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A new constraints framework for International Project Management: practices in *Lechler*

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"errant consilia nostra, quia non habent quo derigantur; ignoranti quem portum petat nullus suus ventus est.".

- Our plans miscarry because they have no aim. When a man does not know what harbour he is making for, no wind is the right wind.

L. A. Seneca. *Moral Letters to Lucilius*. Letter LXXI: On the supreme good, line 3.

TABLE OF CONTENTS

Introduction

Is project success not a question of chance, is it? Nowadays companies need to manage more and more projects internationally to compete in a global market influenced by rapid changes, high risk, innovation and time to market. The project is fast becoming a mode of business in itself, particularly for large-scale and highly risky projects carried out for internationalisation. Companies (especially the smaller ones) lack of suitable tools to manage those international projects and the risks related, fail to turn internationalisation into a competitive advantage. Project management means managing a project, like an intervention of internationalisation, using a methodology defined by logic and analytical rules in order to guarantee its success without leaving anything to chance. Project management is a methodology (application of knowledge, skills, tools and techniques) that improves the ability to plan, implement, and manage different cross-functional-activities, balancing the project requirements of time, cost and quality to realise the scope of the project. However, regarding these project pillars, the project success and its performance, different frameworks have been applied in the discipline and the standards provide a vague definition.

The purpose of this work is to present the *science of project management* as analytical discipline to manage a project increasing the probability of its success, especially considering *large-scale international operations* full of complexity and uncertainty. In particular, a clear defined *project management methodology*, based on the project management standards, is studied for practices by leveraging on *analytical tools*. This new theoretical framework is applied to a *real case project* which I have personally implemented in a foreign market during my internship experience in the multinational company *Lechler* in the summer of 2014. What stands out is trying to clarify what is intended for *project success* and *performance* by unifying into a mathematical formula the *pillars of project management*. This framework suggests how to link the project success to the concept of scope that in turn is influenced by the project pillars quality, cost and time. It provides a *mathematical model*, in line with the project management

standards and practices, in order to maximise the project scope by obtaining the optimal values for time, quality and cost depending upon their priority over the project. A *function to describe the concept of quality* is presented and a quantified and consistent measure of the project priorities is obtained by leveraging on the application of the *Analytical Hierarchy Process*. However, in carrying out large-scale projects, the risk is a relevant issue impacting over the project success and then it has always to be on the radar of the project manager. Then, a clear defined *project risk management methodology* is defined and applied to the case study. The real case project studied has been carried out by the company without being framed in a clear and logical methodology but now thanks to project management it is possible to frame it by showing how this discipline can be really useful for the successful implementation of a project. Tangible results can be tracked if future projects leverage on project management. Data and assumptions are gathered through interviews to the main project stakeholders. Moreover this work is developed by complying with the standards of The Project Management Institute (2013) and by leveraging on interviews with professional project managers and on a wide spectrum of bibliographic research.

The first chapter introduces the concept of *International Project Management* developing and elaborating the universally recognised project management standards and providing a theoretical background about themes as internationalisation, international projects, the broader context in which they are carried out, their management and the key role of the project manager by showing how project management is a concept already awarded in the ancient times. The second chapter provides a theoretical background over the *project pillars* and their role as project constraints, clarifying what is intended for *project success* and *performance*. Then, a mathematical model to unify the project pillars and to find the optimal project success is provided. The *Multi-Criteria Decision Analysis* is presented as analytical tool in order to assess consistent values to the project priorities and a formula to measure the project performance is provided. The third chapter develops the practices for project management by providing a project management methodology to frame *Lechler* real

case project. It leverages on the *Project Scope Statement*, *MCDA*, *WBS*, *Critical Path,* *three-point estimating, PERT* analysis, *Crashing Costs*, *Earned Value Management* and the *new constraints framework* developed in chapter 2. The last chapter develops a model to manage *project risk* and its application to the case study.

1. Project Management to support internationalisation

"It's not clear exactly what the future holds for project management, but with challenges such as globalization, diminishing resources, and increasing population there is no more fitting vehicle for managing such issues than project management".[1]

Internationalisation means breaking the value chain globally, taking a set of non-ordinary activities performed in different geographical regions and it denotes engaging in a set of projects internationally. For a company it is necessary to manage more and more projects internationally to compete in a global market influenced by rapid changes, innovation, high risks and time to market. The project approach dictates the style of the business in particular considering large-scale projects carried out for internationalisation such as a construction of a new plant abroad, international marketing of a new product, implementation of IT software in a foreign market. Nowadays project management has spread to many kinds of projects and project teams carry out everything from market expansions to product creation. Most companies, especially the smaller ones, do not have proper tools to manage those international projects and it is underlined by a lack of a suitable methodology that leads companies in failing to turn internationalisation into a competitive advantage. Project management means managing a project, like an intervention of internationalisation, through a logical and organised approach that favours problem solving in a planned and scientific way, using a methodology defined by logical rules. This chapter relates to the analysis and the study of project management in supporting internationalisation defining a methodology to sustain companies in the management of the interventions of international development (international project management). In particular, this project-culture should be really considered and developed by small and medium-sized enterprises that want to expand and to grow abroad.

An indicator of project management demand can be tracked by the rapid expansion of the Project Management Institute (PMI)[2], by the largest companies that just organize

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[1] Seymour et al. (2014).

themselves with a methodology to successfully carry-out a set of projects, by the increasing business periodicals and articles related. Also by the raising of project management associations as the International Project Management Association[3] or the Associations of Project Managers[4] whose aims are to develop and to promote the figure of project manager as a professional branch of knowledge. The fundamentals of this methodology are considered universal so it can be applied for every kind of project: to develop a new product, to create a new service, to organize an event and so on. Understanding and adopting this methodology is really useful for a company.

This chapter introduces the concept of international project management developing and elaborating the universally recognised project management standards provided by Project Management Institute (2013) and cited in almost all project management books with the support of an accurate bibliographic research[5] as well some interviewees to professional project managers[6]. A general snapshot of re-elaborated concepts as international projects, international project manager, the management of international projects and its broader context in which is carried out is provided.

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[2] It was founded in 1969 as an international society of project managers and it is a professional organization for project managers which membership has rapidly increase to more than 270,000 members currently. Its professionals come from every major industry from more than 125 countries. This organisation has published the Project Management Body of Knowledge Guide (PMBOK® Guide) that provides the project management standards and it is used as study to get the certification of Project management Professional issued by the same organisation. The number of certifications has grown a lot during the years covering more than 350000 certified project managers in the end of 2009.

[3] The International Project Management Association (IPMA) has published its standards of project management practice in the ICB-IPMA Competence Baseline (2006) this association, composed by a membership of organisations coming from 45 countries, was founded in Vienna in 1965 and it has involved more than 40,000 members in 2007. It provides four levels of project manager certifications and it also publishes a scholarly journal named the International Journal of Project Management.

[4] The Association of Project Managers (APM), based in United Kingdom with more than 10000 members and 40 countries, has promulgated its project management standards of practice by the APM Body of Knowledge (2006).

[5] Binder (2008), Grisham (2011), Larson et al. (2011), Lientz et al. (2003), Altese (2013), Rodriguez et al. (2010), Kwak (2005), Seymour et al. (2014).

[6] See appendix A where interviews are called.

1.1. A first glance on internationalisation

Globalisation has evolved during the last decades and in line with it, companies have to adjust the way they compete and collaborate in this changing environment, coping with their business operations. Globalisation is a process of economic, political, social and cultural integration. It encompasses the growth of economic interdependences among countries with the flow of goods and services, capital and know-how across the borders. It aims at standardising trade, culture, customs and thinking, along with making the information, ideas, know-how available everywhere to everybody, hence in overall terms "*levelling the playing field*". However different perspective should be adopted in order to cope with it.

''*Some writers in this vein view globalization as a good thing-an escape from the ancient tribal rifts that have divided humans, or an opportunity to sell the same thing to everyone on Earth. Others lament its cancerous spread, a process at the end of which everyone will be eating the same fast food*".[7]

On one side globalisation should be seen as a phenomenon of world flattening in terms of integration between institutions, societies and economies. Mainly present through the flux of trade, financial flows, knowledge and labour across international borders where cultural and physical distance no longer influence the flow of goods, services, capital and know-how. Business and individuals are the driving force that flattens the world, powered by digitalisation and new technologies. Digital tools change the way people interact in a less expensive and a more accessible way, in a flat world within which geographical boundaries are of little significance for businesses powered by digitalisation that go global for labour and market. The value chain is broken down globally and the slogan sounds to be "*let's move the work around!*". Firms increase their market presence by developing their supply chain internationally. They also reach efficiency by off-shoring those activities that can be done where costs

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[7] Ghemawat (2007).

are low. Furthermore firms out-source the work to those who have the required skill-set sounding the slogan: ''*Work gets done where it can be done most effectively and efficiently*''.[8] The speed at which the world has become so-called "*flat*", is way beyond the capacity at which people had realised: ''*[..] I think the world is flat. [..] I realized this flattening had been taking place while I was sleeping and I had missed it [..]*''.[9] This rapid transformation is due in major part by digitalisation and the rapid advancement of technology. Fifteen years ago, having an android phone to chat around the world was unimaginable by those teenagers that now (no longer teenagers) are using it to chat with people worldwide.

On the other side, an opposed viewpoint about globalisation should figure a world still *round* where, even if geographical boundaries can be broken, it is more difficult to do so. Namely by considering political, social and culturally broader dimensions in which the critical role of national cultures and narrow-minded nationalism create barriers to globalisation.[10] Over the past decades consumers reacted to an overdose of standardised global products, demanding for differentiated goods while national governments introduced a variety of regulations to manage these globalisation trends in the name of national interests to retain or attract business operations. If business believes that borders do not matter, it will fail in following strategies that not consider local needs, institutional, cultural and geographical differences. It is needed to recognise "*the barriers between countries as well as the bridges between them*"[11]. A business that operates worldwide has to understand and leverage on cultural differences across countries, respecting the cultural distance and not passing over it by claiming that everything can be sold in the same manner to everybody and everywhere worldwide. What is also of importance is recognising these differences and understanding them in a way that is more constructive than destructive.

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[8] Friedman (2005).
[9] Friedman (2005).
[10] For more details, see Stephens (2014), Van Genderen (2013).
[11] Ghemawat (2011).

The rate of change in the international market continues to increase, supported by digitalisation, internet accessibility, connectivity and the speed of global business. Globalisation is shaping the demographics of the world, where knowledge and skills are available worldwide. Low-cost resources in developing countries can be exploited for efficiency gains and market accessibility allowed to increase the global presence, providing significant opportunities for organizations that benefit from this flexible global competition. In a world where the markets are becoming global and in which physical distances are shortening at the same time to compete on a large scale, it is crucial to harness the potential of project management that impacts on business. Companies have to understand that now it is time to break the value chain globally embodying in a series of projects within different geographical regions. On the background of internationalisation, the project is fast becoming a mode of business in itself in order to compete in a global market influenced by rapid changes, high risk, innovation and time to market. Nowadays project management has spread to many kinds of projects and project teams carry out everything from market expansions to product creation. Though, most of the time those projects are mismanaged and most companies, especially the smaller ones, do not have proper tools to manage those international projects and it is underlined by a lack of a suitable methodology that leads companies in failing to turn internationalisation into a competitive advantage. Project management means managing a project, like an intervention of internationalisation, through a logical and organised approach that favours problem solving in a planned and scientific way. It is useful to capture those non-ordinary international operations, into a logical methodology defined by clear standards to carefully manage them in order to increase the probability of success. In particular, the following chapters will help to provide an in-depth understanding of this matter.

1.2. International Projects

The Project Management Institute defines a project in its PMBOK Guide, as a "*temporary endeavour undertaken to create a unique product, service, or result*"[12].

The temporary nature of the project just emerges in this definition meaning that it has longevity (from short - as in some days - to large - as in some years-) with a definite beginning and end, terminating when the project's scope is achieved or, in overall terms, when the need for the project no longer exists.

It also emerges that the outcome of the project is a unique product, service or result that cannot be met with an ongoing work effort (an ordinary and repetitive organisational process). Most certainly, to reach a non-ordinary result it is needed to carry out a non-repetitive and non-ordinary process that do not follow the exiting procedures of an organisation, involving a set of cross-functional-activities and different organisational hierarchical levels as well as departments. All those characteristics (time-constrained, unique outcome, unique process) just differentiate the project from a process, like the manufacturing one. Examples of projects are the development of a new product or service, the improvement of a modified information system, the construction of an industrial plant. Even the Roman bridge over the Rhine built during the fifth Gallic campaign by Roman legions is an example of a project.

Furthermore, according to the International Project Management Association, "*a project is a time and cost constrained operation to realise a set of defined deliverables (the scope to fulfil the project's objectives) up to quality standards and requirements*"[13]. Here it emerges, as stressed in PMBOK Guide, that a project has to balance and respect the four constraints of time, cost, quality and scope. In addition it means achieving the project objective (aligned with the strategy) in a specified range of time, within the budget and respecting the quality standards preset – the latter refers to the technical or non-technical quality requirements that the project outcome needs to ensure, as well as the proper quality performance in order to satisfy the stakeholders' needs to which the project is targeted.

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[12] Project Management Institute (2013).
[13] IPMA, I. (2006).

Project managers are required to manage those constraints that rely on time, cost, scope and quality. The constraints idea has been a framework for project managers to evaluate and balance these conflicting requirements. It has become a way to track and monitor project progress and its success.

In a methodology of project management the constraints of scope, quality, cost and time have to be just defined in the project charter and managed over the project lifecycle. The project charter is the document that formally authorises the project once approved by the major stockholder involved (in this case the organisation having the major interest over the project and becoming its sponsor) and it gives to the project manager the authority to plan and to execute the project. This charter provides the formal existence of the project and the boundaries in which has to be carried out, figuring the requirements of time (providing a deadline), cost (providing a summary budget), quality (providing high-level requirements) and scope (figuring its purpose to satisfy the major stakeholders' needs) that a project manager has to understand, for an efficient resource allocation to project activities.

When a project is outsourced to an external organisation, the project charter becomes a formal contract and here the project turns on a so called *project on commission*: it is outsourced by a company, when there are specific requirements, from another one specialised in the project management field, to directly manage and carry out the project. It is a different case than a company that has just embraced project management as a key function carrying out different projects and so managing a portfolio of projects whose scopes are aligned with the business strategy.

The concept of a project has been defined but now what is an international project? Here are a few exemplary definitions:

- "*International project – a unique, transient endeavour undertaken to create a unique product or service that utilizes resources from, or provides product or services in, more than one country*".[14]

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[14] Grisham (2011).

- *"International projects require the collaboration of people from different country cultures and languages, sometimes with the added complexity of the locations over various time zones".*[15]
- *"An international or regional project is a project that involves multiple locations, entities, organizations, and business units".*[16]

So, basing on some non-standard definitions, a project becomes international when it encompasses national boundaries involving more than one country. And by doing so, it embraces a large-scale dimension with the involvement, in various locations, of multiple business units that diverge on organisational assets and cultures. It includes different cross-cultural stakeholders, involving high risk, complexity and uncertainty, whilst embracing high costs and extensive input of time. It also has to tackle differences in national security, politics and legislation, as well as in technological advancement, society, culture, economics and marketplace conditions. In addition, there is the geography and environment (e.g. time-zone and infrastructures), thus creating complex projects in a complex environment.

Figure 1: Set of dimensions faced by International Project.

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[15] Binder (2008).
[16] Lientz et al. (2003).

However, it is a project and, as such, it reflects the methodology of project management. Therefore, its success depends on satisfying the quality outcome, reaching the scope within the budget and within a specific range of time, but it becomes international, embracing a global dimension and not just a local one. While managing project constraints in an international environment is necessary, it is not sufficient. The projects that are delivered on time, within budget and scope and meeting the specifications are not necessarily perceived as a success by the main stakeholders. Even though an international project has to be managed over long-term sustainability and here the knowledge area of project quality management takes relevance on ensuring that project quality requirements as well as its outcome quality requirements are met and validated. *"If the project is not conducted in a sustainable way, or the product project is not sustainable, then society and history will judge it a failure"*.[17]

The pressures pushed by globalisation have turned the focus on sustainability. Globalisation faces economic activities across borders that impacts society and the environment. Despite the efforts on ethical and social regulations provided by transnational organisations as United Nations, ethical and social inconsistencies spill over in the international markets forcing organisations to define their own standards for the environment and the societies within which they carry out their activities. Sustainability and ethics are a central issue between the society and the organisation that carry out an international project, so an organisation has to focus over this matter adopting sustainable business practices through a clear CSR[18] because the business cannot just aim on maximizing the profit at the expenditure of the environment. Furthermore, a business lacking in social responsibility in the name of economic interests, ought to consider the alternative view: *"developing a product or service for the wellbeing of the current generation, without compromising the wellbeing of the future generations"*[19] .

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[17] Grisham (2011).
[18] CSR refers to the Corporate Social Responsibility.
[19] Holland (2014).

In overall terms, combining the definition of project with its international dimension, one can define an international project not as a routine, but instead as a large-scale set of temporary, non-ordinary and cross-functional[20] activities, which carries out a unique outcome in an international and complex environment, respecting the constraints of quality/scope, cost and time.

However the project idea and its management practices based on managing the project constraints are not so new. Despite the terminology used is relatively recent, it is not difficult to realise that in human history, the role of project manager has been covered (perhaps unconsciously) already in ancient civilisations. History can figure many examples of challenging projects successfully completed, despite their complexity and uncertainty. Many of these projects needed a large workforce and resource commitment, large scope and extensive labour time, as well forward planning, accurate execution and constant monitoring. Some case examples for the application of project management methodology, dealing with time, resources and scope in Classical times, is mentioned by *De Bellium Gallicum*.[21]

In paragraph XVII of Book IV Julius Caesar describes the technical and organisational details of managing time, scope and resources for the successful construction of a bridge over the Rhine during the fifth Gallic campaign. Its creator, Julius Caesar, was the one who, at that time, held the role of project manager. There is no doubt that such an extraordinary effort, according to modern standards of project management, would be considered as a project. It is sure that the creation of this strategic work, like many others during ancient times, was not the daughter of improvisation: Caesar was undoubtedly clear about the objective and how the construction would have helped (project scope), as well as how it should have been completed (project quality). Caesar planned the work and the number of people who, over a period of time, would be committed to build the bridge (project resources and their cost), whilst trying to optimise the timing for the completion of the work (project time). In Ancient Times, the *PERT* analysis, *Critical Path* method and all those analytical tools for managing a

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[20] It means that the activities of a project involve most organisational hierarchical levels and departments.
[21] For more details, see Cesare, De Bellio Gallico, IV, 17.

project were not imaginable for sure, but beyond those arguably clear project management tools, there was the logical idea of managing a project. Throughout history, experts worked on improving and refining the project management practices and only half a century ago, organisations had started to leverage project management tools and techniques to complex projects.

Especially during the era of globalisation, firms (in particular the large ones) have experienced an explosion of large-scale, internationally based projects, breaking their value chain globally: "*Most multinational organizations have well established international value chains, but many firms must create them project by project*".[22] The value chain can be broken internationally by carrying on international projects and its likelihood of success is incremented by applying the methodology of project management and its practices developed during the years. Some examples include those firms searching for efficiency gains by off-shoring production or by implementing IT systems in their foreign business units. In some cases, it is in searching for new geographical presence by establishing new subsidiaries in foreign countries or in increasing global market power by developing a new product. "*Project management is no longer a special-need management. It is rapidly becoming a standard way of doing business.[..] An increasing percentage of the typical firm's effort is being devoted to projects*"[23]

What kinds of projects are carried out internationally? This question is outlined in a survey[24] that considers data about international projects.

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[22] Grisham (2011).

[23] Larson et al. (2011).

