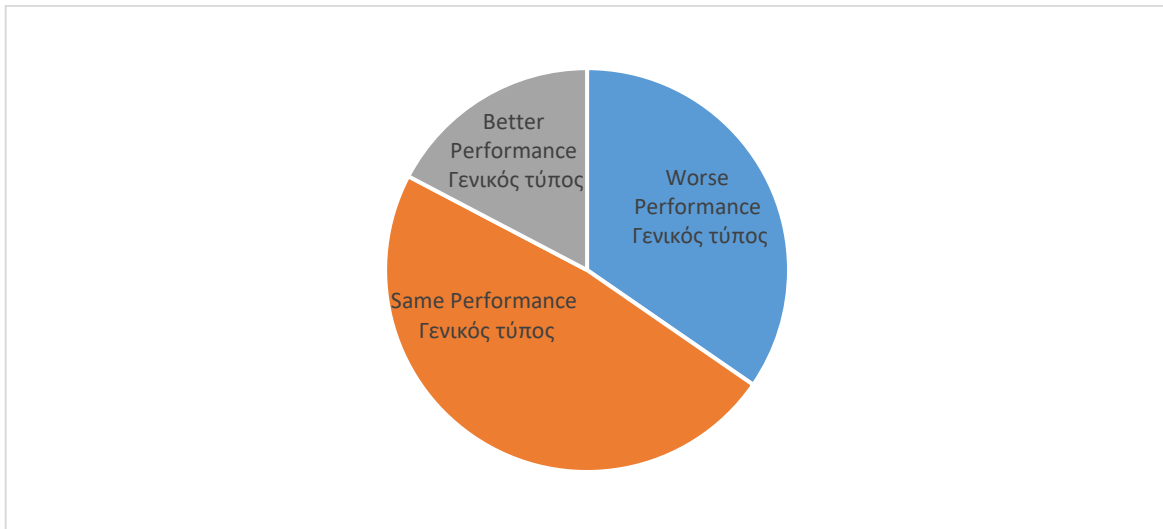


Figure 4 - 11: Number of new products' release in 2020.

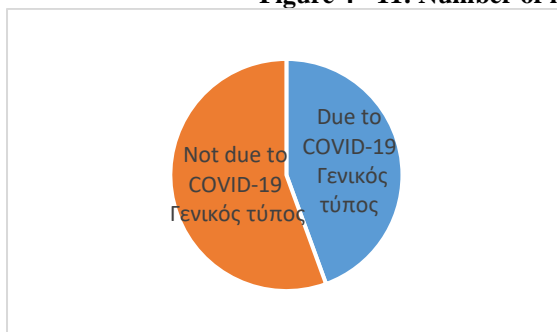


Figure 4 - 12: Decreased number of products released in 2020.

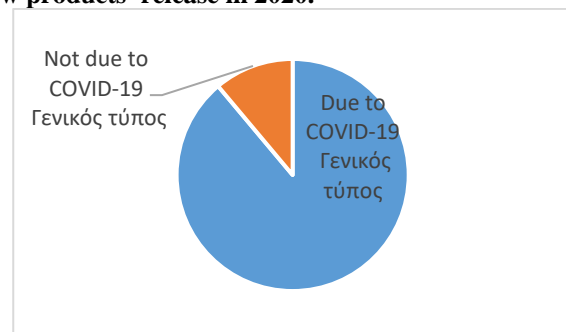


Figure 4 - 13: Increased number of products released in 2020.

From the figures above, it becomes clear that COVID-19 affected positively the organizations who increased the number of products they released in 2020, by generating new needs or demanding the maturity of products before their expected time. Regarding the cases that the organizations released less products in 2020, COVID-19 was not the most important reason, but played its part in delaying the activities of some companies.

Last, for return of investment, COVID-19 caused the only positive effects, either by enhancing the demand of developed products beyond expectation. Another, conservative explanation for this phenomenon is that companies may withdrew investments before the reach their full potential due to the uncertainty created, yielding a fraction of their potential profit. The total number of companies suffered losses in 2020, was 17, with 8 of them caused

by the pandemic outbreak. For 21 out of the 49 companies that find the metric significant, their return of investment in 2020 was in the same levels as in previous years.

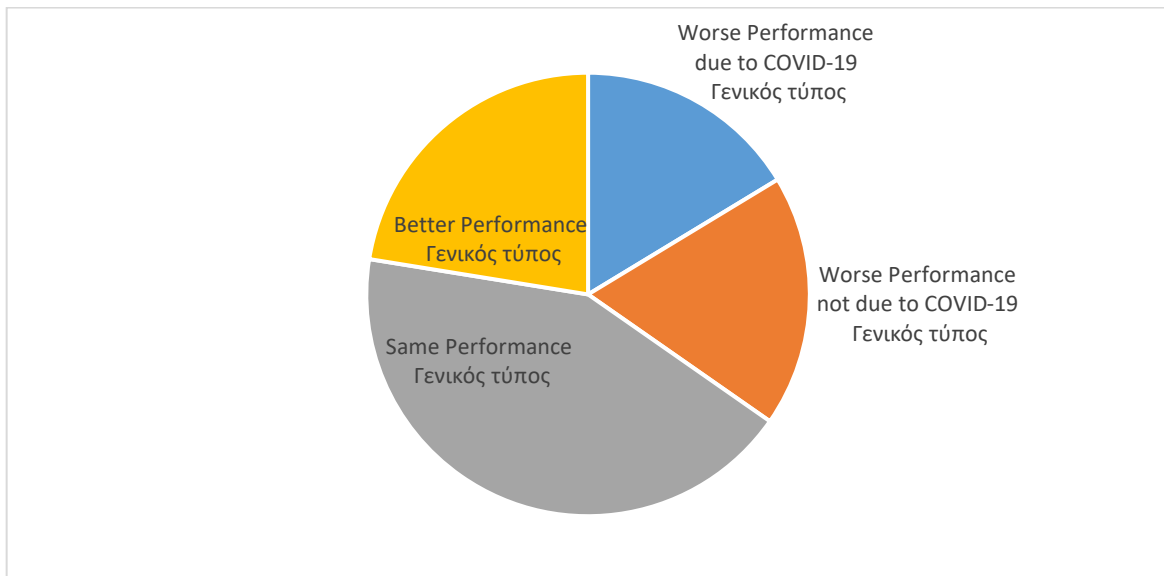


Figure 4 - 14: Return of Investment performance in 2020.

A complete numerical summary of the answers presented in figures 3 – 6 to 3 – 14 are shown in the Table 4 – 6.

Despite COVID-19 outbreak inflicted a lot of damage in a lot of organizations, based on the results described above, organizations focusing on innovation or with a solid business operation could make important decisions to contain the losses or even create profit taking advantage of the rise on new needs. For the most of the participants R&D performed as expected despite COVID-19 outbreak and in 14 cases exceeded expectations for 2020. Of course, COVID-19 caused poor performance in some cases, but they were few compared to the rest (see Table 4 – 7 and Figure 4 – 15).

Table 4 - 6: Performance summary in 2020.

R&D spending as a percentage of sales		
Worse Performance	Due to COVID-19	19
	Not due to COVID-10	0
Same Performance		30
Better Performance	Due to COVID-19	0
	Not due to COVID-10	0
R&D Headcount		
Worse Performance	Due to COVID-19	8
	Not due to COVID-10	8
Same Performance		40
Better Performance	Due to COVID-19	3
	Not due to COVID-10	2

Number of patents per year		
Worse Performance	Due to COVID-19	0
	Not due to COVID-10	18
Same Performance		18
Better Performance	Due to COVID-19	3
	Not due to COVID-10	1
Number of new products released per year		
Worse Performance	Due to COVID-19	8
	Not due to COVID-10	10
Same Performance		25
Better Performance	Due to COVID-19	8
	Not due to COVID-10	1
Return of Investment		
Worse Performance	Due to COVID-19	8
	Not due to COVID-10	9
Same Performance		21
Better Performance	Due to COVID-19	11
	Not due to COVID-10	0

Table 4 - 7: R&D overall performance in 2020.

In 2020 R&D performed poorly, due to COVID-19.	8
In 2020 R&D performed poorly, but not due to COVID-19.	0
In 2020 R&D performed as expected.	39
In 2020 R&D exceeded expectations, because of COVID-19.	3
In 2020 R&D exceeded expectations, despite the COVID-19 outbreak.	11

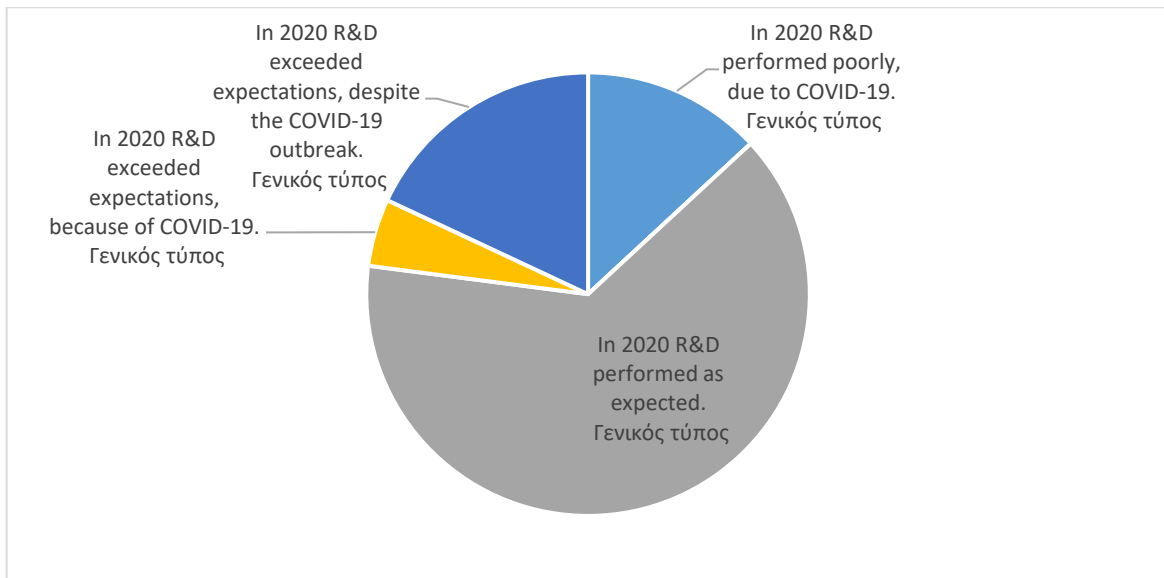


Figure 4 - 15: R&D overall performance graph in 2020.

Regarding remote working in 2020 as a precaution safety measure, 42 out of 61 companies implemented remote work and the detailed summary of the given answers given is shown on the following table.

Table 4 - 8: Remote work for R&D employees in 2020.

R&D employees always had the option to work remotely.	8
Yes, due to COVID-19 and it is proven more efficient and remote work will be in place after COVID-19 as well.	7
Yes, due to COVID-19 and it will be kept as an additional perk for some days after COVID-19.	8
Yes, due to COVID-19 and it will change back to normal after COVID-19	19
No, R&D employees could not work remotely because they were needed to use specific inhouse equipment.	10
No, R&D employees came to office as usual	9

It becomes clear that it is not always feasible for R&D employees to work remotely since their work often require the use of special equipment located in company premises leading to partially applying remote working, or not applying it at all. In other cases, remote working was proven efficient and will be maintained even after the situation with the pandemic outbreak allows it or it will be kept as an additional perk for some days of the week.

4.8 Organizational Performance

The last data collection category was about the whole performance of the organization. The first question was regarding the significance of specific metrics (described in Section 2.3) and as the rest of the question it was a close type question. The available answers were:

- No significance
- Minor significance
- Average significance
- Major significance
- Great significance

For the organizational performance metric, the applicability of each chosen metric was not examined but only the significance of them for the organization since they are commonly used and loosely tied with the business operation itself.

Working similarly with the answers given for R&D performance, the answers were replaced by numbers and an average for each metric was computed. The numbers corresponding to each answer are shown below.

- No significance was replaced by number 0
- Minor significance was replaced by number 1
- Average significance was replaced by number 2
- Major significance was replaced by number 3
- Great significance was replaced by number 4

After computing the average, the results are presented in Table 4 – 9 in descending order for clarity.

A computed average close to 0 indicates that this metric is not generally significant for the majority of the companies, while as the average of each metric approached the number 4, a strong significance for the majority of the companies is indicated. As expected, there were no extreme values in terms of the average of each metric with their values roughly in the range 1.5 to 3.0. The difference between companies' industry and in how they treat their operation plays an important role to the significance of each metric. For example, the company that declared as an additional metric for its R&D the product profitability would perceive profit metric greatly significant, while the company interested in a high rate of success in bids maybe would treat the cash flow metric more important.

Table 4 - 9: Significance averages for Organizational Performance Metrics.

Organizational Performance Metric	Average
Profit	2.89
Actual Revenues vs Target Revenues	2.80
Sales	2.69
Employee satisfaction	2.38
Expenses vs Budget	2.36
Number of customers	2.34
Accumulation of knowledge and expertise	2.31
Cash flow for financing activities	2.30
Innovation spending	2.22
Knowledge achieved with training	2.15
Percentage of product defects	2.03
Customer support tickets	1.74
Cost of Goods Sold	1.69
Average annual expenses to serve one customer	1.66
Salary competitiveness ratio	1.46

As expected, the most significant metrics are those related with the company's income with profit considered the most important, closely followed by the accurate prediction of revenue expectations and sales. A pleasant surprise was the fourth most important metric which was employee satisfaction indicating the importance of people for a prosperous organization. Number of customers, accumulation of expertise and cash flow for financing activities are the next most significant metrics with minor deviation in between them. Innovation spending and knowledge achieved with training are coupled sometimes, hence they are really close in terms of significance. The next metric is the percentage of product defects with an average almost equal to 2 indicating an average significance, since not all products can be measured by their defect rate. After the product defect rate follow the customer support tickets, followed by COGS which is odd if one takes into account that profit was the most important metric. Average annual expenses for the needs of one customer is the second to the end metric and last is the salary competitiveness ratio. Even though companies consider employee satisfaction an important metric, they seem to aim to achieve it with different means than a competitive salary.

The next question regarding the organizational performance was an attempt to link the effect of the R&D with each of these metrics. Once again, the answers were predefined and for the needs of the analysis were replaced by numbers, as follows.

- The answer “R&D activities do not affect the metric” was replaced by number 0
- The answer “R&D activities slightly affect the metric” was replaced by number 1
- The answer “R&D activities affect the metric” was replaced by number 2
- The answer “R&D activities greatly affect the metric” was replaced by number 3

The average for the effect of the R&D for each metric was computed and the results are shown in descending order in the following table. Maximum expected value is 3 indicating a strong effect by the R&D on this metric while as much as the average decreases, such effect on the metric does.

Table 4 - 10: Effect of R&D on each organizational performance metric.

Effect of R&D on	Average
Innovation spending	2.39
Accumulation of knowledge and expertise	2.26
Knowledge achieved with training	1.97
Expenses vs Budget	1.59
Cash flow for financing activities	1.48
Profit	1.39
Employee satisfaction	1.31
Percentage of product defects	1.25
Actual Revenues vs Target Revenues	1.18
Salary competitiveness ratio	1.00
Customer support tickets	0.92
Sales	0.82
Cost of Goods Sold	0.82
Number of customers	0.72
Average annual expenses to serve one customer	0.59

It is no surprise that innovation spending is the most affected metric by the R&D activities closely followed by accumulation of knowledge which perfectly makes sense since the knowledge and expertise are produce inside the R&D departments. Knowledge achieved with training is the next metric followed by the need of expenses to meet the budget. Cash

flow for finance activities and profit are the next metrics affected by R&D. Employee satisfaction is the next metric, a critical metric for R&D efficiency since people are need to work in teams and produce innovation. On the contrary with the expenses, R&D activities do not have significant effect for revenue meeting expectations. Salary competitiveness ratio even though it was the least important metric is affected by R&D activities. That make sense by taking into account that an efficient R&D department would require more experienced and talented professionals in order to keep growing. With average even below number 1, indicating slight effect from the R&D, customers support tickets, sales, COGS, number of customers and annual expenses for the needs of one customer follow in that order. The only surprise here is the COGS, since the choices of R&D in materials were expected to have a more important role.

The last part of this research was the performance of the same metrics in 2020 and the role COVID-19 outbreak played on it. The results for this part are presented below.

Table 4 - 11: Actual revenues vs target revenues metric performance in 2020.

Worse performance due to COVID-19	3	11
Worse performance not due to COVID-19	8	
Same performance		48
Better performance due to COVID-19	0	2
Better performance not due to COVID-19	2	

In the most cases, the target regarding revenues was met in 2020 despite the COVID-19 outbreak and in cases it was not met only 3 out of the 11 was due to COVID-19, hence one can safely conclude that this metric was slightly affected by the pandemic outbreak.

Table 4 - 12: Profit metric performance in 2020.

Worse performance due to COVID-19	4	12
Worse performance not due to COVID-19	8	
Same performance		40
Better performance due to COVID-19	8	9
Better performance not due to COVID-19	1	

The number of companies that had less profit in 2020 is almost the same to those who did not meet their target revenue (12 and 11 respectively) hence it is safe to assume that for the majority of this answers are related, 40 companies had the same profit in 2020 and 9

performed better in 2020, with 8 out of them originating this increase to the pandemic outbreak. Such cases may be companies whose product was more or less used in healthcare units or commercial goods since shopping spiked for them.

Table 4 - 13: Sales metric in 2020.