[24] This survey is reported in this work because it considers the only available data about projects carried out internationally by 85 Austrian companies of different branches and sizes. For more details, see Pool2Business (2009).
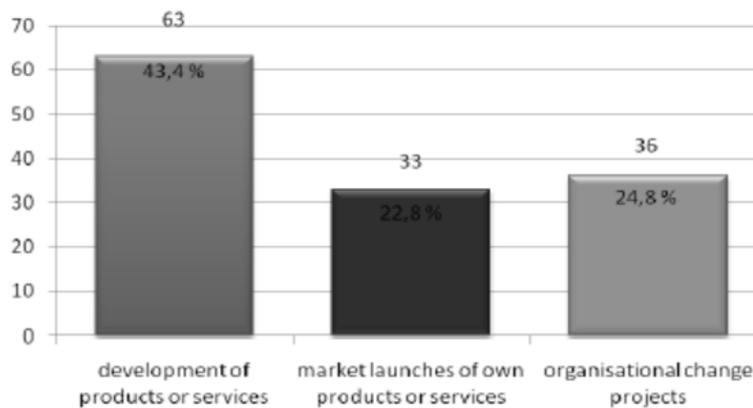
Figure 2: Projects carried out internationally.

The results show that the development of products and services is the major type of project carried out internationally covering 43,4% of the surveyed firms, followed by in-house change projects covering 24,8% (as a process development or a software rollout, HR projects or organisational development) and finally by market launches of own products or services with 22,8%.

In those international projects, the purpose of an organisation becomes more complex for many reasons: searching for efficiency gains, assessing too scarce or unique resources, geographical diversification, increasing global market power or presence. Any of these factors can vary according to the company's needs.

In particular, international projects are utilised to achieve those organisational objectives within an organisation's strategic plan.

A presence abroad can only be guaranteed if strategically managed and here the integration of international projects with organisational strategy emerges, so a project seems to be the *modus operandi*[25] to implement a strategy. International projects create business value helping the company to grow and the value created will be greater to the extent in which the organisation will be able to create a competitive advantage and to support it during time. However they help to achieve the organisational strategic goals if they are aligned with the strategy of an organisation.

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[25] Larson et al. (2011).

This is even more so if there is an organisational culture that grabs project management as a key function. Unfortunately, this mind-set is lacking in smaller companies, as they do not consider project management methodology as a valuable function. Bigger companies have just embraced this approach as useful practices to reach their scopes, understanding the importance of these logical tools.

It is truer competing in a global market influenced by innovation, rapid change and time to market: "*short life cycles has become increasingly important. Speed, therefore, becomes a competitive advantage; more and more organizations are relying on cross-functional project teams to get new products and services to the market as quickly as possible*"[26] and the way to ensure that things get done, is by managing projects.

Nowadays, more and more projects need to be managed for a successful implementation with the aim to translate in action the organisational strategy to achieve long-term goals. However, if many projects need to be carried out to achieve the strategic goals, they have to be prioritised in a project portfolio in which a ranking is needed to best suit organisational needs. In turn, implementing projects will support the long-term organisational mission and the purpose of the project portfolio is to better align the projects with the strategic goals. So, they have to be prioritised in accordance with different criteria. This would be mainly grouped into financial (when the financial return of the project is strategically important) or non-financial criteria (when the return of the project is more aligned with other strategic criteria such as capturing larger market share, developing core technologies, reducing dependency on suppliers, and so on).

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[26] Larson et al. (2011).

1.3. International Project Management

Now the concept of an international project has been discussed, what does international project management refer to?

The same PMBOK guide points out that "*Project management is the application of knowledge, skills, tools, and techniques to project activities to meet the project requirements*"[27].

Project management is a methodology (application of knowledge, skills, tools and techniques) that improves the ability to plan, implement, and manage different cross-functional-activities, balancing the project requirements of time, cost and quality to realise the scope of the project. This is in line with the objective of business strategy, and so project management truly becomes a critical strategic discipline.

It is a role across-the-board involving multiple business functions and hierarchy levels for a common purpose: resources are shared by different functional departments and are channelled to be governed by a project manager and an example is the project team whose members come from different organisational departments. However, one needs to understand which process activities are governed on which project, those that are non-routine activities as handling a production reallocation project with a specific beginning and an end. Compared to those that are routine activities, which are repeatable as in a manufacturing process and have no clear beginning or end.

To ensure the effective project flow along its lifecycle, a project management approach is needed. Specifically, to govern, integrate and implement its interlinked processes that overlap and share in different interrelated[28] knowledge areas in an iterative way. The knowledge areas of project management interrelated with the process group are illustrated in figure 3[29].

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[27] Project Management Institute (2013).
[28] The relationship between the knowledge areas is that if a factor changes, at least another one is influenced. For example if the project scope is enlarged, the end result of the project will be reached with more cost or time effort and furthermore more risks will be assessed, impacting the project.
[29] Project Management Institute (2013). Considering the knowledge area *Procurement Management*, *procurement* refers to the outsourcing of the activities and then this knowledge area consists on the identification, selection and management of the project contractors. It is important to carefully monitor the performance of the contractor chosen.

Knowledge Areas	Project Management Process Groups				
	Initiating Process Group	Planning Process Group	Executing Process Group	Monitoring and Controlling Process Group	Closing Process Group
Project Integration Management	Develop Project Charter	Develop Project Management Plan	Direct and Manage Project Work	• Monitor and Control Project Work • Perform Integrated Change Control	Close Project or Phase
Project Scope Management		• Plan Scope Management • Collect Requirements • Define Scope • Create *WBS*		• Validate Scope • Control Scope	
Project Time Management		• Plan Schedule Management • Define Activities • Sequence Activities • Estimate Activity Resources • Estimate Activity Durations • Develop Schedule		Control Schedule	
Project Cost Management		• Plan Cost Management • Estimate Costs • Determine Budget		Control Costs	
Project Quality Management		Plan Quality Management	Perform Quality Assurance	Control Quality	
Project Human Resource Management		Plan Human Resource Management	• Acquire Project Team • Develop Project team • Manage project Team		
Project Communication Management		Plan Communication Management	Manage Communication	Control Communications	
Project Risk Management		• Plan Risk Management • Identify Risks • Perform Qualitative Risk Analysis • Perform Quantitative Risk Analysis • Plan Risk Responses		Control Risks	
Project Procurement Management		Plan Procurement Management	Conduct Procurements	Control procurements	Close Procurements
Project Stakeholder Management	Identify Stakeholders	Plan Stakeholder Management	Manage Stakeholder Engagement	Control Stakeholder Engagement	

Figure 3: Map of project management process group interrelated with the knowledge areas

Project management process groups can be categorised into five process groups:

Initiating

One must consider all the processes to start a new project phase or a new project obtaining the related authorisation. Initiating a new project, the stakeholders are identified in the stakeholders register, the project statement of work has referenced the business need, the project outcome and its alignment with the strategic objective and the project charter is developed by the sponsor of the project (the project initiator). The project manager is selected, the constraints of time, quality, cost and scope are issued and the initial financial resources are committed, after that the business case has to determine whether the project is worth the required investment. The project is authorised after that the charter is formally approved. The initiating process could be revisited if important changes occur during the project lifecycle.

Planning

It consists of all those processes to establish and refine the scope and define the course of action needed to reach it. Feedback is needed for additional analysis and to revisit the actions planned when significant changes occur during the project lifecycle. The path of action to carry out the project is carefully planned, designing the route to reach the objective. At this point the project management plan is defined, containing the plan for each knowledge area to carry out the project: scope, quality, time, cost, human resources, communication, risk, procurement and stakeholder. Updates arise in the management plan when changes occur identified by monitoring and controlling group processes during the lifecycle. The knowledge areas are interrelated such that if a factor changes, at least one other factor is likely to be affected and so the development of project management plan is an iterative and ongoing work effort during all the project lifecycle. It is a progressive elaboration for continuously improving and updating to manage and define work with a great level of detail.

Executing

This group of processes consists of performing the work designated in the project management plan, to meet specific deliverables and project requirements. It consists on managing people and resources, stakeholder's expectations and all those activities in compliance with the project management plan. If changes occur during the project execution, the project management plan needs to be updated because time, quality, risk or other variables could be altered.

Monitoring and controlling

This group of processes consist of tracking, reviewing, and reporting the progress of the project to meet the performance objectives defined in the project management plan.[30] It allows to track and to measure performance information for continual monitoring in order to take preventive or corrective actions and to identify those areas where change is needed. The aim is to resolve the performance issues. It refers to a continuously controlled project during its lifecycle for corrective or preventive action to possible problems. Moreover, at the end of the most relevant activities (during specific phases of a project lifecycle) there are formal gates, which are formal control points, used to monitor the project performance and its progress. In those points of project review, project time, cost, scope and quality standards are tested. Normally those formal checking points for the project review coincide with milestones[31]. Therefore, it is necessary to establish metrics to measure the progress of each activity and thereby the entire project. The metrics of the project are a set of indicators aimed at monitoring and predicting the trend of the main critical variables of the project (cost, time, quality, scope). Earned Value Management is a technique that combines different key-measures of the activities to gauge project performance over its baseline

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[30] Project Management Institute (2013).

[31] A milestone is a significant point or event in a project that represents a moment in time and so it has zero duration. For more details, see Project Management Institute (2013).

tracking divergences over cost and time schedule. It helps to figure out if the project is going over or under the budget as well behind or ahead of schedule. Using the technique of the EV, the Project Manager will have a number of effective indexes to evaluate and communicate the performance of the activities and of the project. This will allow him to act quickly and in a targeted way even on projects of considerable complexity and duration. This monitoring technique will be discussed and applied in the case study.

Closing

These are processes to complete the activities occurring in the project management process group and to complete and close all the contracts applicable to the project, including the resolution of any items. The aim is to formally close the project or phase as well as contractual relationships.

It is crucial to note that *"The Process Groups are not project life cycle phases"[32]* because the five process groups can run within a single phase (a set of sequential activities) as well over the entire project (a set of sequential phases).
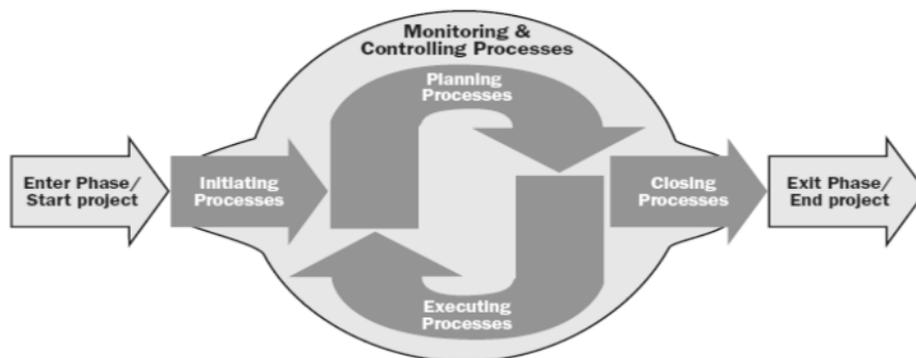
Figure 4[33]: Project Management Process Group.

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[32] Project Management Institute (2013).
[33] Project Management Institute (2013).

However managing a project internationally does not only mean applying a standard methodology, it is more: "*International project management is the leadership of projects that are conducted in multiple countries and cultures*"[34]. As the word *leadership* suggests, international project management is more than just a set of practices and tools, it considers a technical dimension as a socio-cultural one and it becomes truer in a globalised context where a difference gap increases.

The technical dimension is the science of project management involving the managerial practices to conduct a project. It is the technical side of project management that includes the formal and logical processes of planning, scheduling and monitoring projects. It refers to the so called "hard-side-skills" (e.g. analytical thinking, logical activities, control and reports) for the management of the nine PMBOK knowledge areas [35] : time, cost, scope, quality, integration, communication, procurement, human resource, risk, stakeholders.

The second dimension is the art of managing a project, it is the opposite dimension and it considers its socio-cultural side. In contrast to the first one, it alludes on the world of project implementation relating to the soft-side-skills that a project manager needs to have (e.g. leadership and motivation). It is the means of leveraging them to create a temporary social system within a larger organisational environment that combines different skills, cultures, interests, expectations and knowledge of different groups of people from various organisational entities in different countries involved in the project. As well a project manager, leveraging on his soft-side-skills, he needs to shape a project culture inside the team, stimulating the teamwork. He also needs to manage the interface between the project and external environment (working on the expectations of customers, negotiating with functional counterparts, stimulating and persuading all the parties involved, and so on) building a cooperative social network – mutually benefit alliances governed by law of reciprocity - of people with different standards, commitments, and perspectives in different cultural contexts. The management style approach varies across nations and cultures and here the role of an

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[34] Grisham (2011).

[35] A knowledge area is a professional specific field of project management science grouping tools, techniques, concepts and activities to manage a project. For more details, see Project Management Institute (2013).

international project manager emerges as the figure able to mix the both sides, adapting a cross-cultural managerial approach to successfully carry out a project internationally.

1.4. Project Manager as a key player

The PMBOK defines project manager as *"the person assigned by the performing organization to lead the team that is responsible for achieving the project objectives"*[36]. The definition outlines that a project manager is the link between project team and project scope that in turn is aligned with the organisational strategy so its role becomes of strategic importance. This strategic figure performs the same functions of other managers, that is to plan, schedule, motivate and control, but what makes it to stand out is the managing of non-ordinary, non-repetitive and temporary activities completing a project cycle that is fixed. Moreover the role of a project manager differs from that of a functional manager and operation manager. The functional manager takes over existing operations of a business unit managing its existing processes. Operation manager oversees, directs, and controls day-to-day business operations. It normally deals with the ongoing production (transformation of inputs like raw materials to outputs like goods in this example) ensuring their efficiency by using the optimal amount of resources.

Tradition shows that a project manager was usually employed within an organisation in the early years of project management as a strictly technical figure to plan the technical activities, without embracing other sides of management. He was born in a military environment in which technical requirements and carefully technical planning were really needed. One clear example is provided by Manhattan project as a prime example in utilising project management principles and tools (known at that time) to manage a large budget, schedule-driven projects and the technical military objective: building the atomic bomb.

"The Manhattan project on the other hand, was particularly important because many still consider it the beginning of modern project management"[37] applying for the first time the practices of this methodology (even if with poor analytical project management tools – *PERT* analysis and *Critical Path* method will be developed later for example). This R&D project born in 1939 which scope of building the atomic bomb was

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[36] Project Management Institute (2013).
[37] Seymour et al. (2014).

aligned with the objective strategy of defending the country from Germany possible future threats costing 125000 workers and about 2 billion dollars. It was tested on July 1945, a month before the atomic bomb was dropped on Hiroshima in Japan. However, the figure of project manager has evolved during the years becoming a figure with not only technical capabilities, but also managerial ones, being able to combine hard skills with the soft ones and becoming a good leader. A project manager has to be able to define the project in time, cost, scope and quality, allocating the right shared resources to govern and to reach the scope, managing the budget, organizing the activities, managing the risk as well the team and the social system involved in the project. Furthermore, his talents lie in leading, communicating, motivating, influencing, negotiating, solving problems, being proactive among all those soft and hard side skills needed to be a good manager. In overall terms the project manager becomes a mini-entrepreneur in the enterprise, being the figure responsible to orchestrate the overall project ensuring reasonable trade-offs between project time, cost, scope and quality as well leading the team.

For the successful completion of international projects, an international project manager has to harness his cross-cultural leadership side and the soft skills related (creativity, intuition, leading, motivating, communicating, persuading, and so on). And balance this talent with his technical capabilities related to the hard skills (analytical thinking, scheduling, monitoring, planning and so on) to orchestrate the project, by managing it in its broader international context. In a globalised context, culture becomes a critical factor that really influences the success of a project and a project manager has to be equipped with multicultural skills trying to embrace other cultures to make them favourable because "*trying to complete a project in a toxic culture is like paddling upstream*"[38]. An international project manager is involved in different locations working with culturally different mind-sets around the world, from the workers of a foreign business unit to the project customers of another foreign country. As well as different suppliers, vendors, regulatory agencies and governments and in general the different cultures of all those people or entities related to the project. A

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[38] Larson et al. (2011).

cross-cultural leadership is needed in managing a project overseas because there are deep cultural differences and it requires balancing different needs, values, beliefs, common traditions of different cultural backgrounds. Cultures vary internationally but they also vary within a country, within groups and within organizations. In some systems, the intentions of individuals are expressed; the meaning is explicit, while in others intentions are more taken for granted without being explicitly expressed. Navigating the cultural complexity of the international marketplace can be a demanding task, but to be successful, an international project manager must reason with this diversity.

1.5. The broader environment of a project

The PMBOK Guide goes on: "*Projects and project management take place in an environment that is broader than that of the project itself*".[39]

To ensure that the project is carried out in line with the organisational objectives and managed in line with the organisation's established practices, one needs to realise the broader context.

The core elements of this context, stressed by PMBOK Guide and re-elaborated in this case study to include internationalisation, are listed as follows:

Organisational influences

It refers to organisational culture, communication, structure and assets that influence the project:

- Organisational communication has to be effective especially in a globalised scenario, influencing how a project is conducted. Here a project manager has to develop the capacity to effectively communicate within foreign locations with all relevant stakeholders across the organizational structure to facilitate decision-making. With the rapid evolution of IT systems, communication over long distances is facilitated thanks to E-mail, text messaging, project servers, and electronic transfers in general. However international communication is not just a set of IT tools, it also faces a cross-cultural side. Culture affects communication in the verbal sphere where language is the tool (what is mentioned or spoken) as in the non-verbal sphere where the context is the meaning (what is hidden and needed to be interpreted). It is signalled by intercultural differences in the variety of cognitive styles and cultural values. Understanding the cultural differences is really crucial to effectively communicate with those involved in an international project spread across different countries and cultures, in order to absorb the surrounding conditions

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[39] Project Management Institute (2013).

of a project. An international project manager has to adapt to different environments, understanding its context. It is not about yes or no, black or white, acceptable on unacceptable, true or false: It is about balancing different cultural perceptions and understanding the meaning of each factor for a culture. "*Stories abound of poor communication as a major contributor to project failure*".[40] Project problems dealing with communication can be mitigated by relying on developing a communication plan within which it is expressed who, what, when and how the information will be exchanged, to control the flow of information ensuring the work information correctly flows between customers, team members, and other stakeholders without confusion.

- Organisational process assets refer to all those processes and procedures as well policies, plans and knowledge of the performing organisation to govern and perform the project. Examples are the practices and guidelines to conduct a project work fitting the organisation's set of standard processes and procedures or specific organisational standards such as policies. The knowledge of the organisation consists of its accumulation of historical information, lessons learnt and its knowledge base. Examples are project files, financial databases, issue management databases and so on.

- Organisational structure influences the interface between the project and the parent company referring to authority in the level of hierarchy, areas of responsibility, resources availability and in general how the project is conducted inside the organisational structure. A company in which project management is a key function, it is crucial to have a suitable organisational structure to guarantee the success of a project. Projects contradict the fundamental design principle of an organisation that in most cases is designed to efficiently manage the ongoing activities by breaking down complex tasks into simplified repetitive processes, but a project is not a routine, it is like *a fish out of the pond* in this environment. The organisational structure adopted

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[40] Larson et al. (2011).

relays in a continuum where at the opposite extremes there is a functional structure and a project structure. In the functional structure, each department does its project work independently from the other and has fewer interdependences. Resource availability is low and the role of project manager is not clear. In this structure the project is led by a functional manager. In the project structure, project departments are set, team members are co-located and resources are set to carry out the project - more interdependences - and the figure of project manager is assigned to manage the overall project. While between the two sides there is a variety of matrix structures. There is growing empirical evidence that project success is directly linked to the amount of autonomy and authority project managers have over the project.[41] However, it is based on what is best for managing a specific project. An interesting question would be: what project structure should be adopted by an organisation to carry out a project? It depends of several issues. Research[42] has identified seven factors that influence the choice of project management structure: project size, strategic importance, necessity for innovation, need for integration between departments, environmental complexity in the external interfaces, budget and time constraints and stability of resource requirements. The result is that the higher the levels of these seven factors, the more autonomy and authority should be given to the project manager and project team to successfully complete the project. Moreover, when carrying out international projects a difference between centralised and distributed structure has to be pointed out. In the first form, the virtual team[43] collaborates over distant locations with the project manager and they report to him using digital tools. He needs to coordinate and control the overall project far away, carried out in diverse and distant locations. In doing so he manages the resources available in different business units by leveraging on its experience with carrying out international projects and on digital tools. In the second structure, there are teams co-

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[41] Larson et al. (2011).

[42] For more details, see Larson et al. (2011).

[43] Virtual team identifies team members of a project scattered in different business units that report over distant locations to its project manager leveraging on digital collaborative tools.

located to carry out a project activity on a different site. However they are coordinated locally, reporting to local coordinators who are responsible for the assigned activities. In the latter case, the project manager needs to teach and train the local coordinators as well as meeting with them frequently to provide consistent monitoring of the overall project.

- Organisational culture refers to the cultural norms developed over time and shared among the members of an organisation. Each organisation has developed its unique culture and in practice it could be referred to mission, values, beliefs, motivation, code of conduct, work ethic, hierarchy, risk tolerance and so on. In particular it influences on a project's ability to reach its objectives and here a project manager plays an important role in understanding the relevant individuals of the organisation that take decisions. Those decision makers are the ones that the project manager has to work with, in order to establish an effective relationship to increase the probability of a project's success. In particular, in a globalised context, understanding the cultural differences, having a flexible cross-cultural mindset is crucial for a project manager that is involved in far-flung locations, working with different mind-sets and diverse cultures within foreign business units of a parent organisation. Here lies the interdependence between the parent organization, the business units and the project team to work effectively, reaching a flexible organisational structure and having an organisational culture that embraces the project management as a key methodology for project completion.

Environmental factors

In the PMBOK Guide those factors are grouped in *organisational culture* as *enterprise environmental factors* subsection. Here it is suggested that they be separated, stressing their importance for its wide influence on international project management. They include those conditions that cannot be controlled – or controlled in part by implementing mutually beneficial alliances, in particular those related to the political

side - by the project team influencing positively or negatively as well constraining the project carried out internationally. Those conditions vary according to the enterprise and environment as well as geographic distribution, facilities and resources, infrastructure, existing human resources, standards and regulations, marketplace conditions, political climate, stakeholders risk tolerance and so on. Project team has to understand the current conditions and its trends having effect on the project. In particular various books consider different environmental factors of the host country that can influence how a project is implemented.

Really, there are a lot of factors that potentially can influence the project implementation internationally and a project team that is internationally based, has to really consider those variables in selecting site location and implementing a project abroad. In particular it could be useful to gather those factors using different models like PEST (political, economical, societal, technological factors) analysis, SWOT (strength, weakness, opportunities and threats) analysis, PESTEL (political, economic, social, technological, environmental, legal factors) analysis and other variables of analysis. The main factors of a host country than can be gathered are politics and legislation, technological advancement, society and culture, economics and marketplace conditions, geography and environment, and it is suggested that those be combined with a SWOT analysis.

Project stakeholders and governance

Project stakeholders are all those individuals as well groups or other organisational entities involved in the project who impact or are impacted by its activities, decisions, outcome and so having different interests and expectations over it. Therefore they will influence the project having potential positive or negative impacts. An example is the leaders of a community that benefits from an international project of industrial expansion in a foreign country. In this case, facing economic benefits for the community in more jobs, infrastructure facilities and taxes. Here the project will be supported for sure by those individuals with positive expectations, increasing the

likelihood to complete successfully the project. However, stakeholder's expectations could vary and even compete, affecting in turn the project. In the project of the previous example, local inhabitants as well small business owners could be an obstacle for the project, influencing it negatively because they will be forced to accept generally unwanted changes in the local environment such as losing a property and being forced to relocate. The stakeholders have to be identified in a stakeholders register, effectively engaged and monitoring its engagement to understand and to analyze, over the project lifecycle, their level of interest, their power of influence, their degree of impact, understanding who needs a closer relationship or immediate attention. For this reason a governance of an international project is needed to manage the stakeholder's engagement, satisfying strategic organisational objectives and other stakeholder's needs. The project governance embodies structures, processes and a decision-making framework (defining acceptance criteria for deliverables, roles, responsibilities, response for issues, procedures, project lifecycle approach and so on) needed to manage the project during all its lifecycle aligning it with business strategy and ensuring the value of project outcomes. In particular a strict and careful governance is needed more when a project is of a large scale, internationally based with a higher risk. The role of project manager and project team is relevant in managing the various stakeholders' influences and balancing different expectations. They also have to understand their degree of influence and ensure a successful outcome that satisfies all parties, interacting in a cooperative and professional way with them and determining the project requirements. Examples of stakeholders are customers, sponsors, suppliers, contactors, business partners and government agencies. The project sponsor has a key role in the project, it is he who has most interest in its success, and normally it deals with the top management of the organisation. It should be noted that a stakeholder involved can have different level of responsibility and authority that could change during the project lifecycle as well as their involvement. For example, some occasional stakeholders, like a contractor, can have different levels of hierarchy, involvement and authority during the project

lifecycle compared with the project sponsor who provides financial, political and other support.

Project Team

Project team refers to the group of individuals acting together to perform the project work and to achieve the project deliverables managed and lead by project manager to deliver successfully the project. Its composition is a function of organisational structure that can rely on two sides: functional organisation or project organisation. In a project organisational structure a special project dedicated team is created to carry out the project and it is a full-time involved staff from different functional departments that develop its own set of operating procedures and that can rely on most organisational resources involved in the project work. The purpose is having a workable organisational structure made by interdependences and synergies among members. The project manager orchestrates the overall project, and so the team is managed and lead by him as he has the highest level of authority over its members. The more the organisational structure relies on the opposite functional side, the less the authority of the project manager and the fewer organisational resources involved. The figure of the project manager takes a relevant dimension because he manages and leads the team members that accomplish the project work with the involvement of other stakeholders as external contractors. He has the required authority over them with the aim to achieve the project objectives; balancing the project constraints and ensuring the project team interacts with the project stakeholders in a professional and cooperative manner. The project team is responsible for planning, executing, controlling and closing the project under a project governance structure. This consists of having appropriate procedures to meet the project scope, establishing a general approach to complete the work, adapting to the requirement, the degree of rigor for each process, resource commitment and to whom should be involved, as well as maintaining an appropriate communication between stakeholders. The project team is composed of individuals with a different set of skills, competences and capabilities, from various

functional departments, geographical locations with different time-zone conditions, working hours, cultural background and language. In the international dimension, virtual project teams are created and its members work in long distance with collaborative IT tools such as online workspaces and video conferences to coordinate the activities and changing info about the project. The team is formed of the project management staff that includes all those members who perform project management activities such as scheduling, budgeting, reporting, control, and risk management. This involves the members who carry out the work, achieving the project deliverables, by supporting experts that help with their particular skills and knowledge. This aids in developing a project management plan or participating in a project where their specific knowledge is needed as well as by other stakeholders. In carrying out the work, the team is supported by services provided by others stakeholders as external contractor (entering in contractual agreements), that have interests over the successful completion of the project. The composition of the team can vary during the project lifecycle by changing its members when specific deliverables are met and new specific skill sets are needed. Project Human resources management is a knowledge area of project management referring to those processes for organising, managing and leading project team and they consist of:

- Developing a human resources management plan (that is a part of the project management plan) to provide guidance on how human resources should be defined, staffed, managed and realised. It includes defining all those project roles, responsibilities, required skills, reporting relationships, timetable for staff acquisition and release, training needs, rewards programs and safety issues.

- Acquiring project team to obtain the necessary line-up, for successful completion of the project activities.

- Managing the project team by tracking team performance, providing feedbacks, resolving issues, managing changes to optimise resource performance.

What makes a relevant side is creating a project team culture between the team members, consisting of unwritten norms between them, team identity, common

aspiration, shared visions to achieve positive synergies with the aim of creating an atmosphere of mutual trust, effective communication and following professional and ethical behaviours. It is made possible by those project managers whose leadership is recognised by the individuals involved in the project and that is able to motivate the members.

Project Lifecycle

"*A project life cycle is the series of phases that a project passes through from its initiation to its closure*".[44] This definition denotes that a project can be divided into a series of phases, logically and sequentially structured, that encompass its lifecycle from its start to its end. Segmenting the project in a logical subset of phases help the project manager to manage it more easily. Each phase is composed of a series of project activities logically sequenced so that they culminate on the achievement of specific deliverables, precise outcomes consistent with the project scope. Hence, each one is time and resource bound having a different duration, focus and work effort that differs from other ones. It also involves different locations within which each one is carried out, different stakeholders (e.g. a phase can involve contractors released at the end of the same phase), and different people working and so on. The phases can be completed sequentially or even be overlapping. The first example is a sequential relationship carrying out each phase step-by-step (one phase starts when the previous one is completed): it reduces uncertainty but increases the duration. The second one is an overlapping relationship of phases (a phase starts before the conclusion of the previous one): it reduces the duration by schedule compression, doing work in parallel but could increase the resources needed. To control the status of the project the phase structure is broken down into formal gates and here there are checking points to measure the progress of a project to preset standards in scope, quality, cost and time. Normally those formal checking points for the project review coincide with milestones, as previously mentioned. Before each gate, the deliverables linked to the previous

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[44] Project Management Institute (2013).

phases have to be reached and the forms of control are very different, varying from key performance indicators to an improvement of a physical index to measure the technical requirements. Progressively achieving specific deliverables aids in concluding the project scope. The project lifecycle model varies according to the industry type, the project type, size, complexity, and the working-style of the project team (e.g. the entire lifecycle could be considered as a single phase, as in a small project). However, there is a generic structure that a project follows and the typical pattern is illustrated in the figure below:

Figure 5[45]: Project Life Cycle.

During time the project starts, and then the work is carried out while cost and staffing efforts increase until a certain point at which the maximum peak is reached and from that point the efforts start to decrease until the project is closed. Instead, risk and uncertainty is higher at the beginning, decreasing during the life of the project once time deliverables are reached. The possibility of changes influencing the scope and the project itself is higher at the beginning but the cost of changes increases during its lifecycle, as the figure below shows:

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[45] Project Management Institute (2013).
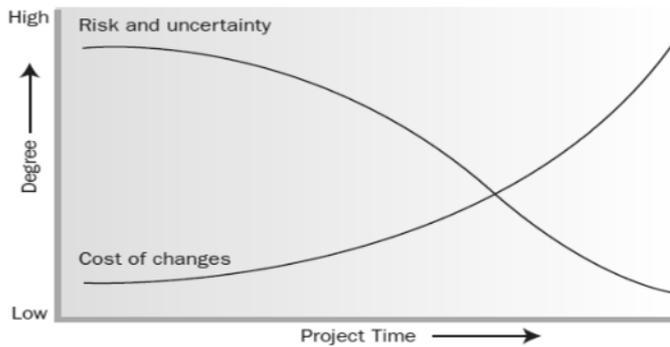
Figure 6[46]: Risk, uncertainty and cost of changes during the lifecycle.

There are two approaches for the project lifecycle: one is predictive and the other one is adaptive. In the predictive approach deliverables of scope, time, quality and cost are well defined at the beginning and any changes are carefully managed. The adaptive one is designed to respond to high level of changes while requirements and scope are difficult to be pre-set, adopting an iterative method in which phases and activities are repeated for incremental improvements, allowing the project team to incorporate feedbacks and to detail the scope whilst interacting.

To ensure the effective flow of the project through its lifecycle a project management process is needed (as discussed previously), because a project is a network of interlinked processes. There isn't a single ideal structure for every kind of project, instead the project manager has to determine the appropriate one for each project: there are organisations that standardise practices for project management whilst others that specifically tailor their practices upon the project manager and project team. Finally it should be noted that the phases of the project lifecycle are not the project management process group: the latter can be related to the entire project as well to a specific activity performed.

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[46] Project Management Institute (2013).

2. A new project constraints framework

"Could it be the reason some project management is labelled as having failed results from the criteria used as a measure of success? The questions then become: what criteria are used and what other criteria could be used to measure success?"[47]

As in Mir et al. (2014), a number of alternative frameworks are available for measuring project success[48] and this chapter provides a new one by unifying the variables of scope, time, cost and quality, separated but at the same time considered as pillars of the project management in literature and practice. As in Project management Institute (2013), completing the project within the constraints of scope, time, cost and quality means to have achieved a successful project, since the projects are temporary in nature.[49] Behind this standard definition, *"a number of studies have investigated what Project Success means and some conceptualise it as a uni-dimensional construct concerned with meeting budget, time and quality (Brown and Adams, 2000; Bryde, 2008; Fortune et al., 2011; Müller and Turner, 2007; Turner, 2009; Wateridge, 1995)"*.[50]

Project scope is defined in this work as achieving a project outcome or result by performing a set of project activities and managing the variables of cost, quality and time, both of which are considered as successful criteria inside a set of constraints identified in the budget and resource availability, technical requirements and schedule needs. Then, project success is intended as achieving the project scope, *the mainstay*

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[47] Atkinson (1999).

[48] *Project success* differs from *project performance* even if positively related as a number of studies suggest and it has been tested by Mir et al. (2014) - for more details, see Mir. Et al. (2014). Project success can be seen as project effectiveness in terms of achieving the project scope within the constraints of time, quality and cost. However, project performance is seen as project efficiency in terms of skilfully performing a set of project activities with an efficient use of resources and time in order to tend to the planned values for cost, time and technical requirements.

[49] Clearly in the standards are considered resources and risks too as constraints within which complete the project to achieve its success. However they are merely considered as factors impacting over the project quality, cost, time and scope. For more details, see Project management Institute (2013).

[50] For more details, see Mir et al. (2014).

of the project[51] and it is reached if the constraints of the different variables are respected. The question that this new framework raises is: knowing the priority of the project committee and having the constraints of time, cost and quality, for which values will the *project success* be maximised? It is a problem of maximisation by obtaining the values for the *project pillars*[52] quality, cost and time that maximise project scope but at the same time respecting their constraints and the priority of the project committee. Clearly best practices of project management to increase its *performance* (the divergence between actual and optimal planned values) are needed but it is not the objective of the work. A project manager's responsibility is to know for which values of time, cost and quality the project scope is maximised. Through a problem of optimisation, one can obtain the optimal values that a project must comply. This model will be applied in the project case developed in the chapter 3 that leverages on the practices of project management and it is open for future developments.

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[51] See appendix A where interviews are called.
[52] See appendix A where interviews are called.

2.1. Theoretical background

"Are project management standards ignoring the characteristics and needs of different types of projects?".[53] Standards are used as a common framework to unify practices and concepts, presenting a consensual understanding without exceptions. However, they can be based too much on the generalisation of the matter. Project management standards are an example of such a characteristic. Standardisation has produced refined definitions regarding projects and its management. Otherwise the knowledge captured in these standards seems to change project by project, differentiated by function of its nature. As already introduced in Chapter 1.2, "*a project is a time and cost constrained operation to realise a set of defined deliverables (the scope to fulfil the project's objectives) up to quality standards and requirements*"[54]. This definition, provided by The International Project Management Association, explains what it means to carry out a project. This definition seems to be the most complete and least indefinite amongst project management literature as it clearly separates scope, quality, time and cost. However in project management literature, the framework of scope, quality, time and cost is not so clear. Sometimes it is interpreted as reaching something vague by managing some criteria identified in time and cost. Sometimes it is designed by setting scope, expressed in *what* is needed to be done and *how*, managed jointly with time and cost. Sometimes it sets scope in *what* is needed to be done, clearly separated by quality, time and cost managed to reach it. In some cases, it considers scope as part of the quality, cost and time constraints, needed to be managed jointly in order to achieve a greater result. Different frameworks about what is intended for project constraints have been developed in literature. Following Atkinson (1999), just in Oisen (1971) [55] project framework emerges in the "*accomplishment of a unique, complex, one-time task within time, cost and quality constraints*". Here project scope seems implicitly assumed on the result of this unique, complex, one-time task under three constraints: quality, cost, time. In 1995, the

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[53] IPMA (2013).
[54] IPMA, I. (2006).
[55] For more details, see Atkinson (1999).

Association of Project Management (1995)[56] considers project management as the way to reach a project objective within a certain time, cost and performance criteria. In this case the performance criterion (the functionality) seems to refer to the objective of the project, such that this definition is similar to the first one. The same Atkinson (1999) argues that "*cost, time and quality (The Iron Triangle) over the last 50 years* – at that time - *have become inextricably linked with measuring the success of project management*" and that "*the criteria for success, namely cost, time and quality remain and are included in the actual description*". In this view, scope seems to remain a variable apart by quality, time and cost success criteria. Turner (1996)[57] vaguely defines project management as "*the art and science of converting vision into reality*". In this definition the constraints (scope included) do not appear and they seem to be just implicit in the project concept. Wright (1997)[58] links the project success to time and budget. This framework demonstrates that the project has to be carefully managed under time and cost constraints. Here the success seems to be linked with time and cost management, whilst the scope and quality variables do not appear. Project Management Institute (1996)[59] depicts the aim of project management in meeting stakeholders' needs, balancing the constraints of time, scope, quality and cost. Here quality, scope, time and cost seem to be managed to meet the stakeholders' needs, a greater purpose. Adopting modern visions, Project Management Institute (2013) simply drafts the project as a way to create a unique result. Separated, it notes that it needs to be done managing quality, time and cost. Quality, scope and cost seem to be managed in function of reaching the scope. Larson et al. (2011), defines "*quality and the ultimate success of a project are traditionally defined as meeting and/or exceeding the expectations of the customer and/or upper management in terms of cost (budget), time (schedule), and performance (scope) of the project*". Here, the pillar of the project seems to rely on a triangle of scope, cost and time that influence its quality (in terms of how the project is conducted). One considers that a project needs to move between three fundamental elements: scope (what needs to be done and how), time

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56 For more details, see Atkinson (1999).
57 For more details, see Atkinson (1999).
58 For more details, see Atkinson (1999).
59 For more details, see Atkinson (1999).

and cost.[60] Here scope and quality (of the result) seem to be merged, managed jointly with time and cost. Even professional project managers have developed their own framework. In Eng. Gallo (2015)[61], the scope of the project becomes the mainstay of the project itself and, developing specific projects (in nature), it becomes really aligned with the quality of the result. Such that scope and quality seem to merge in *what* is needed to be done and *how*. *What/how* means scope/quality becoming the reason for which a project is carried out and so it needs to be reached by managing cost and time constraints (malleable in function of the primary reason: reaching a preset result with a preset quality). In Dr. Bevilacqua (2015)[62] project means achieving a scope managing quality, cost and time. This framework seems to best suit that of The Project Management Institute (2013). Over time the phenomena of project management has evolved and now it is reaching even the international dimension[63], becoming an extended and complex matter, full of techniques, tools, knowledge and ambiguous frameworks under which a project is implemented. However in many years the discipline has not really changed its basic logical standards, recognised by the Project Management Institute (2013), but different perspectives over this matter have evolved in particular, considering the framework of project constraints. Project framework covers clear concepts: quality, scope, time and cost. They are uniquely known and interpreted but they are mixed in an ambiguous way. Different frameworks and perspectives, leveraging on the same concepts, have evolved according to the nature of the project, the experiences of professional project managers, and differing schools of thought within literature, covering a generally vague spectrum. Already, Haughey (2011) rationalises this matter whilst figuring the triple constraint framework in the triangle of scope, time and cost. Both provide the framework of the diamond, setting the constraints of scope, quality, time and cost in function of the primary reason: reaching customer expectation (a greater purpose). He accentuates the importance of

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[60] De Luca (2011/12).
[61] For more details, see appendix A where interviews are called.
[62] For more details, see appendix A where interviews are called.
[63] For more details, see Larson et al. (2011), Project management Institute (2013), Lientz et al. (2003), Grisham (2011), Binder (2008).

the customer as a major targeted stakeholder, however the purpose really depends upon the nature of the project.

Then, two main frameworks in this system of constraints can be outlined.

- In the first one, the mainstay of the project is identified in the quality of the project (its performance). It is affected by scope, time and cost forming a triangle in which each factor is influenced by the other. In this view, quality (of the outcome) is implicit to scope, identifying *what* is needed to be done and *how* it is needed to be done. The project success depends upon managing scope, time and cost, which are strictly linked, such that if a factor changes, another factor is likely to be affected, influencing the success of the project. There are some kinds of projects in which their performance is dependent upon their scope, which in turn, also depend upon the quality of the outcome. This is because if the quality requirements are not achieved, the primary reason for which the project is carried out (its scope) is not accomplished, hence scope and quality are intrinsically linked. Time and cost are malleable in function of reaching this performance, taking secondary priority. Figure 7 illustrates this triangle constraints framework.