Worse performance due to COVID-19	13	14
Worse performance not due to COVID-19	1	
Same performance		38
Better performance due to COVID-19	8	9
Better performance not due to COVID-19	1	

For the sales metric, the tendency followed by the two previous metrics is still valid with small deviations. It is observed that slightly more companies made less sales than the previous years, but managed to maintain their profit or reach their target revenue. Also, sales metric is not sensitive to pandemic in cases of energy products (e.g., solar panels) or in cases of companies focusing on tenders in industries.

Table 4 - 14: COGS metric in 2020.

Worse performance due to COVID-19	3	12
Worse performance not due to COVID-19	9	
Same performance		49
Better performance due to COVID-19	0	0
Better performance not due to COVID-19	0	

COGS sold was maintained as a metric for the majority of cases and for some them it did not perform as good as previous years, indicating an increase on this cost. A possible explanation to this is that a lot of companies altered their operation, limiting their available resources giving part of their market share to competitors who took advantage of the increased demand on their end. Also, with courier services overwhelmed, companies would demand express deliveries in order to meet contractual deadlines, resulting in being charged more for services the normally would not.

Table 4 - 15: Expenses vs Budget metric in 2020.

Worse performance due to COVID-19	3	20
Worse performance not due to COVID-19	17	
Same performance		35
Better performance due to COVID-19	6	6
Better performance not due to COVID-19	0	

It was expected for the unpredicted situation caused by COVID-19 outbreak a lot of companies to fail to meet their budget facing more expenses and it is confirmed, since 1/3 of them did so. Surprisingly the most of them do not think the pandemic was the reason for this. Probably their expenses increased indirectly by the pandemic, by making investment in new equipment or software allowing remote working and online meetings. For 6 of the answers pandemic helped to meet their budget more effectively and improve their performance in this area and for the rest the performance was the same.

Table 4 - 16: Cash flow for financing activities metric performance in 2020.

Worse performance due to COVID-19	12	13
Worse performance not due to COVID-19	1	
Same performance		45
Better performance due to COVID-19	3	3
Better performance not due to COVID-19	0	

For the majority of the participants (45 out of 61), 2020 was the same in terms of cash flow for financing activities, but for 13 out of the 61 the previous year was not as good as the years before, with 12 considering the pandemic the main reason. It is true that investment were made more conservatively, especially during the first wave of the outbreak, limiting financing activities to those necessary. A few companies (3 out of 61) saw an opportunity in COVID-19 and actually increased their cash flow for financing activities.

Table 4 - 17: Innovation spending metric performance in 2020.

Worse performance due to COVID-19	2	14
Worse performance not due to COVID-19	12	
Same performance		40
Better performance due to COVID-19	3	7
Better performance not due to COVID-19	4	

Regarding innovation spending, 40 out of 61 companies kept performing in the same manner while 7 of them performed better in 2020, with 3 of them increasing their innovation spending due to COVID-19. For those who spent less for innovation (14 out of 61) only 2 of them limited their expenses due to COVID-19.

Table 4 - 18: Number of customers metric performance in 2020.

Worse performance due to COVID-19	2	3
Worse performance not due to COVID-19	1	
Same performance		39
Better performance due to COVID-19	11	19
Better performance not due to COVID-19	8	

In terms of number of customers, in 2020 there was an improving tendency with 39 companies performing comparably with the previous years and with 19 managing to increase their number of customers. From those 19, 11 was due to COVID-19. The cases of decrease of number of customers was only 3, with 2 of them to be due to COVID-19.

Table 4 - 19: Customer support tickets metric performance in 2020.

Worse performance due to COVID-19	4	5
Worse performance not due to COVID-19	1	
Same performance		45
Better performance due to COVID-19	0	11
Better performance not due to COVID-19	11	

The positive tendency regarding customers is kept for this metric as well with 11 out of 61 participant companies to manage to reduce the need of their customers for support based solely on their actions. 45 companies kept the same performance with only 5 to receive more support requests. A possible explanation to this is the fact that some products had to be released in market before reaching maturity (e.g., with unclear user instructions), hence they would require additional support.

Table 4 - 20: Percentage of products defects metric performance in 2020.

Worse performance due to COVID-19	0	1
Worse performance not due to COVID-19	1	
Same performance		48
Better performance due to COVID-19	1	12
Better performance not due to COVID-19	11	

COVID-19 clearly did not affect the number of defect products. Only 1 of the participants reports increase in their defect products, 48 maintained their performance in this area and 12 made improvements.

Table 4 - 21: Average annual expenses to serve one customer metric performance in 2020.

Worse performance due to COVID-19	3	4
Worse performance not due to COVID-19	1	
Same performance		46
Better performance due to COVID-19	3	11
Better performance not due to COVID-19	8	

As observed in other metrics, companies participated in this research appear to have a tendency for improving their customers satisfaction rate, hence 11 out of 61 managed to decrease their expenses for one customer with most of the cases to be due to business operation and not pandemic outbreak (e.g., customers requesting less support due to pandemic). 46 managed to keep their performance the same despite the difficulties and only 4 spent more on serving customers, with 3 out of 4 to be due to COVID-19.

Table 4 - 22: Employee satisfaction metric performance in 2020.

Worse performance due to COVID-19	1	1
Worse performance not due to COVID-19	0	
Same performance		49
Better performance due to COVID-19	3	11
Better performance not due to COVID-19	8	

Employee satisfaction resulted to be the fourth most significant metric for the participants of this research, hence it could not perform poorly in 2020, only 1 case was reported and it was due to COVID-19 outbreak. 11 companies managed to improve the employee satisfaction rate and 49 maintained it.

Table 4 - 23: Salary competitiveness ration metric performance in 2020.

Worse performance due to COVID-19	0	1
Worse performance not due to COVID-19	1	
Same performance		46
Better performance due to COVID-19	6	14
Better performance not due to COVID-19	8	

Salary competitiveness ratio was not significantly import on its own for the participants, but paired with the desire for increased employee satisfaction, only 1 case was reported that the company offered less competitive salaries than previous years and it was not due to COVID-19. 46 companies maintained the same policy in this aspect and 14 increased their competitiveness. From the 14 that increased their competitiveness 6 did so due to COVID-19, possibly because they needed to increase their experienced staff urgently.

Table 4 - 24: Accumulation of knowledge and expertise metric performance in 2020.

Worse performance due to COVID-19	1	2
Worse performance not due to COVID-19	1	
Same performance		48
Better performance due to COVID-19	0	11
Better performance not due to COVID-19	11	

Accumulation of knowledge was another metric proven insensitive to COVID-19, with 48 of the participants managing to maintain the same performance and with 11 to improve their performance in this area solely based on their actions. For the 2 cases that a worse performance was reported, only 1 was due to the pandemic outbreak.

Table 4 - 25: Knowledge achieved with training metric performance in 2020.

Worse performance due to COVID-19	4	5
Worse performance not due to COVID-19	1	
Same performance		48
Better performance due to COVID-19	0	8
Better performance not due to COVID-19	8	

It was expected that COVID-19 would limit opportunities for training, hence 4 out of the 5 companies that reported that the knowledge achieved with training in 2020 was less than previous years. The majority of the companies maintained their performance in this area and 8 out of 61 took the initiative to increase theirs.

4.9 R&D Performance Linear Models

In this section, an analysis based on the collected data is performed attempting to connect the R&D metrics with the performance metrics. In the first part the calculated R&D Involvement Index and each R&D performance metric will be evaluated in terms of their statistical significance in respect to the R&D attributes of the company, hence for each metric a linear regression model will result. In the second part the same procedure will be followed for each performance metric using as variables the R&D Involvement Index and the R&D performance metrics and a linear regression model will result as well. In the last part the R&D performance values will be substituted by the regression models of the first part, ultimately linking the most significant R&D attributes of the company with each performance metric. For each part, a level of confidence equal to 97.5% will be taken into account resulting in the final model having a level of significance less than 5%. For all models a least-square method will be used by using Excel's Data Analysis tool. All results are presented with two decimal digits while calculation are performed with actual values.

4.10 R&D Performance Linear Models

For this part the R&D Involvement Index and the five R&D performance measures are approximated for the size of the company, the R&D size as percentage of size of the company, the number of the R&D departments operating within the company and the R&D structure. Specifically for the R&D structure, the case of having an R&D with a single discipline is coded with 0, the case in which there is a single R&D manager is coded with 2 and the case in which there are discipline managers is coded with 1. For each of the four variables the level of significance is determined by performing a least-square analysis omitting in each iteration the least significant variable. In the end only the variables with a level of significance with less than 2.5% are kept in the model. The summary of the results is presented on the following table.

Table 4 - 26: Regression Analysis for R&D Involvement Index – Initial Model

	Coefficients	Standard Error	t	P-Value
Intercept	1.15	0.11	10.82	0.00%
C1	-1.33E-05	6.44-06	-2.06	4.38%
C2	-0.40	0.13	-3.02	0.38%
C3	0.09	0.04	2.47	1.66%
C4	-0.13	0.05	-2.62	1.12%

From the table above it becomes clear that the variable C1 will be omitted for the next iteration. C1 refers to Company Size.