Figure 7: Triangle constraints framework.

- Another framework is represented by a tetrahedron of scope, quality, time and cost. In this view quality – the "*how*" of what has needed to be done - is clearly separated by scope – the "*what*" has needed to be done. One factor influences the other in the same way and they need to be balanced in order to achieve the

greatest purpose of the project. Figure 8 illustrates this tetrahedron framework.
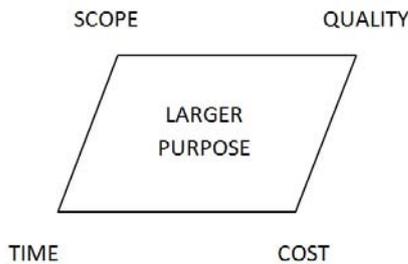
Figure 8: Tetrahedron constraints framework.

Four constraint factors that influence project success purpose can be revealed most of the time:

- A project must be delivered within *cost*. The cost constraint is the budget available in terms of cost referred to financial or non-financial resources allocated to the project.

- A project must be delivered on *time*. The time constraint is the amount of time available to complete the project.

- A project must meet the agreed *scope*. The scope constraint is what is needed to be done carrying out the project. It refers to the minimum result of the project.

- A project must meet *quality.* The quality constraint is the project outcome and its deliverables in terms of quality requirements.[64]

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[64] The Project Management Institute (2013) distinguishes quality matter in two kinds of concepts: quality level and grade. The first one refers to the set of characteristics/delivered performance of the results to reach quality requirements, according to ISO 9000. While grade refers to the design intent assigned to deliverables. In this work, quality refers to both concepts. It is needed to evaluate the appropriate level of accuracy and precision. The quality management approach provided by The Project Management Institute (2013) is compatible with ISO quality standards. Achieving ISO compatibility means to have achieved the required results with minimal divergences from the quality management plan. Furthermore, customer satisfaction ranks as one of the highest quality requirements. Has the project result satisfied customer needs? Did the project achieve the desired results? However, customer satisfaction is not only the real need that is catered for. It also considers other aspects: continuous improvement, management responsibility, cost of quality, prevention over inspection. For more details, see Project Management Institute (2013).

Naturally the mainstay of the project relies on achieving the project scope. It is possible to vary the time, budget or quality standards preset in order to reach it (clearly respecting the constraints for each one) but it would not be acceptable to fail in achieving the main purpose of the project. This is because if the scope is not reached, the primary reason for which the project is carried out, no longer exists. So, considering as mainstay that a project must reach its scope, the constraints of quality, cost and time become boundaries in which the scope has to be met. They will be more or less aligned with it upon the type of the project or the priority of the committee. Then, the success of the project encompasses the achievement of a minimum result (yes/no) under certain conditions for cost, time and quality, malleable upon certain thresholds provided by the project committee. For those projects that really depend upon the quality of the outcome to fit the scope, the latter would be more aligned with the quality. For example, in an international project for a new product development, if the quality requirements of the product are not reached, the success of the project (providing a preset product with specific quality requirements to reach customer satisfaction) goes down. In this kind of project, quality is really important because the scope of the project really depends upon the quality level. Clearly, the quality will take more relevance over cost and time. There are other types of projects in which time or cost constraint prevails over the others. Those are known in literature as time-constrained and resource-constrained projects. In the first case the project priority is aligned with the critical factor of time (in particular for time-to-market projects) while the variables of cost and quality requirements take less relevance. The resources, and so its cost, are managed in function of achieving the project scope within a specific date without delaying the critical path (quality can be compromised, budget can be overrun, but the project time cannot be exceeded absolutely). In the second case the cost or the resources level available cannot be exceeded and in this case the priority is aligned with this factor while the time and quality variables have less importance, managed in function of achieving the project scope within the budget. These three variables (quality, cost and time) relationship can be figured as picking any two factors between *Quick, Good and Cheap*. Quick refers to the time to deliver the

product/service/result. Good represents the quality of the final outcome, while cheap figures the cost of the project. For example it is possible to carry out something quickly and with high quality, but at a higher cost. It is also possible to carry out something quickly and cheaply but with a lower standard of quality. It is possible to carry out something good and cheap but the project will require more time. This reasoning is illustrated in figure 9.
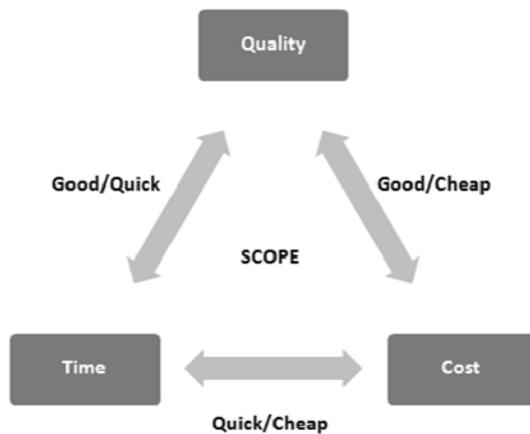
Figure 9: Quality, cost and time relationship can be figured as picking any two factors between *Quick, Good and Cheap*.

As example: taking a bridge construction project, the bridge will have to stand allowing users to pass (primary minimum scope). It will be achieved if the minimum quality requirements will be accomplished (quality threshold), if it will be finished before the start of the Expo 2015 (time threshold), and if it will be developed within a preset cost (cost threshold). Then, the bridge itself could be weak or sturdy, lasting for two months or lasting 100 years, within the preset quality requirements (quality malleable above the minimum threshold). The Project Manager could use a lower budget, within the preset cost (cost malleable above the minimum threshold). The construction of the bridge (minimum scope, not malleable) could even be achieved within the preset period (time malleable above the minimum threshold). One can realise many ways to achieve the minimum scope based on the preset thresholds. Therefore, in this vision, a project manager has to attain a primary scope (the result needed to be delivered, the

reason for which the project exists). This is done by managing the project pillars *q.c.t.*[65] (quality, cost and time) through a trade-off between them but delivering the project outcome by attaining certain characteristics, within a certain scheduled time and preset budget, as identified by the committee. The problem of the project manager will be to find the solutions for time, cost and quality that maximise the delivering of the outcome. A practical example: if an organisation must carry out a time-to-market project but provide a high quality outcome within budget, the project manager has to meet the optimal solution that provides the maximum quality of the outcome in a short time, within the preset cost. It becomes a problem of maximisation in three variables but before formulating the problem, one needs to consider the following:

- The project success depends upon the achievement of a minimum scope, managing three variables (time, cost and quality requirements), whose importance depends upon the priorities of the committee or the nature of the project, each influencing differently upon the scope. In this view, quality (of the outcome) and minimum scope are separated from the larger concept of the scope itself. Then, reaching a minimum scope becomes a dummy variable that takes two modes: yes (if it is achieved) or no (if it is not achieved).[66]

- The constraints relationship of time, quality and cost relies on the fact that each constraint cannot be changed without affecting each other. Each one varies in accordance with the other and it means that if at least one factor changes, at least one other factor is likely to be affected. Therefore managing project time, cost and quality becomes of major importance to ensure the project is completed successfully in a preset scope, balancing the trade-offs between them. These constraints are closely related: varying a variable of the project typically means varying at least one of the others among project time, cost and quality. Reducing time can involve higher costs (more resources

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[65] For more details, see appendix A where interviews are called.

[66] It has to be noted that the primary scope of a companies' international efforts can be different: sometimes they choose to internationalise part of their production, sometimes certain services, sometimes one or several processes such as supply or sales and it is possible breaking their value chain globally project by project. Choosing what should be internationalised is very important; reeling on a clear internationalisation strategy but what is more important is managing the thresholds of budget, schedule and quality so that the output has to comply. That determines if a project succeeds or fails.

needed to be allocated), a tight budget or scheduled time can face fewer quality requirements.

- For each variable there is an identified threshold which the project manager must comply with, in compliance with the project committee. It has to be noted that the quality threshold is to be seen in a different perspective from time and cost threshold. Quality threshold is the minimum value in terms of quality a project can comply with, and as such it is needed to find a formula that quantifies it. Clearly, depending upon the intersection between the thresholds constraints, the latter will have different maximum points in which quality improvement cannot go beyond. Time and cost thresholds are the maximum values a project can spend.

This maximisation problem consists of finding the best solution between many hundreds of possible solutions inside the critical area of the figure formed by the intersections of the project pillars constraints. Then, the project manager needs to find the solution for project cost, quality and time to maximise the scope, considering their dependences and the constraints related.

2.2. A mathematical model to unify the project pillars: finding the optimal project success

The problem needs to be identified.

First of all one needs to define the variables: let q, c, t identify respectively the quality of the outcome, the cost of the project and the project time. Let s identify the scope, defined as a function of quality, cost and time such that:

$$s = f(q, c, t)$$

In the practices, developed in the next chapter, time will be expressed in labour days, cost in thousands of Euro and quality in percentage of issues resolved plus quality requirements met. In particular:

- $q = \frac{q(t,c)}{\max achivable\, q}$ where $q(t, c)$ will be a suitable function to be specified later.

- $c = \frac{Euros}{1000}$

- $t = labour\; days$

It introduces the different perspectives in which cost is seen in project management. They will be used in chapter 3.6 to disclose the project budget baseline and in chapter 3.8 to present the *Earned Value Management* technique. The different values considered[67] are:

- $AC_{i,t}$: the actual cost per day t of an activity i. The sum of the actual costs of all the activities in a specific day gives the actual cost value at that time t, $AC_t = \sum_{i=1}^{n} AC_{i,t}$. While the sum of the actual costs of all the days for a specific activity gives the actual cost value for activity i, $AC_i = \sum_{t=1}^{T} AC_{i,t}$. The

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[67] It is possible to plan the cost for each activity and time-phase it in order to obtain the planned cost value of an activity i at time t ($PV_{i,t}$). It is possible to create a matrix where planned costs are broken up for activities (the planned cost for each activity i, PV_i) and in time. Time-phasing costs means that the planned values of each activity i are scheduled over time obtaining a planned cost for each activity at each time. In this work, the planned value for each activity i is divided by the number of labour days that such activity i spends. It allows one to obtain the cost per day for such activity i assuming that it employs in each day the same project labour hours, the same materials, equipment and human staff. PV_i is the sum of the values of the matrix lines (that correspond to the activities planned cost values) by fixing the values of the matrix columns (that correspond to the time planned cost values). While, PV_t is the sum of the values of the matrix columns (that correspond to the time planned cost values) by fixing the values of the matrix lines (that correspond to the activities planned cost values).

cumulative values of time-phased actual costs until time t is indicated as $ACWP_t = \sum_{k=0}^{t} AC_k$.

- $PV_{i,t}$: the planned cost per day t of an activity i. The sum of the planned costs of all the activities in a specific day gives the planned value at that time t, $PV_t = \sum_{i=1}^{n} PV_{i,t}$. While the sum of the planned costs of all the days for a specific activity gives the planned value for activity i, $PV_i = \sum_{t=1}^{T} PV_{i,t}$. The cumulative values of time-phased planned costs until time t is indicated as $BCWS_t = \sum_{k=0}^{t} PV_k$.

At the end of the project T, $BCWS_{t=T} = BAC$ where BAC is the budget at completion (the budget disclose for the project in the planning phase). The actual cost value of the work performed until time T should be aligned with the budget at completion, which in turns needs to be equal to the optimal cost found through this optimisation problem. Then there is an optimal waste of resources if $BCWS_T = BAC = c^* \leq \bar{c}$. Then, the project manager must compare other measures to determine the real state of the project: actual quality and time values are compared against planned and optimal quality and time values in order to reach the optimal performance.

It is necessary to maximise the scope of the project as a function of q, c, t such that:

$$\max s(q, c, t)$$

Where:

$$s(q, c, t) = w_q \cdot q + w_c \cdot (-c) + w_t \cdot (-t)$$

The logic behind the positive and negative signs of the variables in the scope function is that less time and cost will be spent to deliver a more qualitative outcome, more the project will be aligned to its scope: providing time-to-market qualitative outcome with tight budget.[68] Project scope is directly scaled to quality of a factor w_q, inversely scaled

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[68] It has to be noted that, in the practices, more a qualitative outcome is delivered, more the stakeholders to which the project outcome is targeted will be satisfied. And in doing so, less time and cost the project spend, more the company will be satisfied. This is because nowadays, globalisation pushes companies to deliver time-to-market qualitative outputs trying to safeguard costs (for more details, see chapter 1). The process of internationalisation is long and difficult and many experts share the opinion that costs are high and expectations about schedules and costs often go unfulfilled (Rodriguez et al. (2011)). But that's not all because ensuring that the project outcome requirements are met and validated is another pillar for the project management practices: as in appendix A where

to cost and time of a factor w_c and w_t respectively. $\underline{w} = \begin{bmatrix} w_q \\ w_c \\ w_t \end{bmatrix}$ is the weight vector that

measures the importance given to each variable by the committee priorities and reported in the *project scope statement*. The scope of the project has to be more or less aligned with the constraints of time, cost or quality depending upon the project type and the priorities of the project committee. If the project is more oriented upon satisfying customers' requirements, the quality of the outcome takes more importance over time and cost. However if the top management needs the outcome of the project delivered within a specific deadline, the time cannot be exceeded, absolutely affecting the budget as well the quality. In the last instance, if the project must respect the budget, the project manager must focus on not exceeding the cost and the resources available and in doing so, time and quality could vary. Clearly the priorities cannot be assigned.

Through a multi-criteria decision analysis, the project manager can determine the values of the triple (w_q, w_c, w_t). The values of the vector weight are obtained by leveraging on this analytical methodology to acquire a consistent ranking without leaving anything to chance. It is discussed at the end of this section.

This work uses the Cobb-Douglas function to represent the production in qualitative terms of the project outcome. A certain quality deliverable q is obtained performing a set of different project activities that involve a certain amount of time t and cost c with a different impact (α for time and $1 - \alpha$ for cost) over the quality deliverable. Then, the project outcome is considered in qualitative terms (the output of the production) employing a certain amount of time (the first type of input) and resources that in turn they are a cost for the project (the second type of input). Then:

$$q = t^\alpha \cdot c^{1-\alpha}$$

Where, α is a parameter that represents the impact of time and in turn $1 - \alpha$ that of cost over the quality. Each value is determined by the experience of the project

interviews are called, if the outcome of the project is not qualitative, the needs of the customers will be not met and in turn the scope will be not reached, failing the project.

manager in managing the project. He is able to quantify the impact of project cost and time over the quality of its outcome having an overview of the project, its boundaries, resources, activities and deliverables and knowing that the Cobb-Douglas function can display three types of scale returns. As evidence, this work considers a *Cobb-Douglas quality production function* with constant returns to scale because it is considered that at the increasing/decreasing of cost and/or time value, the quality deliverable increases/decreases proportionally. Moreover, this function faces its factor of productivity equal to 1 and the reason behind this is that the work considers the use of a unit of cost and time, the quality improvement of 1%.[69] It is graphically represented in figure 10[70]

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[69] In literature the Cobb-Douglas function is used to represent the production, in general terms. Its most standard form for production of a single output with two inputs, the function is:

$$z = k \cdot x^\alpha \cdot y^\beta$$

Where:

- z is the value of the output produced in a certain period of time.
- x is the value of the first type of input in the same period of time considered.
- y is the value of the second type of input in the same period of time considered.
- k is the factor of productivity. It is a constant.
- α and β are the output elasticity of input x and y respectively. These values are constants determined by the available technology. Output elasticity measures the responsiveness of output to a change in levels of both inputs used in production, ceteris paribus. If $\alpha + \beta = 1$ the production function has constant returns to scale, If $\alpha + \beta > 1$ the production function has increasing returns to scale, while if $\alpha + \beta < 1$ the production function has decreasing returns to scale.

For more details, see Barnett (2003).
[70] Fuleky (2006).

production/utility function = a x₁ᵅ x₂ᵝ
a=1, α=β=0.5 - constant returns to scale
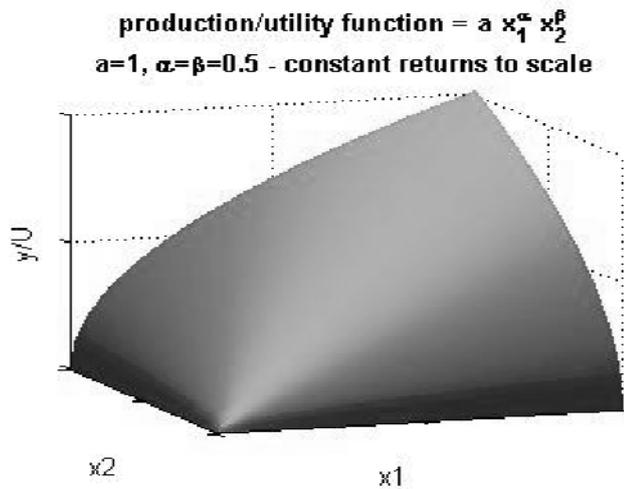
Figure 10: Cobb-Douglas function with constant returns to scale.

Considering this Cobb-Douglas function, the situations that emerge are:

- Quality is directly scaled to time and to cost of a factor α and $1 - \alpha$ respectively.

- Time is directly scaled to quality of a factor $\frac{1}{\alpha}$ and inversely scaled to cost of a factor $\frac{\alpha-1}{\alpha}$, as in function:

$$t = \left(\frac{q}{c^{1-\alpha}}\right)^{\frac{1}{\alpha}} = \left(q \cdot \frac{1}{c^{1-\alpha}}\right)^{\frac{1}{\alpha}} = (q \cdot c^{-(1-\alpha)})^{\frac{1}{\alpha}} = (q \cdot c^{\alpha-1})^{\frac{1}{\alpha}} = q^{\frac{1}{\alpha}} \cdot c^{\frac{\alpha-1}{\alpha}}$$

- Cost is inversely scaled to time of a factor $\frac{\alpha}{\alpha-1}$ and directly scaled to quality of a factor $\frac{1}{1-\alpha}$, as in function:

$$c = \left(\frac{q}{t^{\alpha}}\right)^{\frac{1}{1-\alpha}} = \left(q \cdot \frac{1}{t^{\alpha}}\right)^{\frac{1}{1-\alpha}} = (q \cdot t^{-\alpha})^{\frac{1}{1-\alpha}} = q^{\frac{1}{1-\alpha}} \cdot t^{-\frac{\alpha}{1-\alpha}} = q^{\frac{1}{1-\alpha}} \cdot t^{\frac{\alpha}{\alpha-1}}$$

The logic behind these situations are such that, more the outcome provided by carrying out the project is qualitative, the more costs and time are needed to carry out the project. Moreover, as just mentioned, reducing project time to deliver a qualitative outcome needs more resources to be allocated and in turn higher costs. While reducing project budget means that tight resources are at disposal for the project and in turn it will take more time to complete the outcome.

It has to be pointed out that, having obtained a formula for the quality, the maximum value that this variable can assume is obtained by spending all the time and cost at the disposal of the project ($q_{max} = \bar{t}^\alpha \cdot \bar{c}^{1-\alpha}$). On the other side, the minimum threshold that this variable can assume ($\bar{q}$) is determined by the project manager by knowing the desired quality completion set by project committee ($r\%$) over its maximum value achievable. Then, the project manager can obtain the quality threshold $\bar{q} = \frac{r\%}{100} \cdot q_{max}$

There are some constraints that identify the admissible set D of the function $f(q, c, t)$, defined on:

$$D: \begin{cases} 0 \le t \le \bar{t} \\ 0 \le c \le \bar{c} \\ c^\alpha \cdot t^{1-\alpha} \ge \bar{q} \end{cases}$$

The minimum threshold for quality is the constant value $\bar{q}$ set in accordance with the project committee. It indices the quality of the project outcome cannot go under this value. While its maximum threshold is identified by $q^{max} = \bar{c}^\alpha \cdot \bar{t}^{1-\alpha}$, depending of the maximum thresholds for time and cost set by the project committee ($\bar{c}$ and $\bar{t}$ respectively). These values mean that project cost and time cannot go beyond these values. Clearly their minimum thresholds are equal to 0, but to reach a minimum quality outcome (different from 0) it is necessary to spend minimum cost and time values (in turn different from 0).