Table 4 - 27: Regression Analysis for R&D Involvement Index – First Iteration

	Coefficients	Standard Error	t	P-Value
Intercept	1.19	0.11	11.02	0.00%
C2	-0.35	0.13	-2.63	1.11%
C3	0.05	0.03	1.67	10.02%
C4	-0.14	0.05	-2.86	0.59%

From the first iteration, the variable C3, referring to the number of the R&D departments becomes the most insignificant variable and it will be omitted for the next iteration.

Table 4 - 28: Regression Analysis for R&D Involvement Index – Second Iteration

	Coefficients	Standard Error	t	P-Value
Intercept	1.27	0.10	13.17	0.00%
C2	-0.34	0.14	-2.48	1.61%
C4	-0.15	0.05	-2.97	0.44%

From the table above it is clear that the C2 variable referring to the R&D size as a percentage of the size of the company and the S variable, referring to the R&D structure are the statistically significant variables for the R&D Involvement Index. The linear regression model for RD1 (R&D Involvement Index) follows.

$$RD1 = -0.34C2 - 0.15C4 + 1.27 \quad (4-1)$$

The next model is the R&D spending as percentage of sales (RD2).

Table 4 - 29: Regression Analysis of R&D Spending as percentage of Sales – Initial Model

	Coefficients	Standard Error	t	P-Value
Intercept	0.76	0.16	4.77	0.00%
C1	-1.37E-05	9.10E-06	-1.51	13.87%
C2	-0.13	0.23	-0.55	58.35%
C3	0.37	0.05	7.10	0.00%
C4	0.04	0.07	0.58	56.37%

The variable referring to R&D size as a percentage of the company size is the first to be omitted from this regression model.

Table 4 - 30: Regression Analysis of R&D Spending as percentage of Sales – First Iteration

	Coefficients	Standard Error	t	P-Value
Intercept	0.74	0.15	4.83	0.00%
C1	-1.25E-05	8.74E-06	-1.43	16.08%
C3	0.37	0.05	7.31	0.00%
C4	0.04	0.07	0.58	56.55%

The next variable omitted from the model is the R&D structure (C4). The second iteration follows in the table below.

Table 4 - 31: Regression Analysis of R&D Spending as percentage of Sales – Second Iteration

	Coefficients	Standard Error	t	P-Value
Intercept	0.81	0.09	8.94	0.00%
C1	-1.16E-05	8.54E-06	-1.35	18.26%
C3	0.36	0.05	7.41	0.00%

The company size (C1) is the last variable to be omitted, leaving R&D spending as percentage of sales directly linear to the number of R&D departments (C3). The results of the last regression along with the linear model follow below.

Table 4 - 32: Regression Analysis of R&D Spending as percentage of Sales – Third Iteration

	Coefficients	Standard Error	t	P-Value
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Intercept	0.84	0.09	9.37	0.00%
C3	0.33	0.04	7.48	0.00%

$$RD2 = 0.33C3 + 0.84 \quad (4-2)$$

The next R&D performance measure is R&D headcount (RD3).

Table 4 - 33: Regression Analysis for R&D Headcount – Initial Model

	Coefficients	Standard Error	t	P-Value
Intercept	0.98	0.19	5.22	0.00%
C1	-3.57E-05	1.13E-05	-3.15	0.26%
C2	-0.39	0.23	-1.64	10.67%
C3	0.40	0.06	6.27	0.00%
C4	-0.01	0.09	-0.12	90.20%

From the initial model, the least significant variable for R&D headcount metric resulted to be the structure (C4) of the department. The next iteration with the variable omitted follows.

Table 4 - 34: Regression Analysis for R&D Headcount – First Iteration

	Coefficients	Standard Error	t	P-Value
Intercept	0.96	0.12	7.75	0.00%
C1	-3.59E-05	1.11E-05	-3.22	0.21%
C2	-0.38	0.23	-1.65	10.37%
C3	0.40	0.06	6.40	0.00%

The next less statistically significant variable was proven to be the R&D size as a percentage of company size (C2). The variable will be omitted in the next iteration.

Table 4 - 35: Regression Analysis for R&D Headcount – Second Iteration

	Coefficients	Standard Error	t	P-Value
Intercept	0.86	0.11	7.89	0.00%
C1	-3.23E-05	1.11E-05	-2.91	0.51%
C3	0.38	0.06	6.12	0.00%

After the second iteration the remaining variables are proven to be statistically significant for the R&D headcount metric, hence the linear regression model is as follows.

$$RD3 = -3.23 \cdot 10^{-5} \cdot C1 + 0.38C3 + 0.86 \quad (4-3)$$

The next variable for which the regression analysis is performed is the number of patents released per year (RD4).

Table 4 - 36: Regression Analysis for Patents released per year – Initial Model

	Coefficients	Standard Error	t	P-Value
Intercept	0.75	0.09	8.15	0.00%
C1	1.92E-05	3.73E-06	5.14	0.00%
C2	0.10	0.10	1.08	28.63%
C3	0.25	0.02	11.73	0.00%
C4	-0.01	0.04	-0.28	77.90%

Same with the previous metrics, the least statistically significant variable is the structure (C4) of the department. The structure variable will be omitted in the next iteration.

Table 4 - 37: Regression Analysis for Patents released per year – First Iteration

	Coefficients	Standard Error	t	P-Value
Intercept	0.73	0.06	13.05	0.00%
C1	1.90E-05	3.64E-06	5.22	0.00%
C2	0.11	0.09	1.23	22.56%

C3	0.25	0.02	12.20	0.00%
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R&D size as percentage of company size is the next variable to be omitted.

Table 4 - 38: Regression Analysis for Patents released per year – Second Iteration

	Coefficients	Standard Error	t	P-Value
Intercept	0.78	0.04	18.59	0.00%
C1	1.80E-05	3.58E-06	5.04	0.00%
C3	0.25	0.02	12.23	0.00%

Similar with the headcount metrics, after the second iteration the same variables are proven statistically significant. The linear model for the number of patents per year follows.

$$RD4 = 1.80 \cdot 10^{-5} \cdot C1 + 0.25C3 + 0.78 \quad (4-4)$$

The following metric is the number of new products released per year (RD5).

Table 4 - 39: Regression Analysis for New Products per year – Initial Model

	Coefficients	Standard Error	t	P-Value
Intercept	2.47	0.26	9.34	0.00%
C1	3.85E-06	1.47E-05	0.26	79.38%
C2	-0.68	0.35	-1.96	5.58%
C3	-0.11	0.08	-1.29	20.43%
C4	-0.05	0.12	-0.41	68.10%

For the new products released per year the least statistically significant variable is the company size (C1) which is omitted in the next iteration.

Table 4 - 40: Regression Analysis for New Products per Year – First Iteration

	Coefficients	Standard Error	t	P-Value
Intercept	2.45	0.26	9.57	0.00%
C2	-0.70	0.33	-2.09	4.16%
C3	-0.10	0.07	-1.33	18.83%
C4	-0.05	0.12	-0.38	70.87%

Following company size, the structure of the R&D (C4) is omitted in the following iteration.

Table 4 - 41: Regression Analysis for New Products per Year – Second Iteration

	Coefficients	Standard Error	t	P-Value
Intercept	2.38	0.16	14.87	0.00%
C2	-0.70	0.33	-2.10	4.13%
C3	-0.09	0.07	-1.30	19.90%

The number of R&D departments (C3) is omitted next since it is proven to be statistically insignificant for the metric of new products.

Table 4 - 42: Regression Analysis for New Product per Year – Third Iteration

	Coefficients	Standard Error	t	P-Value
Intercept	2.25	0.13	17.40	0.00%
C2	-0.77	0.33	-2.33	2.39%

After the third iteration, the linear model resulted is shown below.

$$RD5 = -0.77C2 + 2.25 \quad (4-5)$$

The last metric is the Return of Investment (RD6). The regression analysis follows.

Table 4 - 43: Regression Analysis for Return of Investment – Initial Model

	Coefficients	Standard Error	t	P-Value
Intercept	2.17	0.11	20.59	0.00%
C1	5.96E-06	5.68E-06	1.05	29.98%

C2	-0.41	0.14	-2.96	0.50%
C3	-0.11	0.03	-3.28	0.20%
C4	0.03	0.05	0.60	55.28%

From the initial model for the RoI metric, the structure of the R&D resulted to be the least statistically significant variable and it is omitted in the next iteration.

Table 4 - 44: Regression Analysis for Return of Investment – First Iteration

	Coefficients	Standard Error	t	P-Value
Intercept	2.22	0.06	34.50	0.00%
C1	6.54E-06	5.55E-06	1.18	24.53%
C2	-0.41	0.14	-3.01	0.43%
C3	-0.11	0.03	-3.52	0.10%

The company size (C1) is the next least significant variable which is omitted in the second iteration.