Then, denoting $t = x$ and $c = y$, the problem will be maximising a suitable function s of scope depending on quality, time and cost and defined as following:

$$s = w_q \cdot x^\alpha \cdot y^{1-\alpha} - w_t \cdot x - w_c \cdot y$$

Subject to an admissible set D defined on:

$$D: \begin{cases} 0 \le x \le \bar{t} \\ 0 \le y \le \bar{c} \\ x^\alpha \cdot y^{1-\alpha} \ge \bar{q} \end{cases}$$

This set can be graphically represented as in figure 11.
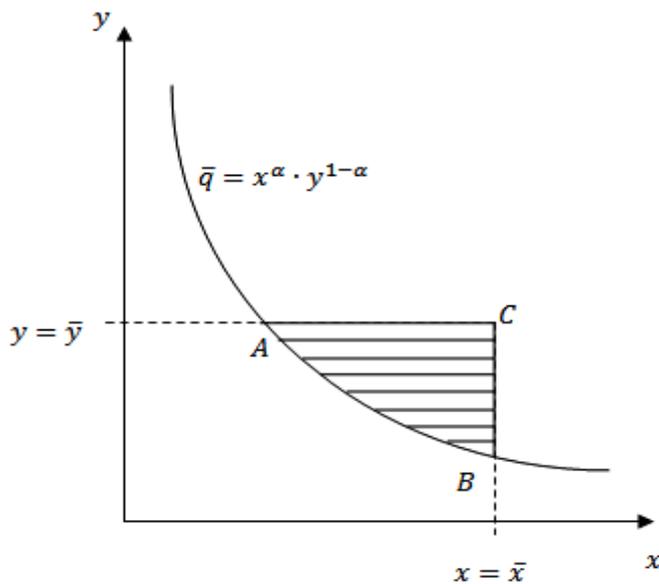
Figure 11: Critical area of scope as function of time and cost.

Summering, the problem is: $\max s(x, y)\ over\ D$.

According to the *Weierstrass Theorem*, if function $f(x,y)$ is continuous in a closed, bounded and not empty plan set D, then it exists both a point (a,b) in D where f attains a minimum and a point (c,d) in D where f attains a maximum – that is:

$$f(a,b) \leq f(x,y) \leq f(c,d)\ for\ each\ (x,y)\ in\ D$$

Then, the problem consists on finding maximum and minimum values of a differential function $f(x,y)$, defined in a plan closed bounded set D by:

a) Defining all stationary points of the function f at the interior of D.

b) Defining the biggest and the smallest value of f on the frontier of D where f is defined and the related points.

c) Evaluating the values of the function f in correspondence to the all points found at the previous steps. The biggest value that f assumes in D will be its maximum, while the smallest one will be its minimum.[71]

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[71] For more details, see Knut et al. (2008).

Note that, being s continuous on a compact domain D a global maximum exists. One is left to find it. The interior of D and its frontier are studied separately.

1) *Stationary points at the interior of the set D*

First of all, one needs to calculate the stationary points at the interior of D by solving:

$$\begin{cases} \dfrac{\partial s(x;y)}{\partial x} = 0 \\ \dfrac{\partial s(x;y)}{\partial y} = 0 \end{cases}$$

Computing the following mathematical calculations:

$$\frac{\partial s(x;y)}{\partial x} = 0$$

$$\frac{\partial [w_q \cdot x^\alpha \cdot y^{1-\alpha} - w_t \cdot x - w_c \cdot y]}{\partial x} = 0$$

$$[\alpha \cdot w_q \cdot y^{1-\alpha}] \cdot x^{\alpha-1} - w_t = 0$$

$$x^{\alpha-1} = \frac{w_t}{\alpha \cdot w_q \cdot y^{1-\alpha}}$$

$$x = \left(\frac{w_t}{\alpha \cdot w_q \cdot y^{1-\alpha}} \right)^{\frac{1}{\alpha-1}} = \left(\frac{1}{\alpha} \cdot \frac{w_t}{w_q} \cdot \frac{1}{y^{1-\alpha}} \right)^{\frac{1}{\alpha-1}} = \left(\frac{1}{\alpha} \cdot \frac{w_t}{w_q} \cdot y^{-(1-\alpha)} \right)^{\frac{1}{\alpha-1}}$$

$$= \left(\frac{1}{\alpha} \cdot \frac{w_t}{w_q} \right)^{\frac{1}{\alpha-1}} \cdot y$$

$$\frac{\partial s(x;y)}{\partial y} = 0$$

$$\frac{\partial [w_q \cdot x^\alpha \cdot y^{1-\alpha} - w_t \cdot x - w_c \cdot y]}{\partial y} = 0$$

$$[(1-\alpha) \cdot w_q \cdot x^\alpha] \cdot y^{1-\alpha-1} - w_c = 0$$

$$y^{-\alpha} = \frac{w_c}{(1-\alpha) \cdot w_q \cdot x^\alpha}$$

$$y = \left[\frac{w_c}{(1-\alpha) \cdot w_q \cdot x^\alpha}\right]^{-\frac{1}{\alpha}} = \left(\frac{1}{1-\alpha} \cdot \frac{w_c}{w_q} \cdot \frac{1}{x^\alpha}\right)^{-\frac{1}{\alpha}} = \left(\frac{1}{1-\alpha} \cdot \frac{w_c}{w_q} \cdot x^{-\alpha}\right)^{-\frac{1}{\alpha}}$$

$$= \left(\frac{1}{1-\alpha} \cdot \frac{w_c}{w_q}\right)^{-\frac{1}{\alpha}} \cdot x$$

In summary, the following is obtained:

$$\begin{cases} x = \left(\frac{1}{\alpha} \cdot \frac{w_t}{w_q}\right)^{\frac{1}{\alpha-1}} \cdot y \\[2mm] y = \left(\frac{1}{1-\alpha} \cdot \frac{w_c}{w_q}\right)^{-\frac{1}{\alpha}} \cdot x \end{cases}$$

Then:

$$y = \left(\frac{1}{1-\alpha} \cdot \frac{w_c}{w_q}\right)^{-\frac{1}{\alpha}} \cdot \left(\frac{1}{\alpha} \cdot \frac{w_t}{w_q}\right)^{\frac{1}{\alpha-1}} \cdot y = \left(\frac{1}{1-\alpha}\right)^{-\frac{1}{\alpha}} \cdot \left(\frac{w_c}{w_q}\right)^{-\frac{1}{\alpha}} \cdot \left(\frac{1}{\alpha}\right)^{\frac{1}{\alpha-1}} \cdot \left(\frac{w_t}{w_q}\right)^{\frac{1}{\alpha-1}} \cdot y$$

$$= \frac{w_c^{-\frac{1}{\alpha}} \cdot w_t^{\frac{1}{\alpha-1}}}{w_q^{-\frac{1}{\alpha}+\frac{1}{\alpha-1}}} \cdot \left(\frac{1}{1-\alpha}\right)^{-\frac{1}{\alpha}} \cdot \left(\frac{1}{\alpha}\right)^{\frac{1}{\alpha-1}} \cdot y$$

$$= \left(\frac{1}{1-\alpha}\right)^{-\frac{1}{\alpha}} \cdot \left(\frac{1}{\alpha}\right)^{\frac{1}{\alpha-1}} \cdot y \cdot \frac{w_c^{-\frac{1}{\alpha}} \cdot w_t^{\frac{1}{\alpha-1}}}{w_q^{\frac{-(\alpha-1)+\alpha}{\alpha\cdot(\alpha-1)}=\frac{-\alpha+1+\alpha}{\alpha\cdot(\alpha-1)}=\frac{1}{\alpha\cdot(\alpha-1)}=-\frac{1}{\alpha\cdot(1-\alpha)}}}$$

Since $y \neq 0$:

$$\frac{w_c^{-\frac{1}{\alpha}} \cdot w_t^{\frac{1}{\alpha-1}}}{w_q^{-\frac{1}{\alpha\cdot(1-\alpha)}}} \cdot \left(\frac{1}{1-\alpha}\right)^{-\frac{1}{\alpha}} \cdot \left(\frac{1}{\alpha}\right)^{\frac{1}{\alpha-1}=-\frac{1}{1-\alpha}} := 1$$

$$\frac{w_c^{-\frac{1}{\alpha}} \cdot w_t^{-\frac{1}{1-\alpha}}}{w_q^{-\frac{1}{\alpha\cdot(1-\alpha)}}} \cdot (1-\alpha)^{\frac{1}{\alpha}} \cdot (\alpha)^{\frac{1}{1-\alpha}} = 1$$

$$\frac{1}{w_c^{\frac{1}{\alpha}}} \cdot \frac{1}{w_t^{\frac{1}{1-\alpha}}} \cdot w_q^{\frac{1}{\alpha\cdot(1-\alpha)}} = \frac{1}{(1-\alpha)^{\frac{1}{\alpha}} \cdot (\alpha)^{\frac{1}{1-\alpha}}}$$

$$\boxed{\frac{w_q^{\frac{1}{\alpha\cdot(1-\alpha)}}}{w_c^{\frac{1}{\alpha}} \cdot w_t^{\frac{1}{1-\alpha}}} = \frac{1}{(1-\alpha)^{\frac{1}{\alpha}} \cdot (\alpha)^{\frac{1}{1-\alpha}}}}$$

Therefore, assigning a specific value[72] to α, if the parameters for the vector weights $\underline{w} = \begin{bmatrix} w_q \\ w_c \\ w_t \end{bmatrix}$ satisfy that condition, there will be infinite stationary points characterised by $x = y$.

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[72] For more details, see note 69.

2) Stationary points at the frontier of D

It is needed to obtain the stationary points for the function s restricted within the three boarders $\overline{AB}$, $\overline{BC}$ and $\overline{AC}$.

a) Function s restricted on the boarder $\overline{AB}$

Function s restricted on $\overline{AB}$ is characterised by:

$$\begin{cases} q = \bar{q} \\ y = \left(\dfrac{\bar{q}}{x^\alpha}\right)^{\frac{1}{1-\alpha}} \end{cases}$$

Then:

$$s(x) = s_{|ab}(x; y) = s\left[x; \left(\frac{\bar{q}}{x^\alpha}\right)^{\frac{1}{1-\alpha}}\right] = w_q \cdot \bar{q} - w_t \cdot x - w_c \cdot \left(\frac{\bar{q}}{x^\alpha}\right)^{\frac{1}{1-\alpha}}$$

One needs to calculate the stationary points on the boarder $\overline{AB}$ by solving:

$$\frac{ds(x)}{dx} = \frac{d\left[w_q \cdot \bar{q} - w_t \cdot x - w_c \cdot \left(\frac{\bar{q}}{x^\alpha}\right)^{\frac{1}{1-\alpha}}\right]}{dx} = 0$$

$$-w_t - w_c \cdot \bar{q}^{\frac{1}{1-\alpha}} \cdot \frac{d\left[\left(\frac{1}{x^\alpha}\right)^{\frac{1}{1-\alpha}}\right]}{dx} = 0$$

$$-w_t - w_c \cdot \bar{q}^{\frac{1}{1-\alpha}} \cdot \frac{d\left[(x^{-\alpha})^{\frac{1}{1-\alpha}}\right]}{dx} = 0$$

$$-w_t - w_c \cdot \bar{q}^{\frac{1}{1-\alpha}} \cdot \frac{d\left[x^{\frac{-\alpha}{1-\alpha}}\right]}{dx} = 0$$

$$-w_t - w_c \cdot \bar{q}^{\frac{1}{1-\alpha}} \cdot \left[\frac{-\alpha}{1-\alpha} \cdot x^{\frac{-\alpha}{1-\alpha}-1}\right] = 0$$

$$-w_t - w_c \cdot \bar{q}^{\frac{1}{1-\alpha}} \cdot \left[\frac{-\alpha}{1-\alpha} \cdot x^{\frac{-\alpha-(1-\alpha)}{1-\alpha}}\right] = 0$$

$$-w_t - w_c \cdot \bar{q}^{\frac{1}{1-\alpha}} \cdot \left[\frac{-\alpha}{1-\alpha} \cdot x^{\frac{-1}{1-\alpha}}\right] = 0$$

$$\frac{-\alpha}{1-\alpha} \cdot x^{\frac{-1}{1-\alpha}} = \frac{w_t}{-w_c \cdot \bar{q}^{\frac{1}{1-\alpha}}}$$

$$x^{\frac{-1}{1-\alpha}} = \frac{w_t}{-w_c \cdot \bar{q}^{\frac{1}{1-\alpha}}} \cdot \frac{1-\alpha}{-\alpha}$$

$$x = \left(\frac{w_t}{w_c} \cdot \frac{1-\alpha}{\alpha} \cdot \frac{1}{\bar{q}^{\frac{1}{1-\alpha}}}\right)^{\frac{1-\alpha}{-1}=\alpha-1} = \left(\frac{w_t}{w_c} \cdot \frac{1-\alpha}{\alpha}\right)^{\alpha-1} \cdot \left(\bar{q}^{-\frac{1}{1-\alpha}=\frac{1}{\alpha-1}}\right)^{\alpha-1}$$

$$= \left(\frac{w_t}{w_c} \cdot \frac{1-\alpha}{\alpha}\right)^{\alpha-1} \cdot \bar{q}$$

Summering, the following is obtained:

$$\begin{cases} x = \left(\dfrac{w_t}{w_c} \cdot \dfrac{1-\alpha}{\alpha}\right)^{\alpha-1} \cdot \bar{q} \\[2em] y = \left(\dfrac{\bar{q}}{x^\alpha}\right)^{\frac{1}{1-\alpha}} \end{cases}$$

Substituting the value found for x in y:

$$y = \left\{\frac{\bar{q}}{\left[\left(\frac{w_t}{w_c} \cdot \frac{1-\alpha}{\alpha}\right)^{\alpha-1} \cdot \bar{q}\right]^\alpha}\right\}^{\frac{1}{1-\alpha}} = \left[\frac{\bar{q}}{\left(\frac{w_t}{w_c} \cdot \frac{1-\alpha}{\alpha}\right)^{\alpha \cdot (\alpha-1)} \cdot \bar{q}^\alpha}\right]^{\frac{1}{1-\alpha}}$$

$$= \left[\frac{\bar{q} \cdot \bar{q}^{-\alpha}}{\left(\frac{w_t}{w_c} \cdot \frac{1-\alpha}{\alpha}\right)^{\alpha \cdot (\alpha-1)}}\right]^{\frac{1}{1-\alpha}=-\frac{1}{\alpha-1}}$$

$$= (\bar{q}^{1-\alpha})^{\frac{1}{1-\alpha}} \cdot \left[\left(\frac{w_t}{w_c} \cdot \frac{1-\alpha}{\alpha}\right)^{-\alpha \cdot (\alpha-1)}\right]^{-\frac{1}{\alpha-1}} = \bar{q} \cdot \left(\frac{w_t}{w_c} \cdot \frac{1-\alpha}{\alpha}\right)^\alpha$$

At the end, knowing $x = t$ and $y = c$, the stationary point on the boarder $\overline{AB}$ is:

$$\begin{cases} t^* = \bar{q} \cdot \left(\dfrac{w_t}{w_c} \cdot \dfrac{1-\alpha}{\alpha}\right)^{\alpha-1} \\[1.5em] c^* = \bar{q} \cdot \left(\dfrac{w_t}{w_c} \cdot \dfrac{1-\alpha}{\alpha}\right)^{\alpha} \\[1em] q^* = \bar{q} \end{cases}$$

These solutions needs to be verified for their acceptability in the admissible set D once quantified the vector weights $\underline{w} = \begin{bmatrix} w_q \\ w_c \\ w_t \end{bmatrix}$, α and the threshold values $\bar{q}$, $\bar{c}$, $\bar{t}$. If admissible, one has to measure the function s at this stationary point.

b) *Function s restricted on the boarder $\overline{BC}$*

Function s restricted on $\overline{BC}$ gives:

$$x = \bar{x}$$

Then:

$$s(y) = s_{|bc}(x; y) = s(\bar{x}; y) = w_q \cdot \bar{x}^\alpha \cdot y^{1-\alpha} - w_t \cdot \bar{x} - w_c \cdot y$$

One needs to calculate the stationary points on the boarder $\overline{BC}$ by solving:

$$\frac{ds(y)}{dy} = \frac{d\left[w_q \cdot \bar{x}^\alpha \cdot y^{1-\alpha} - w_t \cdot \bar{x} - w_c \cdot y\right]}{dy} = 0$$

$$-w_c + (1-\alpha) \cdot w_q \cdot \bar{x}^\alpha \cdot y^{1-\alpha-1} = 0$$

$$y^{-\alpha} = \frac{w_c}{(1-\alpha) \cdot w_q \cdot \bar{x}^\alpha}$$

$$y = \left(\frac{1}{(1-\alpha)} \cdot \frac{w_c}{w_q} \cdot \frac{1}{\bar{x}^\alpha}\right)^{-\frac{1}{\alpha}} = \left(\frac{1}{(1-\alpha)} \cdot \frac{w_c}{w_q}\right)^{-\frac{1}{\alpha}} \cdot (\bar{x}^{-\alpha})^{-\frac{1}{\alpha}} = \frac{\bar{x}}{\left(\frac{1}{(1-\alpha)} \cdot \frac{w_c}{w_q}\right)^{\frac{1}{\alpha}}}$$

At the end, knowing $x = t$ and $y = c$, the stationary point on the boarder $\overline{BC}$ is:

$$\begin{cases} t^* = \bar{t} \\ c^* = \dfrac{\bar{t}}{\left(\dfrac{1}{(1-\alpha)} \cdot \dfrac{w_c}{w_q}\right)^{\frac{1}{\alpha}}} \\ q^* = t^{*\alpha} \cdot c^{*1-\alpha} \end{cases}$$

These solutions needs to be verified for their acceptability in the admissible set D once quantified the vector weights $\underline{w} = \begin{bmatrix} w_q \\ w_c \\ w_t \end{bmatrix}$, α and the threshold values $\bar{q}$, $\bar{c}$, $\bar{t}$. If admissible, one has to measure the function s at this stationary point.

c) *Function s restricted on the boarder $\overline{AC}$*

Function s restricted on $\overline{AC}$ gives:

$$y = \bar{y}$$

Then:

$$j(x) = s_{|ac}(x; y) = s(x; \bar{y}) = w_q \cdot x^\alpha \cdot \bar{y}^{1-\alpha} - w_t \cdot x - w_c \cdot \bar{y}$$

One needs to calculate the stationary points on the boarder $\overline{AC}$ by solving:

$$\frac{dj(x)}{dx} = \frac{d[w_q \cdot x^\alpha \cdot \bar{y}^{1-\alpha} - w_t \cdot x - w_c \cdot \bar{y}]}{dy} = 0$$

$$-w_t + \alpha \cdot w_q \cdot \bar{y}^{1-\alpha} \cdot x^{\alpha-1} = 0$$

$$x^{\alpha-1} = \frac{w_t}{\alpha \cdot w_q \cdot \bar{y}^{1-\alpha}}$$

$$x = \left(\frac{1}{\alpha} \cdot \frac{w_t}{w_q} \cdot \frac{1}{\bar{y}^{1-\alpha}}\right)^{\frac{1}{\alpha-1}} = \left(\frac{1}{\alpha} \cdot \frac{w_t}{w_q}\right)^{\frac{1}{\alpha-1}} \cdot \left(\bar{y}^{-(1-\alpha)=\alpha-1}\right)^{\frac{1}{\alpha-1}} = \bar{y} \cdot \left(\frac{1}{\alpha} \cdot \frac{w_t}{w_q}\right)^{\frac{1}{\alpha-1}}$$

At the end, knowing $x = t$ and $y = c$, the stationary point on the boarder $\overline{AC}$ is::

$$\begin{cases} c^* = \bar{c} \\ t^* = \bar{c} \cdot \left(\frac{1}{\alpha} \cdot \frac{w_t}{w_q}\right)^{\frac{1}{\alpha-1}} \\ q^* = t^{*\alpha} \cdot c^{*1-\alpha} \end{cases}$$

These solutions needs to be verified for their acceptability in the admissible set D once

quantified the vector weights $\underline{w} = \begin{bmatrix} w_q \\ w_c \\ w_t \end{bmatrix}$, α and the threshold values $\bar{q}$, $\bar{c}$, $\bar{t}$. If

admissible, one has to measure the function s at this stationary point.

d) *Function s restricted at the extreme points A, B and C*

The last step is to evaluate the value of the function s at the extreme points A, B and C of its set D:

- Function s restricted at point A is characterised by:

$$\begin{cases} x = \left(\frac{\bar{q}}{\bar{y}^{1-\alpha}}\right)^{\frac{1}{\alpha}} \\ y = \bar{y} \end{cases}$$

Then:

$$s(A) = s\left(x = \left(\frac{\bar{q}}{\bar{y}^{1-\alpha}}\right)^{\frac{1}{\alpha}}; y = \bar{y} \right)$$

$$= w_q \cdot \left(\frac{\bar{q}}{\bar{y}^{1-\alpha}}\right)^{\frac{1}{\alpha}} \cdot \bar{y}^{1-\alpha} - w_t \cdot \left(\frac{\bar{q}}{\bar{y}^{1-\alpha}}\right)^{\frac{1}{\alpha}} - w_c \cdot \bar{y}$$

Knowing $x = t$ and $y = c$, the following is obtained:

$$\begin{cases} t^* = \left(\frac{\bar{q}}{\bar{c}^{1-\alpha}}\right)^{\frac{1}{\alpha}} \\ c^* = \bar{c} \\ q^* = t^{*\alpha} \cdot c^{*1-\alpha} \end{cases}$$

- Function s restricted at point B is characterised by:

$$\begin{cases} x = \bar{x} \\ y = \left(\frac{\bar{q}}{\bar{x}^{\alpha}}\right)^{\frac{1}{1-\alpha}} \end{cases}$$

Then:

$$s(B) = s\left(x = \bar{x}; y = \left(\frac{\bar{q}}{\bar{x}^{\alpha}}\right)^{\frac{1}{1-\alpha}} \right) = w_q \cdot \bar{x}^{\alpha} \cdot \left(\frac{\bar{q}}{\bar{x}^{\alpha}}\right)^{\frac{1}{1-\alpha}} - w_t \cdot \bar{x} - w_c \cdot \left(\frac{\bar{q}}{\bar{x}^{\alpha}}\right)^{\frac{1}{1-\alpha}}$$

Knowing $x = t$ and $y = c$, the following is obtained:

$$\begin{cases} t^* = \bar{t} \\ c^* = \left(\frac{\bar{q}}{\bar{t}^{\alpha}}\right)^{\frac{1}{1-\alpha}} \\ q^* = t^{*\alpha} \cdot c^{*1-\alpha} \end{cases}$$

- Function s restricted at point C is characterised by:

$$\begin{cases} x = \bar{x} \\ y = \bar{y} \end{cases}$$

Then:

$$s(c) = s(x = \bar{x}; y = \bar{y}) = w_q \cdot \bar{x}^{\alpha} \cdot \bar{y}^{1-\alpha} - w_t \cdot \bar{x} - w_c \cdot \bar{y}$$

Knowing $x = t$ and $y = c$, the following is obtained:

$$\begin{cases} t^* = \bar{t} \\ c^* = \bar{c} \\ q^* = \bar{t}^{\alpha} \cdot \bar{c}^{1-\alpha} \end{cases}$$

Once evaluated the function *s* at the stationary points and at the extreme ones, these values assumed by *s* have to be compared. The project manager has to compare them by picking the biggest value that *s* assumes for a specific point. At that point, what the project manager is searching for corresponds to the value for project time, quality and cost that maximise the project scope.

Note that in order to provide a better interpretation of the results, the optimal values q^*, c^* and t^* are scaled. They are normalised between 0 and 1, as following: $\frac{q^*}{q_{max}}$, $\frac{c^*}{\bar{c}}$ and $\frac{t^*}{\bar{t}}$. Then results are interpreted considering the percentage reached of the maximum value of a variable at the disposal of the project. The maximum value for quality that the project can reach is obtained by spending all the time and cost available, as following: $q_{max} = \bar{t}^{\alpha} \cdot \bar{c}^{1-\alpha}$.

2.3. Multi-criteria Decision Analysis to assess consistent values to project priorities

Another consideration needs to be done about the multi-criteria decision analysis used as an analytical tool in order to assess the values for the project priorities. In daily as well as their professional life, people need to make decisions time to time varying from simple choices like "which jacket should I wear to work?", to complex decisions such as "which location do I select for the project?". "*We are all fundamentally decision makers. Everything we do consciously or unconsciously is the result of some decision*".[73] Every decision-making problem deals with multiple alternatives, which need to be evaluated but normally conflicting choices are acted upon intuitively. However when decision is more complex, it is useful to properly structure the problem-choice by defining the set of alternatives that need to be ranked. This includes the set of criteria associated with these alternatives to make the necessary judgement and an analytical methodology to obtain a consistent ranking of alternatives. One also has to consider the preferences of the decision maker (who makes the choice identifying the value of each attribute), with the aim to choose the one that most benefits their needs. Decision-making techniques have been developed for a while, to evaluate the alternatives, taking better-informed decisions and achieving consensus among people.[74]

During the project lifecycle, decision-making problems come up when a decision is required, in order to choose the best alternative from a set of available alternatives, taking into account a number of important aspects (criteria) whilst comparing them. The ultimate aim is to choose the alternative that best suits the needs of the project issue in a decision-making situation. These analytical techniques can be applied to different kinds of project issues such as assessing priorities to activities or selecting the best project-site location. It can also be used to select the best subcontractors,

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[73] Saaty (2008).
[74] For more details, see Oakshott (2012) and Saaty (2008).

measure the complexity of the project, control project performance, balancing the trade-off between the project constraints of time, cost, quality and scope. Finally, it can assist in creating a project team, prioritising projects in a project portfolio, prioritising stakeholders in the stakeholders register, assessing risk and choosing the required risk responses and other issues related to MCDA.[75]

The Project Manager is a decision maker and as such, he has to make choices whenever a decision-making situation arises. The aim of MCDA is to help project managers make better-informed decisions that best suit the project needs and in achieving consensus between all the stakeholders involved, managing and leading the project effectively. The aim of this work is using a multi-criteria decision analysis technique to obtain a ranking of values for the weights assessed for the variables of quality, cost and time in the function that needs to be maximised. It is a sort of assessing priorities for the project pillars. This work introduces the application of AHP (Analytical Hierarchy Process) method in project management to assess consistent values to the vector weights $\underline{w} = \begin{bmatrix} w_q \\ w_c \\ w_t \end{bmatrix}$.

The alternatives quality, cost and time are ranked along one single criterion weight that consists of their importance over the project scope. AHP is used for the consistent measurement of the values through a pair-wise comparison: the project manager (the decision-maker) compares the alternatives in pairs. *"The most effective way to concentrate judgement is to take a pair of elements and compare them on a single property"*.[76]

1. The decision-maker needs to identify the problem: the project manager faces three alternatives quality, cost and time (q, c, t) that need to be prioritised along one single criterion w - the impact (weight) of the alternative over the project scope according to its nature or the priority of the committee. The aim

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[75] For more details, see Project Management Institute (2013), Larson et al. (2011), Al-Harbi (2001), Górecka (2013), Tavana et al. (2014), Gorecka (2012), de Miranda Mota et al. (2009), Linkov et al. (2006), Fregonara (2009), Vidal et al. (2011), Ahmed et al. (2012),
[76] Saaty (1990).

is to obtain an approximation of the vector ranking $\underline{w} = \begin{bmatrix} w_q \\ w_c \\ w_t \end{bmatrix}$ that prioritises

the project pillars.

2. The project manager has to compare the alternatives in pairs by assessing priority for each one in terms of their importance over the others based on verbal judgements as in figure 12:

   o Quality Vs. Quality, Quality Vs. Cost, Quality Vs. Time.

   o Cost Vs. Quality, Cost Vs. Cost, Cost Vs. Time.

   o Time Vs. Quality, Time Vs. Cost, Time Vs. Time.

The pair-wise comparisons are done in terms of which element prevails over the other (alternative a_i Vs. alternative a_j) in function of their importance over the scope (weight).

Figure 12: Verbal Judgements to compare two alternatives.

The project manager translates the verbal judgements giving a value $w_{i,j}$ to each pair, that is the ratio between the importance of an alternative a_i over the alternative a_j in numerical terms. He uses the scale measurement of figure 13.

Numerical rating	Verbal judgments of preferences
9	Extremely preferred
8	Very strongly to extremely
7	Very strongly preferred
6	Strongly to very strongly
5	Strongly preferred
4	Moderately to strongly
3	Moderately preferred
2	Equally to moderately
1	Equally preferred

Figure 13: Scale measurement for verbal judgements.

The evaluation scale of pairs goes from 1 (equal importance) to 9 (extreme importance: one element has extreme importance over the other).

Then, $w_{i,j} = numerical\ rating_{a_i\ over\ a_i}$

3. The project manager constructs a pair-wise comparison matrix W size 3×3 for the criterion weight by putting the different values w obtained by the comparison between alternatives. The matrix is illustrated in figure 14.

W	q	c	t
q	$w_{q,q}$	$w_{q,c}$	$w_{q,t}$
c	$w_{c,q}$	$w_{c,c}$	$w_{c,t}$
t	$w_{t,q}$	$w_{t,c}$	$w_{t,t}$

Figure 14: Pair-wise comparison matrix W.

The matrix is based on the pair-wise comparison analysis of the alternatives of the column i with the alternatives of column j based on the scale measurement.

The matrix needs to be consistent. This matrix is perfectly consistent if the following are respected:

o The diagonal of the matrix presents value 1 in each box. It means that each pair-wise comparison in the diagonal provides the value 1. Then,

$$w_{q,q} = w_{c,c} = w_{t,t} = 1$$

o The values are symmetrical with respect to the diagonal. It means that if alternative a_i Vs. alternative $a_j = w_{i,j}$, then alternative a_j Vs. alternative $a_i = \dfrac{1}{w_{i,j}}$

o If alternative $a_{i=1}$ Vs. alternative $a_{j=2} = x$ and alternative $a_{i=2}$ Vs. alternative $a_{j=3} = y$, then alternative $a_{i=1}$ Vs. alternative $a_{j=3} = x \cdot y$.

o $W \cdot \underline{w} = n \cdot \underline{w}$, where W is the comparison matrix, n is the dimension of the matrix and $\underline{w}$ is the vector weight. When it is verified n is eigenvalue of W, while $\underline{w}$ the eigenvector of W.

If the matrix is inconsistent in place of n, there is a similar but different value indicated as lambda λ.

4. Once the pair-wise comparison matrix is created, the project manager proceeds to obtain the priority vector, which is the normalized eigenvector of the matrix. This methodology provides an approximation of the eigenvector $\underline{w}$ and eigenvalue λ of a reciprocal matrix W.

   a) The geometric mean for each alternative can be calculated by:

   $$Geometric\ mean = \sqrt[n]{\prod_{i,j=1}^{n} w_{i,j}}$$

   b) The geometric mean of each alternative is then normalised by dividing it for the sum of all geometric means in order to obtain an approximation of the vector ranking $\underline{w}$.

The project manager has obtained an approximation of the priority vector $\underline{w} = \begin{bmatrix} w_q \\ w_c \\ w_t \end{bmatrix}$ but he has to measure the consistency of its results. This methodology allows the decision maker to measure the consistency index according to:

$$CI = \frac{\lambda - 1}{n - 1}$$

If $CI = 0$ there is perfect consistency, while if $CI = 0{,}58$ there is perfect inconsistency for a matrix with $n = 3$.

The consistency is acceptable if it does not exceed the value of 0.10. If the value is higher, judgments needs to be reviewed.

This approach will be developed in the project management practices discussed in the case study.

2.4. Measuring project performance

With this *new constraints framework* it will be easier and more intuitive to understand *what* project success means and *how* to quantitatively monitor its optimal performance. The project success will be reached if the dummy variable scope takes the mode "yes". In turn it simply means that the project, by performing a set of different activities, has been able to deliver a specific project outcome with specific characteristics (by respecting a certain quality threshold: $q \geq \bar{q}$) within a specific budget (by respecting a certain cost threshold: $c \leq \bar{c}$) and within a specific amount of time (by respecting a certain time threshold: $t \leq \bar{t}$). So, generally speaking the success is reached if the scope is achieved and in turn it means to rely in a point of the function where:

$$\begin{cases} q \geq \bar{q} \\ c \leq \bar{c} \\ t \leq \bar{t} \end{cases}$$

Moreover this mathematical model allows the project manager to monitor if the project has reached (reviewing the historical data of the project in progress), is reaching (monitoring actual data of the project in progress) or is going to reach (projecting future estimations for the project in progress), the optimal project performance by performing a set of planned activities. It means if the scope is maximised, or rather the maximum performance is reached in the maximum point of the function studied, that being:

$$\begin{cases} q = q^* \\ c = c^* \\ t = t^* \end{cases}$$

In:

$$s = f(q, c, t)$$

It is the task of the project manager to ensure that the values of time, cost and quality are going to lean towards the optimal values desired, by adjusting the project plan, by making sure activities are performed correctly, by managing project risks (opportunities as well threats). In other words he has to ensure that the project pillar's values will tend to the optimal ones, or rather:

$$\begin{cases} q \to q^* \\ c \to c^* \\ t \to t^* \end{cases}$$

The task of project managers will be to understand how to bring quality, cost and time near to the optimal values by adopting best practices that best suit the project.

At the monitoring time for measuring the project progress, its scope performance should be at the maximum points values (in terms of quality, cost and time) identified by the maximisation problem. Already at time 0, once planning tools such as *Critical Path* method or *Crashing Costs* method are used, the project manager needs to be careful over complying with the project priorities. At this time the project has not been carried out yet and the planning phase is just concluded. The questions that arise are: Whether the project is within the critical area? The values for cost, time and quality are maximising the performance of the project? The same question needs to be made during monitoring time, when the project has been already carried out and at this point, having the needed data, the values for time, cost and quality have to be considered.

Having identified the optimal triplet (q^*, c^*, t^*) the project manager can estimate the performance of the real project by computing a distance of a project (q, c, t) by (q^*, c^*, t^*).

$$P = \sqrt{(q - q^*)^2 + (c - c^*)^2 + (t - t^*)^2}$$

2.5. Considerations

This chapter suggests how to link the project success to the concept of scope (basically, providing a project outcome, technical or non-technical) that in turn is influenced by the project pillars quality, cost and time. It provides an analytical method to obtain the optimal values for time, quality and cost through a problem of optimisation depending upon their priority over the scope. Furthermore this model leverages on the application of an analytical and consistent method (AHP) in order to obtain a quantified measure of the priority of the three variables over the project scope in order to clearly manage it, without leaving anything to chance and qualitative judgements. This maximisation problem is possible by unifying the concept of project success into a formula that considers scope, quality, time and cost. A good Project Manager, is able to make the most accurate trade-offs between those constraints, in order to carry out a project successfully. This work considers a new constraint framework, adding quality of the overall outcome as another critical variable for the success for the project, and not only considering time and cost performance as the *Earned Value Management* technique does. It has been thought to develop a mathematical model to make intuitive and to monitor the project performance. In turn in order to clarify the standards, the literature and the practices of the project management, which independent debates what is intended for project performance, without providing a clear and unitary vision of the project constraints scope, time, cost and quality. This *new constraints framework* wants to try in integrating quantitatively the project pillars quality, cost and time in the scope. It will be developed in the practices of chapter 3.9.

3. Project Management practices in *Lechler*: analytical tools to plan a business-IT project in the Spanish market

"Many companies, especially the smaller ones, do not consider project management as a key function but it is a methodology that, if applied in the right way, is really useful".[77]

This chapter provides a methodology to manage a business-IT project carried out between September 2013 and September 2014 by the multinational corporation *Lechler* in a foreign market. *Lechler* is an Italian company that produces paints having over 150 years of history and it has followed the evolution of paint products during the past three centuries. The company works with different brands in different chemical sectors: industry, refinish, decorative, yachting and the newly acquired sector of wood. More than 500 people work at the Italian headquarters of Como, comprising of two business plants in Seregno and Foligno, four further European subsidiaries in Manchester (UK), Grenoble (France), Barcelona (Spain) and Kassel (Germany) and in the Brazilian subsidiary of Paraì (Rio Grande do Sul).[78] *Lechler* headquarter (*Lechler s.p.a.*) formally authorised to carry out an international project jointly with its Spanish business branch (*Lechler Coatings Iberica s.l.*) in September 2013 consisting of developing a Web system for business orders with the aim of changing the purchase habits of Spanish customers in the Spanish market. Their purchase habits would have changed from a traditional old-fashioned system of mail and phone based business orders to a new and intuitive system of on-line business orders. A careful feasibility study offered important advantages both for organisation and Spanish customers and the project was authorised after the business case was developed. This project needed to be implemented maximum within a year, being the way to translate in action *Lechler* organisational strategy to achieve a long-term goal.[79] Clearly more projects have needed to be managed for a successful implementation of the strategy, in order

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[77] Dr. Bevilacqua (2015) in interviews, appendix A.
[78] For more details, see www.lechler.eu.
[79] For more details, see appendix A where interviews are called.

to achieve the long-term organisational objective. However, this work considers only the business-IT project implemented in the Spanish market for the data available, for my personal involvement in its implementation within the Spanish market and for the availability of the main stakeholders involved in this project. This work considers a project simulation, it means that the practices developed are applied to a project carried out in the past and already concluded without being framed by the same organisation in a project management methodology. It implies assumptions about the data. However, the aim of this work is to use the project management branch of knowledge to frame it. Information and evaluations over the variables are made by interviews with some of the main stakeholders involved in carrying out the project and by my personal experience and acknowledgement over this project implementation within the Spanish market. This work uses Excel to track the project management methodology step by step.[80] The chapter provides a specific project management methodology to fit this particular project. Different practices and techniques can be used to fit different types of projects depending upon their nature, complexity, uncertainty and the experience of project manager. The practices are very wide and diversified but the method a project manager chooses should be aligned with the standards provided by the Project Management Institute. For consistency and communication, the method and terminology developed in this work are aligned with such standards. Furthermore, this methodology of project management considers the international dimension of a project already outlined in chapter 1. This project takes an international dimension because the characteristics of an international project, depicted in chapter 1.2, are considered:

- It involves different business branches (*Lechler s.p.a.* and *Lechler Coatings Iberica s.l.*) in different countries (Italy and Spain).
- It involves different cross-cultural stakeholders (Spanish customers, Spanish business branch, Italian head office).
- It considers a large time and cost effort (about 75.000€ over one year).

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[80] Then, *Project Libre* (an open software for project management) will be used to track the GANTT chart for this business-IT project management.

- It faces differences between the countries of Spain and Italy in terms of political, social, economic and technological systems.
- It involves high risk and complexity over some long-term and clearly specified activities.

In particular, this project presents uncertainty in developing an IT system to change Spanish customers business orders habits facing historical and cultural barriers over the Spanish customers accustomed to rely on an old-fashioned system for business orders in the chemical industry. Clearly part of the objective has been to provide an intuitive, easy and quick system to meet customers' needs on easy-way practices. Furthermore, to provide the possibility of monitoring the business order just in time from their IT tools like PC, smart phones and tablets. One of the major risks involved, would be to lose the customer who is exposed to such a radically different way of inputting business orders. This IT system would have resolved other practical problems tracked in the possibility of integration between the IT tool and a general ERP software of the Spanish customer. Each ERP generates the business order sent directly to *Lechler Coatings Iberica s.l. Customer Service*. The ERP should generate a preloaded format text with certain characteristics and fields to be uploaded into the Web system directly, enabling it to be read. Another relevant risk faced by the project was to not meet a solution enabling integration with all customers ERP. This is due to the fact that there is no homogeneity of ERP between Spanish customers. A preloaded text to be imported directly in the Web system was the result of an accurate research.

The methodology to manage *Lechler* business-IT project leverages on the practices provided by Larson et al. (2011), Oakshott (2012), Project Management Institute (2013) and on the experience of professional project managers[81]. Furthermore it uses *Praxis*, a free framework for the management of projects[82], some articles published in the website *www.pmi.it/impresa/business-e-project-management*[83] and the data and

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[81] For more details, see appendix A where interviews are called.