Table 4 - 45: Regression Analysis for Return of Investment – Second Iteration

	Coefficients	Standard Error	t	P-Value
Intercept	2.22	0.06	34.36	0.00%
C2	-0.45	0.13	-3.38	0.15%
C3	-0.09	0.03	-3.34	0.17%

After the second iteration the remaining variables are proven statistically significant for the chosen confidence level. The linear regression model for RoI follows.

$$RD6 = -0.45C2 - 0.09C3 + 2.22 \quad (4-6)$$

From the analysis above for the chosen six metrics for R&D performance, the following statistical significance resulted for the four variables used.

1. Number of R&D departments (C3) appears with statistical significance in four out of the total six cases
2. R&D size as percentage of company size (C2) follows, having statistical significance in three out of the total six cases
3. Company Size (C1) appears with statistical significance in two out of six cases
4. Lastly, the structure of the R&D department (C4) has the less statistical significance, affecting only the involvement of the R&D to company's activities.

It is interesting to observe that for all six metrics, the variables related with the company data are not exceeding the number of two for each model, making it easier to take actions and predict their effect on each metric, ultimately allowing the organization to choose a course of action to affect the most important metrics for it.

4.11 Organizational Performance Linear Models in Respect to R&D metrics

For this part, linear regression models are estimated for the each of the organization performance metrics using as variables the six performance metrics for the R&D. For this part of the study the effect the importance of each performance metric will be taken into account and the effect of the R&D on each metric according to the answers of the questionnaire.

Table 4 - 46: Regression Analysis for actual vs target revenues – Initial Model

	Coefficients	Standard Error	t	P-Value
Intercept	-3.75	3.13E-13	-1.20E+13	0.00%
RD1	-5.25	2.44E-13	-2.15E+13	0.00%
RD2	2.32E-14	1.38E-13	0.17	86.84%
RD3	3.25	2.43E-13	1.34E+13	0.00%
RD4	0.50	6.92E-14	7.22E+12	0.00%
RD5	1.00	6.70E-16	1.49E+15	0.00%
RD6	2.00	1.39E-13	1.44E+13	0.00%

For the initial model the variable measuring R&D spending as percentage of sales (RD2) is proven to be the most statistically insignificant and it is omitted in the next iteration.

Table 4 - 47: Regression Analysis for actual vs target revenues - First Iteration

	Coefficients	Standard Error	t	P-Value
Intercept	-3.75	7.29E-15	-5.14E+14	0.00%
RD1	-5.25	7.81E-15	-6.72E+14	0.00%
RD3	3.25	4.36E-15	7.45E+14	0.00%
RD4	0.50	6.63E-16	7.54E+14	0.00%
RD5	1.00	6.25E-16	1.60E+15	0.00%
RD6	2.00	2.92E-15	6.85E+14	0.00%

As expected, the rest of the variables are proven statistically significant, hence the linear model is the following.

$$P01 = -5.25RD1 + 3.25RD3 + 0.5RD4 + RD5 + 2RD6 - 3.75 \quad (4-7)$$

The same procedure is applied for the next performance metric, profit (P02).

Table 4 - 48: Regression Analysis for Profit – Initial Model

	Coefficients	Standard Error	t	P-Value
Intercept	-3.75	3.13E-13	-1.20E+13	0.00%
RD1	-5.25	2.44E-13	-2.15E+13	0.00%
RD2	2.32E-14	1.38E-13	0.17	86.84%
RD3	3.25	2.43E-13	1.34E+13	0.00%
RD4	0.50	6.92E-14	7.22E+12	0.00%
RD5	1.00	6.70E-16	1.49E+15	0.00%
RD6	2.00	1.39E-13	1.44E+13	0.00%

In the initial model, the resulted values resulted identical with the one for the target revenues vs actual revenues, indicating that organizations perceive both metrics in the same manner, hence the linear model would be the same.

$$P02 = -5.25RD1 + 3.25RD3 + 0.5RD4 + RD5 + 2RD6 - 3.75 \quad (4-8)$$

The regression analysis for sales (P03) follows.

Table 4 - 49: Regression Analysis for Sales – Initial Model

	Coefficients	Standard Error	t	P-Value
Intercept	-5.75	2.86E-13	-2.01E+13	0.00%
RD1	-5.25	2.23E-13	-2.36E+13	0.00%
RD2	4.52E-14	1.26E-13	0.36	72.35%
RD3	3.25	2.22E-13	1.47E+13	0.00%
RD4	0.50	6.31E-14	7.92E+12	0.00%
RD5	1.00	6.10E-16	1.64E+15	0.00%
RD6	3.00	1.27E-13	2.37E+13	0.00%

Similarly with the previous two metrics, R&D spending as percentage of sales is not statistically important, hence it is omitted in the next iteration.

Table 4 - 50: Regression Analysis for Sales – First Iteration

	Coefficients	Standard Error	t	P-Value
Intercept	-5.75	6.65E-15	-8.64E+14	0.00%
RD1	-5.25	7.13E-15	-7.37E+14	0.00%
RD3	3.25	3.98E-15	8.17E+14	0.00%
RD4	0.50	6.05E-16	8.27E+14	0.00%
RD5	1.00	5.70E-16	1.75E+15	0.00%
RD6	3.00	2.66E-15	1.13E+15	0.00%

Based on the values above, the linear model for sales follows.

$$P03 = -5.25RD1 + 3.25RD3 + 0.5RD4 + RD5 + 3RD6 - 5.75 \quad (4-9)$$

The next performance metrics is Cost of Goods Sold (P04).

Table 4 - 51: Regression Analysis for COGS - Initial Model

	Coefficients	Standard Error	t	P-Value
Intercept	-22.50	1.19E-12	-1.89E+13	0.00%
RD1	-24.50	9.26E-13	-2.65E+13	0.00%
RD2	4.99E-13	5.24E-13	0.95	35.06%
RD3	14.50	9.22E-13	1.57E+13	0.00%
RD4	1.00	2.62E-13	3.81E+12	0.00%
RD5	2.00	2.54E-15	7.88E+14	0.00%
RD6	9.00	5.27E-13	1.71E+13	0.00%

Once again, the spending for R&D activities as percentage of sales is proven the least statistically significant variable and is omitted for the next iteration.

Table 4 - 52: Regression Analysis for COGS – First Iteration

	Coefficients	Standard Error	t	P-Value
Intercept	-22.50	2.83E-14	-7.96E+14	0.00%
RD1	-24.50	3.03E-14	-8.09E+14	0.00%
RD3	14.50	1.69E-14	8.58E+14	0.00%
RD4	1.00	2.57E-15	3.89E+14	0.00%
RD5	2.00	2.42E-15	8.25E+14	0.00%
RD6	9.00	1.13E-14	7.95E+14	0.00%

After the first iteration, the remaining variables are proven to be statistically significant, leading to the following linear model.

$$P04 = -24.5RD1 + 14.5RD3 + RD4 + 2RD5 + 9RD6 - 22.50 \quad (4-10)$$

The next metric for which regression analysis would be performed is the Expenses vs the Budget (P05). The initial model follows below.

Table 4 - 53: Regression Analysis for Expenses vs Budget – Initial Model

	Coefficients	Standard Error	t	P-Value
Intercept	-5.00	4.27E-13	-1.17E+13	0.00%
RD1	-7.00	3.33E-13	-2.10E+13	0.00%
RD2	3.86E-13	1.89E-13	2.04	5.26%
RD3	5.00	3.32E-13	1.51E+13	0.00%
RD4	-1.93E-13	9.44E-14	-2.04	5.26%
RD5	1.00	9.13E-16	1.09E+15	0.00%
RD6	2.00	1.90E-13	1.05E+13	0.00%

For this metric both RD2 and RD4 exceed the required level of significance. By paying a closer attention to the rest of the digits (not shown in the table) RD4's P-value is slightly greater than RD2's, hence it is the first to be omitted. The results for the first iteration follow.

Table 4 - 54: Regression Analysis for Expenses vs Budget – First Iteration

	Coefficients	Standard Error	t	P-Value
Intercept	-5.00	8.73E-15	-5.73E+14	0.00%
RD1	-7.00	1.01E-14	-6.91E+14	0.00%
RD2	1.32E-15	1.93E-15	6.84E-01	50.07%
RD3	5.00	5.71E-15	8.76E+14	0.00%
RD5	1.00	9.10E-16	1.10E+15	0.00%
RD6	2.00	3.44E-15	5.81E+14	0.00%

As expected RD2 needs to be omitted to, since it was proven statistically insignificant.

Table 4 - 55: Regression Analysis for Budget vs Expenses – Second Iteration

	Coefficients	Standard Error	t	P-Value
Intercept	-5.00	8.39E-15	-5.96E+14	0.00%
RD1	-7.00	9.76E-15	-7.17E+14	0.00%
RD3	5.00	5.61E-15	8.91E+14	0.00%
RD5	1.00	8.74E-16	1.14E+15	0.00%
RD6	2.00	3.34E-15	5.98E+14	0.00%

The rest of the variables have statistical significance, resulting in the following linear model.

$$P05 = -7RD1 + 5RD3 + RD5 + 2RD6 - 5 \quad (4-11)$$

The next metric is the Cash Flow for Financing activities (P06). The initial model follows.