[82] It includes a body of knowledge, methodology, competency framework and capability maturity model. The framework is supported by a knowledgebase of resources and an encyclopaedia. For more details, see *www.praxisframework.org*.

[83] For more details, see Bressan (2007).

information provided by the interviews with some of the main project stakeholders[84]. Moreover this methodology of project management introduces the application of the Multi-criteria Decision Analysis in supporting project managers whenever complex decision-making situations arise and the *new constraints framework*, outlined in chapter 2. The last section discusses Project Risk Management, detailing a specific chapter and denoting a model to manage the risk and uncertainty in projects carried out internationally. To frame *Lechler* business-IT project one needs to make the following assumptions:

- The project charter is just defined and approved, giving the project manager the authorisation to manage it, containing the business case and providing the draft of the project about quality requirements, time to be completed and containing costs (they will be reported in the *project scope statement* discussed in the activity *project kick-off*).

- The major stakeholders are the multinational company *Lechler* that carries out the project involving two organisations (*Lechler s.p.a.* headquarter and *Lechler Coatings Iberica s.l.* Spanish branch) and the customers of the Spanish market.

- The project work is carried out by the same organisation without outsourcing activities to external contractors such that the procurement management knowledge area is not considered.

- Due to the fact that this project was not framed by the organisation in a methodology of project management, specific data and specified activities are not available. However the estimation for staff, time and cost activities, as well as the activity network and risk assessment, are all made by the main stakeholders involved in the project.

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[84] For more details, see appendix A where interviews are called.

3.1. Project scope statement

The first step is having a clear description of the scope of the project, its boundaries, constraints, exclusions, its main deliverables, acceptance criteria and milestones. Furthermore, outlining the needs of the stakeholders involved, to plan and monitor the project in accordance with the scope and increasing the probability of its success. The project scope is the end result or mission of the project and to provide a detailed description of the scope, in line with the project constraints (quality, cost and time) and the needs of the stakeholders involved, it is necessary to create a scope template checklist (the *project scope statement*). This is turn needs to be progressively elaborated during the project lifecycle, with the following criteria:

- The needs of the major stakeholders.

- The definition of the project scope by identifying what the organisation expects to deliver to its customers once the project is completed, upon a certain time, as well as cost and quality requirements.

- The project scope requires some boundaries in order to avoid false expectations or waste of resources. They consist of exclusions (what is out from the project scope as providing software without outsourcing any activity) and constraints (a limiting factor over the execution of the project as contractual provisions that impose a predefined budget, imposed date or scheduled milestones).

- The technical requirements of the overall project outcome to guarantee suitable performance.

- Major deliverables: specific, expected and relevant intermediate outcomes, tangible (e.g. intermediate product component) or intangible (e.g. a result as an improvement of a physical index), consistent with the project scope, reached by carrying out an activity or a series of activities.

- Acceptance criteria: a set of conditions required to accept a major deliverable.

- Milestones: a significant point/event during the project occurring at a point in time. They are used as specific and formal checking points during the project lifecycle to check the progress of the project and monitoring it.

This template checklist is not the project charter. The latter is the high level project description and outcome characteristic definition that formally authorises a project manager, assigning him responsibility and a level of authority. Project charter document is the basis to develop the *project scope statement*. The business case is already developed determining what the project is worth to the required investments, containing a feasibility case study and preliminary cost estimation, such that the initial financial resources can be committed. The project scope will be achieved when all the deliverables will be reached in accordance to each acceptance criterion, the preset timeline and not overrunning the budget. The overall project progress will be monitored by leveraging on the *Earned Value Management* technique in four different gates. These gates correspond to the achievement of a specified result in a preset date (milestones). The *project scope statement* of *Lechler* business-IT project is illustrated in figure 15[85].

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[85] The *project scope statement* reports the minimum quality threshold the project must comply with. As in chapter 2, the minimum threshold that quality variable can assume ($\bar{q}$) is determined by the project manager by knowing the desired quality completion set by project committee ($r\%$) over its maximum value achievable. Then, the project manager can obtain the minimum quality threshold by knowing the time and cost thresholds and considering the same impact of cost and time over quality ($\alpha = 0,5$). Then: $\bar{q} = \frac{r\%}{100} \cdot q_{max} = \frac{61}{100} \cdot \bar{t}^\alpha \cdot \bar{c}^{1-\alpha} = 0,61 \cdot 200^{0,5} \cdot 75^{0,5} \cong 75.$

Project name: Web system for business orders	
Project type: business-IT Project	
Industry: Chemistry Industry	
Stakeholders involved	• *Lechler s.p.a. - head-office* • *Lechler Coatings Iberica s.l. - Spanish branch* • *Spanish customers*
Stakeholders needs	• *Changing the ordinarily way to purchase of the Spanish customers by providing an IT system that satisfy their needs (Lechler s.p.a.)* • *Having the possibility to make business orders online and monitoring them (Spanish customers)*
Project scope	• *Creating an easy, intuitive and quick web system order to purchase and monitor the orders online and implementing it in the Spanish market. Without outsourcing activities.*
Project time	• *Reaching the project scope before 200 labour days.*
Project cost	• *The overall project has not to exceed the cost of 75.000€*
Project quality	• *Reaching the technical and non-technical requirements of the project deliverables. The desired quality completion over its maximum is set by the project committee at about 61%.*

Technical requirements	• *The web system must be accessible on Lechler webpage by the customer*
	• *The web system must get inputs:*
	    ○ *externally by the clients when generating the orders*
	    ○ *internally by logistic, customer service and sales departments to gather information*
	• *The web system must generate the output in the form of orders and information accessible for customers*
	• *The Web system to be accessed by different IT tools (Smartphone, tablet, PC) and consultable from any place*
	• *Classifying the catalogue of products in function of the product industry (INDUSTRY, REFINISH, DECORATIVE,YACHTING, WOOD)*
	• *The web system can be compatible with a Spanish customer's ERP turning its orders in online orders*

Major Deliverables	1. *Web system for business orders beta version* 2. *Integration Web system beta - ERP* 3. *Market test over Web system beta* 4. *Fine-tuning for realising Web system official version* 5. *Web system implementation in the Spanish market* 6. *Web system adoption by Spanish customers*
Acceptance criteria	1. *Web system features regarding the acceptance criteria of sub-deliverables* 2. *Preloaded format file from ERP at a minimum cost* 3. *Test with no errors over 78% of customer partners* 4. *Resolution of all customer needs* 5. *Meeting the acceptance criteria of each related activity* 6. *Reaching the customer utilisation rate by business orders via Web repetition over 75% of Spanish customers*
Milestones	• *Web system beta* • *Web System released version* • *Web system implementation* • *Web system adoption*

Figure 15: *Lechler* business-IT *project scope statement*.

3.2. Project priorities through *MCDA*

Once the project template is mastered, it is needed to understand the priorities of the main stakeholders and translating them into thresholds. As in chapter 2, the scope of the project has to be more or less aligned with the constraints of time, cost or quality. If the project is more oriented upon satisfying customers' requirements, the quality of the outcome takes more importance over time and cost. However if the top management needs the outcome of the project delivered within a specific deadline, the time cannot be exceeded, absolutely affecting the budget as well the quality. In the last instance, if the project must respect the budget, the project manager must focus on not exceeding the cost and the resources available and in doing so, time and quality could vary. Each constraint varies according to the other; it means if at least one factor changes, at least one other factor is affected. For example a project can experience a growth in the scope, changing requirements or needs, and thus can overrun time, budget as well as quality (this phenomenon is known as scope creep). The boundaries of the project need to be defined by identifying the thresholds for each one of the criteria.

In overall terms the project manager needs to balance the trade-offs between quality, cost and time over these thresholds. To do so he needs to understand which set of criteria are needed to rank the set of alternatives (quality, cost and time), understanding which variable needs more attention, taking better informed decisions to manage the project, to achieve the consensus among the team members and avoid misunderstanding. Adjustments are needed during the project lifecycle if priorities change.

Multi-criteria decision analysis is used to assess values to weights regarding the project constraints of time, cost, quality in the scope function that needs to be maximised. The vector weight measures the impact of the three alternatives over the scope according to the project nature or the priority of the committee. It is a sort of assessing priorities to the project pillars by an analytical consistency tool and the Project Manager is the

decision maker. This work introduces the application of AHP (Analytical Hierarchy Process) as an analytical consistent method in project management to assess values to the vector weights $\underline{w} = \begin{bmatrix} w_q \\ w_c \\ w_t \end{bmatrix}$.[86] The project manager is the decision-maker and he ranks the alternatives *quality* (*q*), *cost* (*c*) and *time* (*t*) along the criterion *weight* (*w*) that correspond to their importance over the scope. He needs to compare the alternatives in pairs by assessing priority for each one in terms of their importance over the others based on verbal judgements.

- Quality Vs. Quality, Quality Vs. Cost, Quality Vs. Time.
- Cost Vs. Quality, Cost Vs. Cost, Cost Vs. Time.
- Time Vs. Quality, Time Vs. Cost, Time Vs. Time.

The project manager translates the verbal judgements giving a value *w* to each pair that is the ratio between the importance of an alternative of the column *i* over the alternative of column *j* of the matrix W 3×3 as in figure 16.

W	q	c	t
q	$w_{q,q}$	$w_{q,c}$	$w_{q,t}$
c	$w_{c,q}$	$w_{c,c}$	$w_{c,t}$
t	$w_{t,q}$	$w_{t,c}$	$w_{t,t}$

Figure 16: *Weights* matrix.

The evaluation scale of pairs goes from 1 (equal importance) to 9 (extreme importance: one element has extreme importance over the other). The project manager constructs a pair-wise comparison matrix size $n \times n$ for the criterion *w* by using the scale measurement of figure 13 reported in chapter 2. He performs the analysis comparing the three alternatives on a pair-wise basis and he puts the results in the comparison matrix as illustrated in figure 17.

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[86] For more details, see chapter 2.

Weight	Quality	Cost	Time
Quality	1	5	1/2
Cost	1/5	1	1/7
Time	2	7	1

Figure 17: *Weights* comparison matrix.

As in figure 17, the project manager considers[87]:

- Time "equally to moderately preferred" to quality.

- Time "very strongly preferred" to cost.

- Quality "strongly preferred" to cost.

Among the primary reasons, the project outcome must meet the customers' needs and for this the quality is considered of such importance over costs. Clearly there is a budget to be respected but it is malleable in function of achieving quality requirements of project deliverables. Nevertheless, the committee priority is project duration over quality (that in turn is prioritised over costs) because it is unavoidable that the outcome is delivered to market on time.

Once the pair-wise comparison matrix is created, the alternatives are ranked along the criterion *weight* through two steps:

1. It is calculated the geometric mean for each alternative.[88] The results are illustrated in figure 18.

Weight	Quality	Cost	Time	Geometric Mean
Quality	1	5	1/2	1,36
Cost	1/5	1	1/7	0,31
Time	2	7	1	2,41
			Total	4,07

Figure 18: Geometric mean.

2. The geometric mean of each alternative is then normalised by dividing it for the sum of all geometric means in order to obtain the vector ranking $\underline{w}$. The results are shown in figure 19.

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[87] For more details, see chapter 2.
[88] For more details, see chapter 2.

Weight	Normalised Geometric Mean
Quality	0,33
Cost	0,08
Time	0,59

Figure 19: Vector ranking.

The project manager has obtained the vector ranking $\underline{w}$ but he has to measure the consistency of its results. This methodology allows measuring the consistency through an index. The consistency index is calculated through the formula:

$$CI = \frac{\lambda - n}{n - 1}$$

The matrix is considered consistent if the consistency ratio, calculated as $\frac{CI}{INC}$ and expressed in percentage, is $< 10\%$. The project manager has found a value for λ equal to 3,01 and in turn the consistency ratio is equal to 1,22%. Finally, the matrix is considered consistent so that he has obtained a ranking of the three alternatives. He has prioritised the three project pillars through an analytical and consistent method.

3.3. Work Breakdown Structure

The *Work Breakdown Structure* (*WBS*) has to be employed to map the project detailing a structure of the scope (broken down into major deliverables and sub-deliverables) and how to achieve it. Work packages in terms of work activities, time, resources and budget needed to complete each one, becoming a monitoring point to measure its performance. Firstly the overall outcome of the project is identified and then the major deliverables that compose the outcome are signed, furthermore for each major deliverable, the sub-deliverables needed to reach each one are identified. These sub-deliverables are then further broken down into work packages. A work package is the lowest level of *WBS* within work activities. Each work activity takes a certain time (within a definite beginning and end date), a certain cost (employing a certain amount of resources), a certain quality requirement for the deliverable produced and providing a certain result. By adding up the data for each work activity in line with the linked deliverable, one can obtain a snapshot for each deliverable in terms of cost, time and quality requirement. This process of breaking down deliverables guarantees that each work activity is carried out by the individual of an organisational unit over which a responsible agent is identified. Hence, it is much easier for a project manager to monitor the project's progress by its performance, having the appropriate information at each level. To assign responsibilities over work activities, the *Organisational Breakdown Structure* (*OBS*) has to be designed with the aim to link it with the work activities of the *WBS*. *OBS* is useful to break the organisation into organisational units to link them with each work activity. The linked organisational unit becomes accountable for its package of work activities contributing to reach the sub-deliverable in a certain amount of time, within a budget and respecting its quality requirements. In turn, by calculating the data for each work activity corresponding to a specific organisational unit, each one becomes a monitoring point and it is under the responsibility of he who manages it.

Clearly, beforehand one needs to have a list of activities with its specific deliverables and to assign an ID number to each one. Each major deliverable is composed of various

specific activity deliverables, which all the while, become the acceptance criteria for such activity as illustrated in the figure 20.

Activity ID	Activity description	Activities deliverable/acceptance criteria	Major deliverable
D1	Project kick-off	Project documentation	Web system for business orders beta version
A1	Virtual meeting with target customers	Customer needs	
B1	Database model configuration	Database model configuration	
B2	Programs development	Database model development in accordance to the acceptance criteria provided in the project scope statement	
B3	Server development		
B4	GUI development		
B5	Customer info workflow	Database data workflow	
B6	Organisation info workflow		
B7	Logistic IT link development	Database order updating just in time	
B8	Access customised development	Personalised web system access	
C1	Market research	Possibility of Web-ERP integration at min. cost	Integration Web system beta - ERP
B9	Preloadable ERPs format	Preloaded ERP format	
A2	ERPs sample test	Positive test over at least 75% of different ERP models	
C2	Sample gathering	Sample gathering of at least 20 partners	Market test over Web system beta for errors resolution
A3	Test1 over sample partners	Web system errors identification	
A4	Errors evaluation	Evaluation of error type identified in Test1	
B10	Errors resolution	Rosolution of error type identified in Test1	
A5	Test2 over ERP partners	Positive test over at least 78% of partners	
A6	Ghatering new customers needs	New resolvable needs	Fine-tuning for realising Web system official version
B11	Logistic coordination programming	Lot splitting >= minimum number of peaces for a particular product line	
B12	Database programming	Database upgrading for wizard, product code and business line	
A7	Cusotmer portfolio development	Spanish customers portfolio	Web system implementation in the Spanish market
A8	Customers confidence relationship	Business relationship solidity and visit date	
A9	CSM training over SAP and Web system	Training level assased by IT manager	
A10	Handbooks development	.pdf documentation for customers	
A11	Business trips central-north area	Assessment by customer support manager	
A12	Business trips Andalucia area		
A13	Business trips Catalunya area		
A14	Business trips Levante area		
A15	Customers conference call		
A16	Customers post-relationship and problem solving	Assessment by customer support manager	Web system adoption by Spanish customers
A17	Web orders monitoring	Business orders repetition in time by at least 75% of customers	
A18	Results Analysis		
A19	Results evaluation		
D2	Web system evaluation		

Figure 20: Project activities ID and description, acceptance criteria and major deliverables.

Lechler includes two business branches in the project and each one involves different organisational units in carrying out the activities. The activities of an organisational unit are interlinked with these of other organisational units. *Lechler s.p.a.* is the headquarter and it involves four organisational units in carrying out the project: IT department, marketing department, customer service department and administration

department. Whilst *Lechler Coatings Iberica S.L.* is its Spanish branch involving its customer service department in carrying out the project.

Estimating the resources is a process compiled by the project manager developing a list of resources needed for completing the project. A Resource Breakdown Structure is designed to provide a hierarchical structure to show the resource availability in an aesthetically organised manner as illustrated in figure 21.
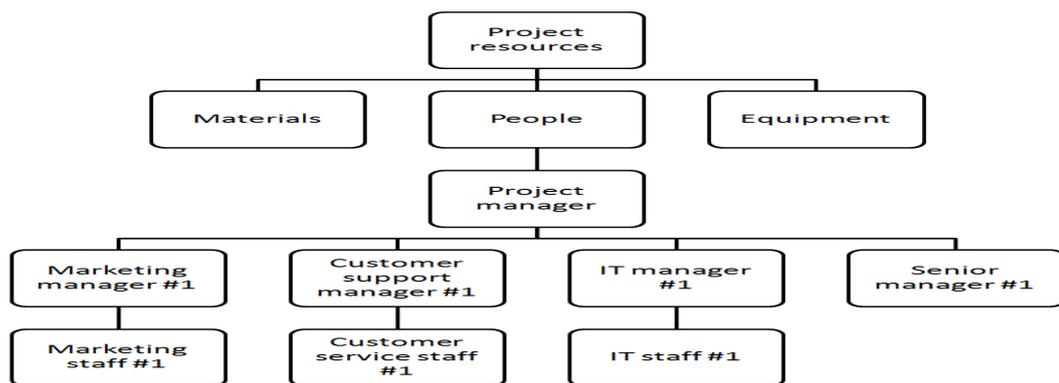
Figure 21: Resource breakdown structure.

Resources are broken down into categories and type of resources used to display the resource information needed to add staff, and equipment/materials for each department that carry out a set of activities as figure 22, 23, 24, 25 and 26 display. This project has no clear data about resources employed, in particular materials and equipment used in each activity are unknown. However an estimation of the staff employed has been done interviewing the stakeholders involved. Human resources will be estimated and then assigned for each department. It has to be noted that estimation is different from scheduling: resources will be scheduled to each activity once a network of activities is created.

Department	Activity ID	Assigned Staff	Activity description	Immediate preceding activities
Custiomer Service (CS) - Lechler head office	A1	CS Manager #1 - Staff #1	Virtual meeting with target customers	-
	A2	CS Manager #1 - Staff #1	ERPs sample test	A1
	A3	CS Staff #1	Test1 over partners ERP	A2
	A4	CS Manager #1	Errors evaluation	A3
	A5	CS Staff #1	Test2 over ERP partners	A4
	A6	CS Manager #1 - Staff #1	Ghatering new customers needs	A5

Figure 22: Customer Service (*Lechler* head office) department activities.

Department	Activity ID	Assigned Staff	Activity description	Immediate preceding activities
Administration - Lechler head office	D1	Senior Manager #1	Project kick-off	-
	D2	Senior Manager #2	Web System Evaluation	D1

Figure 23: Administration department activities.

Department	Activity ID	Assigned Staff	Activity description	Immediate preceding activities
Marketing - Lechler head office	C1	Marketing Staff #1	Market research	-
	C2	Marketing Manager #1 - staff #1	Sample gathering	C1

Figure 24: Marketing department activities.

Department	Activity ID	Assigned Staff	Activity description	Immediate preceding activities
IT - Lechler head office	B1	IT Manager #1 - Staff #1	Database model configuation	-
	B2	IT Manager #1 - Staff #1	Programs development	B1
	B3	IT Manager #1 - Staff #1	Server development	B2
	B4	IT Manager #1 - Staff #1	GUI development	B3
	B5	IT Manager #1 - Staff #1	Customer info workflow	B3
	B6	IT Manager #1 - Staff #1	Organisation info workflow	B3
	B7	IT Manager #1 - Staff #1	Logistic IT link development	B5;B6
	B8	IT Manager #1 - Staff #1	Access customised development	B4;B7
	B9	IT Manager #1 - Staff #1	Preloadable format ERPs sample generat	B8
	B10	IT Manager #1 - Staff #1	Errors resolution	B9
	B11	IT Manager #1 - Staff #1	Logistic coordination programming	B10
	B12	IT Manager #1 - Staff #1	Database Programming	B10

Figure 25: IT department activities.