Table 4 - 56: Regression Analysis for Cash Flow for Financing Activities – Initial Model

	Coefficients	Standard Error	t	P-Value
Intercept	13.50	4.90E-13	2.75E+13	0.00%
RD1	10.50	3.82E-13	2.75E+13	0.00%
RD2	-6.75E-14	2.16E-13	-0.31	75.78%
RD3	-5.50	3.81E-13	-1.44E+13	0.00%
RD4	-1.00	1.08E-13	-9.23E+12	0.00%
RD5	-1.00	1.05E-15	-9.55E+14	0.00%
RD6	-4.00	2.18E-13	-1.84E+13	0.00%

Similarly, to the rest of the metrics, RD2 is proven the least significant variable.

Table 4 - 57: Regression Analysis for Cash Flow for Financing Activities – First Iteration

	Coefficients	Standard Error	t	P-Value
Intercept	13.50	1.16E-14	1.16E+15	0.00%
RD1	10.50	1.24E-14	8.45E+14	0.00%
RD3	-5.50	6.94E-15	-7.93E+14	0.00%
RD4	-1.00	1.06E-15	-9.48E+14	0.00%
RD5	-1.00	9.95E-16	-1.01E+15	0.00%
RD6	-4.00	4.65E-15	-8.61E+14	0.00%

Based on the values estimated above, the linear model for P06 metric follows.

$$P06 = 10.5RD1 - 5.5RD3 - RD4 - RD5 + 4RD6 + 13.5 \quad (4-12)$$

The next metric is Innovation Spending (P07). The initial model follows.

Table 4 - 58: Regression Analysis for Innovation Spending – Initial Model

	Coefficients	Standard Error	t	P-Value
Intercept	8.50	4.07E-13	2.09E+13	0.00%
RD1	10.50	3.18E-13	3.31E+13	0.00%
RD2	-1.33E-13	1.80E-13	-0.74	46.79%
RD3	-5.50	3.16E-13	-1.74E+13	0.00%
RD4	6.70E-14	9.00E-14	7.45E-01	46.41%
RD5	-1.00	8.71E-16	-1.15E+15	0.00%
RD6	-2.00	1.81E-13	-1.11E+13	0.00%

RD2 is the least statistically significant variable and the first to omit.

Table 4 - 59: Regression Analysis for Innovation Spending – First Iteration

	Coefficients	Standard Error	t	P-Value
Intercept	8.50	9.53E-15	8.92E+14	0.00%
RD1	10.50	1.02E-14	1.03E+15	0.00%
RD3	-5.50	5.70E-15	-9.65E+14	0.00%
RD4	3.13E-16	8.66E-16	0.36	72.10%
RD5	-1.00	8.17E-16	-1.22E+15	0.00%
RD6	-2.00	3.81E-15	-5.24E+14	0.00%

RD4 is the next variable to omit while repeating the regression analysis.

Table 4 - 60: Regression Analysis – Second Iteration

	Coefficients	Standard Error	t	P-Value
Intercept	8.50	7.65E-15	1.11E+15	0.00%
RD1	10.50	8.90E-15	1.18E+15	0.00%
RD3	-5.50	5.12E-15	-1.07E+15	0.00%
RD5	-1.00	7.97E-16	-1.25E+15	0.00%
RD6	-2.00	3.05E-15	-6.56E+14	0.00%

As expected, the remaining variables have statistical significance, hence the linear model is

$$P07 = 10.5RD1 - 5.5RD3 - RD5 - 2RD6 + 8.5 \quad (4-13)$$

The next performance metric is the number of customers. The initial model follows.

Table 4 - 61: Regression Analysis for the Number of Customers – Initial Model

	Coefficients	Standard Error	t	P-Value
Intercept	5.50	1.41E-13	3.90E+13	0.00%
RD1	3.50	1.10E-13	3.19E+13	0.00%
RD2	-3.34E-14	6.22E-14	-0.54	59.66%
RD3	-1.50	1.09E-13	-1.37E+13	0.00%
RD4	-1.00	3.11E-14	-3.21E+13	0.00%
RD5	1.10E-15	3.01E-16	3.66E+00	0.13%
RD6	-1.00	6.25E-14	-1.60E+13	0.00%

Similar to the majority of the previous cases, RD2 is the first variable to exclude from the first iteration.

Table 4 - 62: Regression Analysis for the Number of Customers – First Iteration

	Coefficients	Standard Error	t	P-Value
Intercept	5.50	3.31E-15	1.66E+15	0.00%
RD1	3.50	3.54E-15	9.88E+14	0.00%
RD3	-1.50	1.98E-15	-7.58E+14	0.00%
RD4	-1.00	3.01E-16	-3.32E+15	0.00%
RD5	8.93E-16	2.84E-16	3.15E+00	0.43%
RD6	-1.00	1.32E-15	-7.55E+14	0.00%

After removing RD2, the results in the table above were calculated. The coefficient for RD5 is significant small and is not expected to alter the computational result, but it will be included in the linear model since it was proven statistically significant, but practically the term will always be almost equal to zero with negligible effect.

$$P08 = 3.5RD1 - 1.5RD3 - RD4 + 8.93 \cdot 10^{-16} \cdot RD5 - RD6 + 5.5 \quad (4-14)$$

The next performance metric for which the regression analysis is conducted is the number of Customer Support Tickets. The analysis follows.

Table 4 - 63: Regression Analysis for Customer Support Tickets – Initial Model

	Coefficients	Standard Error	t	P-Value
Intercept	-18.00	1.11E-12	-1.62E+13	0.00%
RD1	-21.00	8.65E-13	-2.43E+13	0.00%
RD2	5.97E-13	4.90E-13	1.22E+00	23.55%
RD3	13.00	8.62E-13	1.51E+13	0.00%
RD4	-3.00E-13	2.45E-13	-1.22E+00	23.37%
RD5	2.00	2.37E-15	8.43E+14	0.00%
RD6	7.00	4.93E-13	1.42E+13	0.00%

Based on the results computed in the initial regression model, RD2 is the first variable to omit from the first iteration and RD4 is expected to follow. The results are shown below.

Table 4 - 64: Regression Analysis for Customer Support Tickets – First Iteration

	Coefficients	Standard Error	t	P-Value
Intercept	-18.00	2.67E-14	-6.74E+14	0.00%
RD1	-21.00	2.86E-14	-7.34E+14	0.00%
RD3	13.00	1.60E-14	8.14E+14	0.00%
RD4	-8.05E-16	2.43E-15	-3.31E-01	74.32%
RD5	2.00	2.29E-15	8.74E+14	0.00%
RD6	7.00	1.07E-14	6.55E+14	0.00%

As expected, the RD4 variable needs to be excluded from the next iteration. The next iteration is expected to be the last for this performance metric. The result follow below.

Table 4 - 65: Regression Analysis for Customer Support Tickets – Second Iteration

	Coefficients	Standard Error	t	P-Value
Intercept	-18.00	2.12E-14	-8.50E+14	-18.00
RD1	-21.00	2.46E-14	-8.52E+14	-21.00
RD3	13.00	1.42E-14	9.18E+14	13.00
RD5	2.00	2.21E-15	9.07E+14	2.00
RD6	7.00	8.43E-15	8.30E+14	7.00

As expected, the regression model is statistically accurate after the last iteration. The linear model for P09 follows.

$$P09 = -21RD1 + 13RD3 - RD4 + 2RD5 + 7RD6 - 18 \quad (4-15)$$

The next metric is the percentage of product defects (P10). The initial model follows.

Table 4 - 66: Regression Analysis for Percentage of Product Defects – Initial Model

	Coefficients	Standard Error	t	P-Value
Intercept	-18.00	1.11E-12	-1.62E+13	0.00%
RD1	-21.00	8.65E-13	-2.43E+13	0.00%
RD2	5.97E-13	4.90E-13	1.22E+00	23.55%
RD3	13.00	8.62E-13	1.51E+13	0.00%
RD4	-3.00E-13	2.45E-13	-1.22E+00	23.37%
RD5	2.00	2.37E-15	8.43E+14	0.00%
RD6	7.00	4.93E-13	1.42E+13	0.00%

It is clear from the resulted data that RD2 has no statistical significance in this case too.

Table 4 - 67: Regression Analysis for Percentage of Product Defects – First Iteration

	Coefficients	Standard Error	t	P-Value
Intercept	-21.25	3.13E-14	-6.79E+14	0.00%
RD1	-29.75	3.35E-14	-8.88E+14	0.00%
RD3	17.75	1.87E-14	9.49E+14	0.00%
RD4	-0.50	2.84E-15	-1.76E+14	0.00%
RD5	3.00	2.68E-15	1.12E+15	0.00%
RD6	8.00	1.25E-14	6.39E+14	0.00%

After the first iteration, the linear model results as follows.

$$P10 = -29.75RD1 + 17.75RD3 - 0.5RD4 + 3RD5 + 8RD6 - 21.25 \quad (4-16)$$

The following metric for regression analysis is the annual expenses to serve one customer.

Table 4 - 68: Regression Analysis for Annual Expenses to serve one customer – Initial Model

	Coefficients	Standard Error	t	P-Value
Intercept	-17.50	1.15E-12	-1.52E+13	0.00%
RD1	-24.50	8.99E-13	-2.73E+13	0.00%
RD2	5.67E-13	5.09E-13	1.11	27.65%
RD3	14.50	8.95E-13	1.62E+13	0.00%
RD4	-2.85E-13	2.55E-13	-1.12	27.54%
RD5	2.00	2.46E-15	8.12E+14	0.00%
RD6	7.00	5.11E-13	1.37E+13	0.00%

RD2 is omitted for the first iteration and RD4 is expected to follow in the second one.

Table 4 - 69: Regression Analysis for Annual Expenses to serve one customer – First Iteration

	Coefficients	Standard Error	t	P-Value
Intercept	-17.50	2.76E-14	-6.33E+14	0.00%
RD1	-24.50	2.96E-14	-8.28E+14	0.00%
RD3	14.50	1.65E-14	8.78E+14	0.00%
RD4	-5.37E-16	2.51E-15	-0.21	83.26%
RD5	2.00	2.37E-15	8.45E+14	0.00%
RD6	7.00	1.11E-14	6.33E+14	0.00%

As expected RD4 shows no statistical significance for this metric. The next iteration is expected to result to the linear model.

Table 4 - 70: Regression Analysis for Annual Expenses to serve one customer – Second Iteration

	Coefficients	Standard Error	t	P-Value
Intercept	-17.50	2.18E-14	-8.03E+14	0.00%
RD1	-24.50	2.534E-14	-9.66E+14	0.00%
RD3	14.50	1.46E-14	9.95E+14	0.00%
RD5	2.00	2.27E-15	8.81E+14	0.00%
RD6	7.00	8.68E-15	8.07E+14	0.00%

The linear regression model resulted follows.

$$P11 = -24.5RD1 + 14.5RD3 + 2RD5 + 7RD6 - 17.5 \quad (4-17)$$

The next performance metric is employee satisfaction.

Table 4 - 71: Regression Analysis for Employee Satisfaction – Initial Model

	Coefficients	Standard Error	t	P-Value
Intercept	3.75	5.11E-14	7.33E+13	0.00%
RD1	-1.75	3.99E-14	-4.39E+13	0.00%
RD2	5.30E-15	2.26E-14	0.23	81.64%
RD3	0.75	3.97E-14	1.89E+13	0.00%
RD4	-0.50	1.13E-14	-4.42E+13	0.00%
RD5	-3.55E-16	1.09E-16	-3.24E+00	0.36%
RD6	-5.15E-15	2.27E-14	-2.27E-01	82.24%

For this metric, the least statistically significant variable is RD6 which is omitted for the next iteration.

Table 4 - 72: Regression Analysis for Employee Satisfaction – First Iteration

	Coefficients	Standard Error	t	P-Value
Intercept	3.75	2.66E-16	1.41E+16	0.00%
RD1	-1.75	5.90E-16	-2.96E+15	0.00%
RD2	5.79E-16	5.04E-16	1.15	26.21%
RD3	0.75	3.29E-16	2.28E+15	0.00%
RD4	-0.50	2.04E-16	-2.45E+15	0.00%
RD5	-4.07E-16	1.08E-16	-3.77	0.09%

After the first iteration, the RD2 variable resulted to be the least significant after omitting RD6.

Table 4 - 73: Regression Analysis for Employee Satisfaction – Second Iteration

	Coefficients	Standard Error	t	P-Value
Intercept	3.75	2.45E-16	1.53E+16	0.00%
RD1	-1.75	4.38E-16	-3.99E+15	0.00%
RD3	0.75	2.73E-16	2.75E+15	0.00%
RD4	-0.50	9.09E-17	-5.50E+15	0.00%
RD5	-4.60E-16	8.25E-17	-5.57	0.00%

After the last iteration, the following linear model results.

$$P12 = -1.75RD1 + 0.75RD3 - 0.5RD4 - 4.6 \cdot 10^{-16} \cdot RD5 + 3.75 \quad (4-18)$$

The next metric is salary competitiveness ratio.

Table 4 - 74: Regression Analysis Salary competitiveness ratio – Initial Model

	Coefficients	Standard Error	t	P-Value
Intercept	2.00	6.64E-14	3.01E+13	0.00%
RD1	2.03E-13	5.18E-14	3.91	0.07%
RD2	1.14E-13	2.93E-14	3.91	0.07%
RD3	-2.02E-13	5.16E-14	-3.91	0.07%
RD4	-5.74E-14	1.47E-14	-3.91	0.07%
RD5	-1.00	1.42E-16	-7.05E+15	0.00%
RD6	1.00	2.95E-14	3.39E+13	0.00%

For this metric the linear model resulted from the initial model and all variables are statistically significant. The linear model follows.

$$P13 = 2.03 \cdot 10^{-13} \cdot RD1 + 1.14 \cdot 10^{-13} \cdot RD2 - 2.02 \cdot 10^{-13} \cdot RD3 - 5.74 \cdot 10^{-14} \cdot RD4 - RD5 + RD6 + 2 \quad (4-19)$$

The next metric is the accumulation of knowledge and expertise.

Table 4 - 75: Regression Analysis for Accumulation of Knowledge and Expertise – Initial Model

	Coefficients	Standard Error	t	P-Value
Intercept	1.75	3.61E-14	4.85E+13	0.00%
RD1	-1.75	2.82E-14	-6.21E+13	0.00%
RD2	1.39E-14	1.59E-14	0.87	39.10%
RD3	0.75	2.81E-14	2.67E+13	0.00%
RD4	-0.50	7.98E-15	-6.26E+13	0.00%
RD5	-3.68E-16	7.72E-17	-4.76	0.01%
RD6	1.00	1.60E-14	6.24E+13	0.00%

The least significant variable, omitted for the next iteration is RD2.

Table 4 - 76: Regression Analysis for Accumulation of Knowledge and Expertise – First Iteration

	Coefficients	Standard Error	t	P-Value
Intercept	1.75	7.95E-16	2.20E+15	0.00%
RD1	-1.75	8.52E-16	-2.06E+15	0.00%
RD3	0.75	4.75E-16	1.58E+15	0.00%
RD4	-0.50	7.23E-17	-6.92E+15	0.00%
RD5	-2.63E-16	6.82E-17	-3.853939472	0.08%
RD6	1.00	3.18E-16	3.14E+15	0.00%

The linear model resulted from the regression analysis follows.

$$P14 = -1.75RD1 + 0.75RD3 - 0.5RD4 - 2.63 \cdot 10^{-16} \cdot RD5 + RD6 + 1.75 \quad (4-20)$$

The last metric is the knowledge achieved with training. The initial model follows.

Table 4 - 77: Regression Analysis for Knowledge by training – Initial Model

	Coefficients	Standard Error	t	P-Value
Intercept	-8.00	6.12E-13	-1.31E+13	0.00%
RD1	-14.00	4.77E-13	-2.93E+13	0.00%
RD2	6.44E-14	2.70E-13	0.24	81.38%
RD3	8.00	4.75E-13	1.68E+13	0.00%
RD4	-3.32E-14	1.35E-13	-0.25	80.85%
RD5	1.00	1.31E-15	7.64E+14	0.00%
RD6	4.00	2.72E-13	1.47E+13	0.00%

By the initial model, the least statistically significant variable, resulted to be RD2.

Table 4 - 78: Regression Analysis for Knowledge by training – First Iteration

	Coefficients	Standard Error	t	P-Value
Intercept	-8.00	1.42E-14	-5.65E+14	0.00%
RD1	-14.00	1.52E-14	-9.23E+14	0.00%
RD3	8.00	8.47E-15	9.45E+14	0.00%
RD4	-8.05E-16	1.29E-15	-0.63	53.77%
RD5	1.00	1.21E-15	8.24E+14	0.00%
RD6	4.00	5.67E-15	7.06E+14	0.00%

Based on the results calculated in the first iteration, RD4 needs to be omitted to.

Table 4 - 79: Regression Analysis for Knowledge by training – Second Iteration

	Coefficients	Standard Error	t	P-Value
Intercept	-8.00	1.11E-14	-7.18E+14	0.00%
RD1	-14.00	1.30E-14	-1.08E+15	0.00%
RD3	8.00	7.45E-15	1.07E+15	0.00%
RD5	1.00	1.16E-15	8.61E+14	0.00%
RD6	4.00	4.44E-15	9.01E+14	0.00%

After the second iteration, the following linear model resulted.

$$P15 = -14RD1 + 8RD3 + RD5 + 4RD6 - 8 \quad (4-21)$$

4.12 Organizational Performance Linear Models in Respect to company characteristics

For this last part, the variables used in the linear equations models resulted for organizational performance metrics (Equations 4-7 to 4-21) will be substituted by the linear models for R&D performance metrics (Equations 4-1 to 4-6). By working in this manner, all the organizational performance metrics will be defined by the same type of variables and in the same time the effect R&D has in the organizational performance would be taken into account. The resulted equations follow below.

$$P01 = -9.58 \cdot 10^{-5} \cdot C1 + 0.11C2 + 1.17C3 + 0.80C4 - 0.57 \quad (4-22)$$

$$P02 = -9.58 \cdot 10^{-5} \cdot C1 + 0.11C2 + 1.17C3 + 0.80C4 - 0.57 \quad (4-23)$$

$$P03 = -9.58 \cdot 10^{-5} \cdot C1 - 0.34C2 + 1.08C3 + 0.80C4 - 0.35 \quad (4-24)$$

$$P04 = -4.58 \cdot 10^{-4} \cdot C1 + 2.71C2 + 4.92C3 + 3.71C4 - 16.02 \quad (4-25)$$

$$P05 = -1.61 \cdot 10^{-4} \cdot C1 + 0.70C2 + 1.71C3 + 1.06C4 - 2.94 \quad (4-26)$$

$$P06 = 1.59 \cdot 10^{-4} \cdot C1 - 0.99C2 - 1.97C3 - 1.59C4 + 10.26 \quad (4-27)$$

$$P07 = 1.77 \cdot 10^{-4} \cdot C1 - 1.89C2 - 1.90C3 - 1.59C4 + 10.47 \quad (4-28)$$

$$P08 = 3.04 \cdot 10^{-5} \cdot C1 - 0.73C2 - 0.73C3 - 0.53C4 + 5.68 \quad (4-29)$$

$$P09 = -4.19 \cdot 10^{-4} \cdot C1 + 2.42C2 + 4.28C3 + 3.18C4 - 13.57 \quad (4-30)$$

$$P10 = -5.81 \cdot 10^{-5} \cdot C1 + 4.17C2 + 5.87C3 + 4.51C4 - 19.80 \quad (4-31)$$

$$P11 = -4.68 \cdot 10^{-4} \cdot C1 + 3.61C2 + 4.85C3 + 3.71C4 - 16.24 \quad (4-32)$$

$$P12 = -3.32 \cdot 10^{-5} \cdot C1 + 0.59C2 + 0.16C3 + 0.27C4 + 1.78 \quad (4-33)$$

$$P13 = 5.47 \cdot 10^{-18} \cdot C1 + 0.32C2 - 0.09C3 - 3.07 \cdot 10^{-14}C4 + 1.96 \quad (4-34)$$

$$P14 = -3.32 \cdot 10^{-5} \cdot C1 + 0.14C2 + 0.06C3 + 0.27C4 + 1.99 \quad (4-35)$$

$$P15 = -2.58 \cdot 10^{-4} \cdot C1 + 2.17C2 + 2.67C3 + 2.12C4 - 7.58 \quad (4-36)$$

5. Discussion of Findings

In this chapter, the results from the analysis conducted in the previous chapter are discussed. This chapter is divided in two sections, the first is dedicated to directly discussing the results while the second one is more about the managerial perceptive these results offer.

Based on the equation for the organizational performance (4-22 to 4-36) and the computed coefficients, the most sensitive metric is Percentage of Product Defects (P10) since all the coefficients resulted greater in absolute value for this regression model than the rest.

Specifically, for Company Size (C1) the coefficient resulted equal to $-5.81 \cdot 10^{-4}$ meaning that for every person hired in the company the result for Percentage of Product Defects reduces by $5.81 \cdot 10^{-4}$ and analogously for every person leaving the company and is not replaced the metric increases by the same amount. Looking at these numbers, it could require about 17 people change to observe a difference equal to 1% to the metric, but practically, even though all positions are important for the firm operation, they do not all have the same weight on the performance of the company. Since this metric is about Product Defects, a more experienced or skillful operator in the production of the specific product could prevent the defect and possibly can affect this metric more than the Quality Control Engineer responsible for finding the defect after the product's production. This analysis does not go into such detail; hence the coefficient is a flat indicator.

For R&D size as percentage of company size (C2), the coefficient resulted equal to 4.17, meaning for every 1% the R&D size increases compared to the company size, the importance of product defects also increases by approximately 0.04, practically this makes sense, that as the R&D size increases compared to the rest of the employees, the product defects are more possible to be caused by problematic designs instead of production issues. Also, in cases of companies mainly focused on R&D activities, most of the times production is outsourced to certified manufacturers.

In terms of number of R&D departments, the coefficient resulted equal 5.87, greater in value than all the rest coefficients, indicating that just one R&D department difference could lead significantly affect the importance of this metric, but it's highly unlikely to affect solely this variable, for example, deciding to open an additional R&D department most probably could also require a major increase in company size, hence this variable is tied with the rest more or less, but in the same time can maintain its independency.

Last, for R&D structure, the coefficient resulted equal to 4.51. Since R&D structure is a status and not a quantitative aspect of the R&D the only conclusion that can be drawn here is its importance for the metric, which is high since it is the second greater in terms of value, following number of R&D departments.

Critically approaching the overall result, it makes perfect sense, since the the products are designed and released by the R&D department, hence a product failure cannot be affected by any other division, assuming its proper manufacturing, in case manufacturing is required. On the other hand, the least sensitive variables are Salary Competitiveness Ratio (P13), for which the lowest absolute values are observed for both company size (C1) with a coefficient equal to $5.81 \cdot 10^{-18}$ hinting a really small effect on the metric, practically requiring millions of people for the slightest effect on the metric and R&D structure (C4) with a coefficient equal to $-3.07 \cdot 10^{-14}$, practically equal to zero by comparing with the rest of coefficient for this variable. The next least sensitive variable is Accumulation of Knowledge and Expertise (P14), for which the lowest coefficient for number of R&D departments (C3) is observed equal to 0.06, indicating that for every R&D department opening or closing the effect is only 0.06 and as mentioned before, this metric can rarely be modified without affecting the rest variables. Lastly, Actual vs Target Revenues (P01) and Profit (P02) are the other least sensitive metrics which share the lowest coefficient for R&D size as percentage of company size (C2) equal to 0.11 indicating that the R&D size compared to company size need to be change 10% in order to have 0.01 effect to the importance of the specific metrics.

These results are fairly rational in this case too, since salary policy is tightly connected to HR and higher management, R&D cannot really affect this policy, even the choice to hire experienced professionals that they may require to be paid higher salaries is not a decision affected by the R&D operation itself. In terms for accumulation of knowledge and expertise, it is not up to R&D to accumulated it, only to build new knowledge and expertise for the company. Even in the case of an employee leaving the company, Operations department can create procedures to make all knowledge less people centric, keeping the company growing minimizing the effect each individual employee has in this field. In the end, actual vs target revenues and profit are some cases that R&D cannot impact as well, of course the products must comply with customers' needs, but the responsibility of selling them and the pricing policy are more of a Marketing or Economical issue.

6. Theoretical and Managerial Implications

As mentioned in the previous chapter as well, this approach connects the organizational performance with the company attributes through their significance for the R&D department, hence it is possible to draw conclusions directly affected by the R&D department, without including any information for it, except its size compared to the company size.

By using the equations resulted by the regression analysis, a manager could choose the most important metrics for their company and by using the company attribute variables determine changes required to affect the selected metrics in a proper manner, by setting expectations as goals and act accordingly to achieve them.

For example, in order to improve some metrics a company could choose to restructure its R&D department and hence change its performance for the metrics chosen.

Another approach, is to use the rest of equation (4-1 to 4-21) in order to directly affect R&D performance, or organizational performance using the R&D metrics. The choices and combinations a manager can make using these equations are in fact unlimited since such a large number of diverse variables is used.

Of course, there are limitations and more specific parameters that could not be included in these models. One of these limitations was briefly mentioned in the previous chapter, specifically, while all the positions are important for the smooth business operation, some positions may have different weight in their effect than others depending of the area the regression models are applied. For example, in terms of product defects, by taking into account the size of the company, the designer of the product has definitely significantly greater effect than a logistics employee, hence these models can provide a useful estimation, but a critical approach of the data input to the them is also essential in order to return accurate results. On the other hand, while computing the actual cost, comparing it with a budget for released product, the same logistics employee can play a much more important role than the product designer.

In conclusion, the models can provide with useful outputs, capable of greatly improving the performance metrics of a company, provided they are used properly and the input in them is in line with the expected output. This is the greatest challenge for a manager using these models, to completely understand and make the best use of the equations resulted in order to produce the most useful results.

7. Conclusions

The research conducted above has led to useful information, offering great opportunities for further studying the topic and eventually be a useful part for industry as well.

As for future work, there is great potential for using the conducted analysis in order to build tools for management in which the company status along with the desired position could be entered and in an automated way, a course of action would be recommended in order to approach better the set goals. The said tool, could be built as standalone or even as a plug-in for numerous systems assisting management nowadays and it could include more sector-specific information, aiming to meet a company's specific needs in comparison with a more generic model and allow the possibility of actions.

The described tool could also evaluate choices made by managers if they are included properly and keep improving its performance and suggestions without violating any privacy policies.

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