Department	Activity ID	Assigned Staff	Activity description	Immediate preceding activities
Customer Service (CS) - Lechler Spanish branch	A7	CS Manager #1	Cusotmer portfolio development	-
	A8	CS Staff #1	Customers confidence relationship	A7
	A9	CS Manager #1 - Staff #1	CSM training over SAP and Web system	-
	A10	CS Staff #1	Handbooks development	A9
	A11	CS Manager #1 - Staff #1	Business trips central-north area	A8;A10
	A12	CS Manager #1 - Staff #1	Business trips Andalucia area	A11
	A13	CS Manager #1 - Staff #1	Business trips Catalunya area	A12
	A14	CS Manager #1 - Staff #1	Business trips Levante area	A13
	A15	CS Manager #1 - Staff #1	Customers cinference call	A14
	A16	CS Staff #1	Customers post-relationship and problem	A14
	A17	CS Staff #1	Web orders monitoring	A14
	A18	CS Staff #1	Results Analysis	A15;A16;A17
	A19	CS Manager #1	Results evaluation	A18

Figure 26: Customer Service (*Lechler* Spanish branch) department activities.

Knowing the activities for each department and for each sub and major deliverable, a list of work packages (indicated as *WP*) can be tracked. This helps in obtaining a *work breakdown structure*, which is interlinked with an *Organisational Breakdown Structure* as illustrated in the figure 27. Within each organisational unit there is a work package of activities from which to obtain a specific deliverable.

The overall project can be seen as a large work package that is composed of various smaller work activities creating a hierarchical structure that integrates work and responsibilities, helping the project manager to manage the project across structure levels.
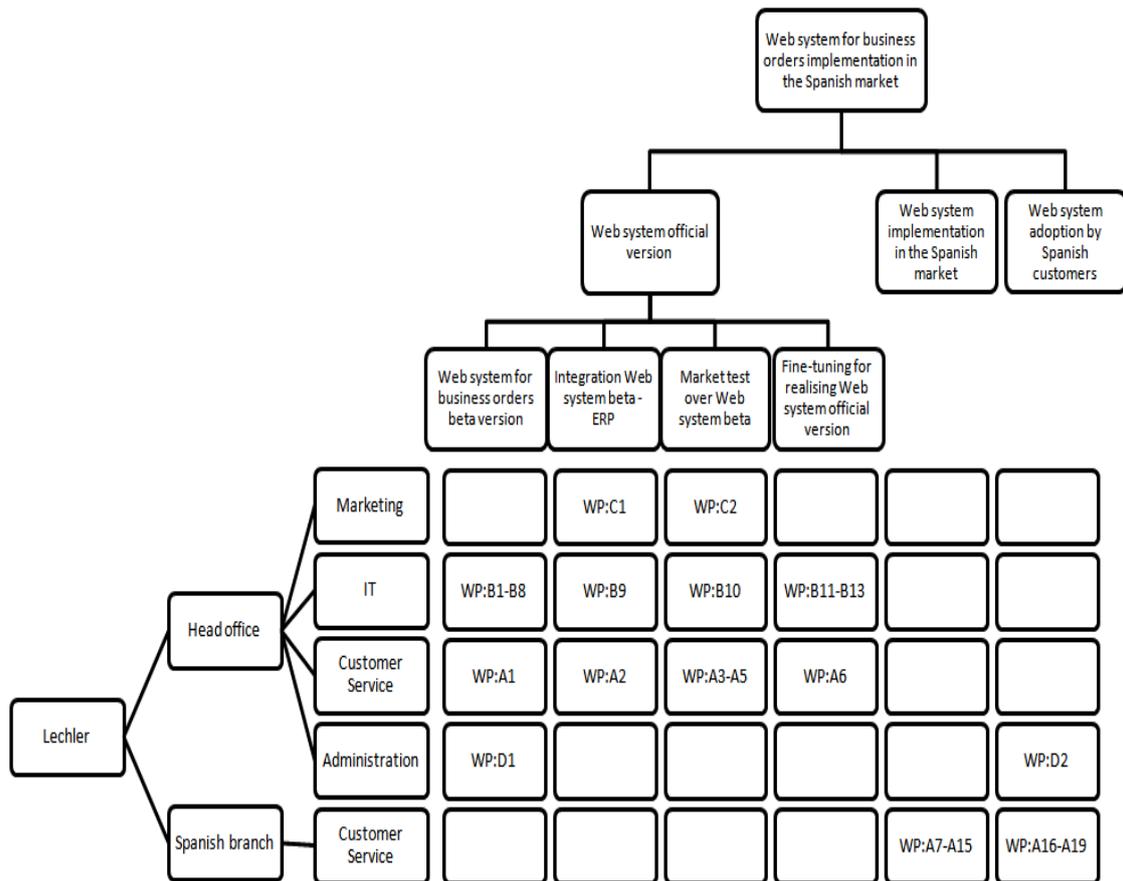
Figure 27: *Work Breakdown Structure* and *Organisational Breakdown Structure*.

3.4. Estimating time and cost: *three-point estimating*

Once a structure of the project has been designed, helping the project manager having its overview, it is necessary to estimate the time and cost of the overall project rolling up the estimation of each work activity to complete a major deliverable. This can be achieved by using the details provided by *WBS/OBS* matrix showing activity durations and resources (costs are assessed for those resources that are charged to the project.). It is a complex task because the accuracy and quality of the estimating can vary upon a lot of factors influencing the success of a project. For example the accuracy of estimating depends upon the distance of the events because the longer the duration of the project, the more uncertainty in estimating: the accuracy of estimating current events is higher than estimating future events in which there is more uncertainty. Moreover, the quality of estimating depends upon the closeness of individuals to the task, their experiences and the number of individuals that contribute to the estimation. The more an individual is involved with the task, the greater his experience and the more individuals involved, then the more accurate and qualitative the estimations become and in turn reducing errors by over or under estimating. In these cases, knowing data about cost and time that an activity can spend, a parametric estimate can be tracked. Furthermore, having historical data of past projects and refining them for the current project is very useful to increase the accuracy and quality of estimation. In fact, having a knowledge base about past projects can help to adjust the estimation by observing historical data over time and cost of similar activities from the past, in turn adjusted by differences in project complexity, and so obtaining a multiplier *X* to adjust the parametric estimation. There are two approaches that can be combined in estimating these variables: top down and bottom up. The first one is made by top management that uses experience and information to estimate time and cost while the second one is made by those responsible for the work activities, closer to the task and having greater knowledge over the process. The ideal estimation method should involve the interdependences between top and bottom levels to converge in an estimation that combines experience, historical data and task

knowledge. However, there are different methods in estimating time and cost but this work will consider one of the most used means of estimating under uncertainty: *three-point estimating*. Considering uncertainty over the estimation, it is adopted by calculating three point estimates to fix an approximate range of an activity time and cost value: Most Likely value is the most probable cost (*MLc*) and time (*MLt*) value of an activity based on a realistic evaluation for the required work. Once *ML* value is obtained, optimistic and pessimistic values are considered. The optimistic value (*O*) is the activity cost and time value based on the best-case scenario analysis for the same activity while the pessimistic value (*P*) is the activity cost and time value based on the worst-case scenario analysis for the same activity. Consensus method uses the experience of the team involved to estimate the time and cost value in the most likely, best and worst case scenario through meetings and brainstorming. A great rigor consensus method is *Delphi Method* that consists of a panel of experts familiar with the project carried out. They are exposed to a questionnaire providing opinions and judgments involving close questions about project time and cost anonymously to avoid the so called *halo effect*[89], providing a summary of responses. Then it is asks to review their estimations in accordance with the results, aiming to yield a better estimation by moving each response to the average for each value. Statistics over the answers are provided identifying the average of each estimation about the three point values of time and cost that are based on the majority of opinions. Clearly, as just explained, the resources are approximated and the data for cost and time available for this project consist of approximation through brainstorming over the total cost and the time a major deliverable or sub-deliverable has spent. Such that the estimation of the three points about time and cost are made leveraging on a brainstorming over time and cost of a major or sub-deliverable between the major stakeholders involved. The brainstorming released the data through a consensus method about the three points for time and cost for each major deliverable and sub-deliverable (that is not the specific deliverable of an activity). The logic behind the assignment of three points time and cost estimation is such: estimates for costs are in euro while estimates for

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[89] The *halo effect* refers to the tendency to make specific interferences on the basis of a general impression. For more details, see Rosenzweig (2007).

time are in labour days. Having the total cost and total time for each major deliverable or sub-deliverable and having assigned specific weights to the activities (according to brainstorming), the estimates of time and cost for each activity are yielded. Having three values for cost and time (Pessimistic, Most Likely and Optimistic values), the expected value (both for time and for cost) used in the network analysis can be tracked. Having a project composed of n activities, with $n \in N$, knowing the three point estimation values for time and cost and assuming a Beta distribution from the *PERT* analysis, the expected value for time ($\bar{t}$) or cost ($\bar{c}$) of an activity i (where $0 \leq i \leq n$) is respectively:

$$\bar{t}_i = \frac{Ot_i + 4 \cdot MLt_i + Pt_i}{6}$$
$$\bar{c}_i = \frac{Oc_i + 4 \cdot MLc_i + Pc_i}{6}$$

Where:

- Ot_i and Oc_i are respectively the optimistic time and cost value of the activity i.
- MLt_i and MLc_i are respectively the most likely time and cost value of the activity i.
- Pt_i and Pc_i are respectively the pessimistic time and cost value of the activity i.

The data over time values leveraging on the three points estimating assessed through the logic already explained are presented in figure 28, while the data over cost values leveraging on the three points estimating and assessed through the same logic are presented in figure 29. The data of optimistic, most likely and pessimistic time values of figure 28 would have resulted with a set of number after the comma but they are approximated. One should note that, considering an activity with the same time in optimistic, pessimistic and most likely value, different types of costs could correspond for the same values. It means that more or fewer labour hours, as well different materials, equipment or staff could have been spent/employed during that time.

Optimistic time	Most Likely time	Pessimistic time	Weights	Activity ID	Optimistic time	Most Likely time	Pessimistic time	Expected Time
58	86	148	0,0108553	D1	1	1	2	1
			0,009	A1	1	1	1	1
			0,069013453	B1	4	6	10	6
			0,399873038	B2	23	34	59	37
			0,079998579	B3	5	7	12	7
			0,177850063	B4	10	15	26	16
			0,095318191	B5	6	8	14	9
			0,095318191	B6	6	8	14	9
			0,031386593	B7	2	3	5	3
			0,031386593	B8	2	3	5	3
10	15	20	0,25	C1	3	4	5	4
			0,25	B9	3	4	5	4
			0,5	A2	5	8	10	8
25	35	40	0,2	C2	5	7	8	7
			0,2	A3	5	7	8	7
			0,2	A4	5	7	8	7
			0,2	B10	5	7	8	7
			0,2	A5	5	7	8	7
10	12	14	0,1	A6	1	1	1	1
			0,1	B11	1	1	1	1
			0,8	B12	8	10	11	10
40	42	44	0,015	A7	1	1	1	1
			0,035	A8	1	1	2	1
			0,075	A9	3	3	3	3
			0,075	A10	3	3	3	3
			0,27	A11	11	11	12	11
			0,22	A12	9	9	10	9
			0,11	A13	4	5	5	5
			0,15	A14	6	6	7	6
			0,05	A15	2	2	2	2
30	32	34	0,14	A16	4	4	5	4
			0,6	A17	18	19	20	19
			0,12	A18	4	4	4	4
			0,1	A19	3	3	3	3
			0,04	D2	1	1	1	1

Figure 28: Three-point time estimating.

Optimistic cost	Most Likely cost	Pessimistic cost	Weights	Activity ID	Optimistic cost	Most Likely cost	Pessimistic cost	Expected cost
29057	43027	74994,25	0,0108553	D1	315,42	467,07	814,09	499,63
			0,009	A1	261,51	387,24	674,95	414,24
			0,069013453	B1	2005,32	2969,44	5175,61	3176,45
			0,399873038	B2	11619,11	17205,34	29988,18	18404,77
			0,079998579	B3	2324,52	3442,10	5999,43	3682,06
			0,177850063	B4	5167,79	7652,35	13337,73	8185,82
			0,095318191	B5	2769,66	4101,26	7148,32	4387,17
			0,095318191	B6	2769,66	4101,26	7148,32	4387,17
			0,031386593	B7	912,00	1350,47	2353,81	1444,62
			0,031386593	B8	912,00	1350,47	2353,81	1444,62
5000	7500	10000	0,25	C1	1250,00	1875,00	2500,00	1875,00
			0,25	B9	1250,00	1875,00	2500,00	1875,00
			0,5	A2	2500,00	3750,00	5000,00	3750,00
6000	6500	7000	0,2	C2	1200,00	1300,00	1400,00	1300,00
			0,2	A3	1200,00	1300,00	1400,00	1300,00
			0,2	A4	1200,00	1300,00	1400,00	1300,00
			0,2	B10	1200,00	1300,00	1400,00	1300,00
			0,2	A5	1200,00	1300,00	1400,00	1300,00
2000	2400	2800	0,1	A6	200,00	240,00	280,00	240,00
			0,1	B11	200,00	240,00	280,00	240,00
			0,8	B12	1600,00	1920,00	2240,00	1920,00
3500	3587	3667	0,015	A7	52,50	53,81	55,01	53,79
			0,035	A8	122,50	125,55	128,35	125,50
			0,075	A9	262,50	269,03	275,03	268,94
			0,075	A10	262,50	269,03	275,03	268,94
			0,27	A11	945,00	968,49	990,09	968,18
			0,22	A12	770,00	789,14	806,74	788,88
			0,11	A13	385,00	394,57	403,37	394,44
			0,15	A14	525,00	538,05	550,05	537,88
			0,05	A15	175,00	179,35	183,35	179,29
1200	1240	1280	0,14	A16	168,00	173,60	179,20	173,60
			0,6	A17	720,00	744,00	768,00	744,00
			0,12	A18	144,00	148,80	153,60	148,80
			0,1	A19	120,00	124,00	128,00	124,00
			0,04	D2	48,00	49,60	51,20	49,60

Figure 29: Three-point cost estimating.

Time and cost estimating can also consider contingency reserves, accounting time and cost reserves to cover the uncertainty over the project. The reserves are part of the budget for certain types of identified risks. The more a project moves forward, the more detailed information is available, further increasing the contingency reserves that could be used, eliminated or reduced.

Contingency reserves are considered in the critical chain method. It was developed by Dr. E. Goldratt.[90] It combines the principles of *Critical Path* method and resource constraints scheduling by recognising chains of activities that are constrained by both network dependencies and resource availability. Moreover, this method considers the aspects of human nature in the fact that people tend to estimate activity duration based on previous negative experiences and implicitly including contingency reserves in those estimations. Such that they can be confident to complete the activity in the time estimated even if, things do not go as efficiently as they could.

If there is so much certainty in scheduling a project, it would be expected to respect the scheduling every time but it does not happen and Goldratt identified three reasons why it does not:

- If people know there is certainty, they will wait until the last minute to start the task.

- When people have multiple activities on multiple projects to perform, they attempt to work on them simultaneously and this creates inefficiencies.

- There is more probability to accumulate delays rather than advances. It means that if an activity will be concluded with delay then the following activity will be delayed. But if an activity will be concluded in advanced, the following activity will start in advance less likely.

Critical chain method can resolve these issues by applying the following principles:

- Estimate activity durations to represent in a way that there is a 50/50 chance of completion. Collect the additional contingency time reserves into 'buffers'.

- Identify the critical chain, which represents the combination of the main project duration constraint: network dependencies and resource constraints.

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[90] Larson et al. (2011).

- Calculate the contingency time reserves on the critical chain to create a 'project buffer' at the end of the critical chain. Calculate the contingency time reserves for non-critical chains to create the 'feeder buffers' at the end of each chain.

Figure 30 represents the critical chain, graphically represented by the dotted line. Based on a combination of the activity dependencies and resource requirements, this critical chain represents the longest path that controls the project duration. The contingency reserves of the activities on the critical chain are used to calculate the project buffer.

Not having details over resources and not considering contingency reserves, this work does not consider the critical chain approach.
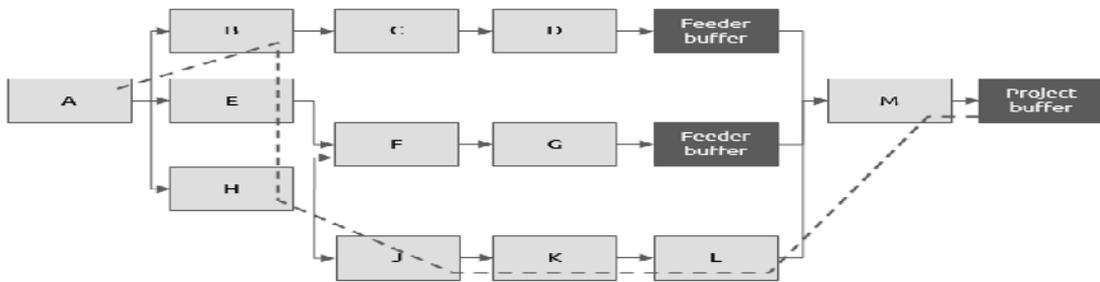
Figure 30: Critical chain example.

3.5. Critical Path Method

Knowing the activities network for each department, provided by data about the preceding activities for each one as in figures 22-26, tracking the logical sequence of activities of the entire project, as illustrated in the figure 31 (by figuring the predecessor activities for each one) and having also the estimation about time and cost already obtained, it is possible to schedule the project activities network path.

Activity ID	Activity description	Immediate preceding activities	Major deliverables
D1	Project kick-off	-	Web system beta
A1	Virtual meeting with target customers	D1	
B1	Database model configuation	A1	
B2	Programs development	B1	
B3	Server development	B2	
B4	GUI development	B3	
B5	Customer info workflow	B3	
B6	Organisation info workflow	B3	
B7	Logistic IT link development	B5;B6	
B8	Access customised development	B4;B7	
C1	Market research	A1	Web-ERP integration
B9	Preloadable format ERPs format	B8;C1	
A2	ERPs sample test	A1;B9	
C2	Sample gathering	C1	Market test
A3	Test1 over partners ERP	A2;C2	
A4	Errors evaluation	A3	
B10	Errors resolution	B9;A4	
A5	Test2 over ERP partners	A4;B10	
A6	Ghatering new customers needs	A5	Fine-tuning
B11	Logistic coordination programming	B10;A6	
B12	Database programming	B10;A6	
A7	Cusotmer portfolio development	B11;B12	Web system implementation
A8	Customers confidence relationship	A7	
A9	CSM training over SAP and Web system	B11;B12	
A10	Handbooks development	A9	
A11	Business trips central-north area	A8;A10	
A12	Business trips Andalucia area	A11	
A13	Business trips Catalunya area	A12	
A14	Business trips Levante area	A13	
A15	Customers conference call	A14	
A16	Customers post-relationship and problem solving	A14	Web system adoption
A17	Web orders monitoring	A14	
A18	Results Analysis	A15;A16;A17	
A19	Results evaluation	A18	
D2	Web system evaluation	D1;A19	

Figure 31: Activities dependency

To schedule the network path of the overall project, the Precedence Diagramming Method is used. It provides a schedule model in which the project activities are depicted by nodes and are graphically linked by a logical relationship that figures their performing sequence. There are different logical relationships: finish to start (a successor activity cannot start until the previous activity has finished), finish to finish (a

successor activity cannot finish until the previous activity has finished), start to start (a successor activity cannot start until a previous activity has started), start to finish (a successor activity cannot finish until the previous activity has started). However the most commonly used method by project management software is the Activity-on-Node (AON) that uses start to finish relationships. The AON approach considers nodes to represent the activities and arrows to sequence and connect them. Each node figures an activity, its duration mean, its earliest start time (calculated by looking at the earliest finish time of the predecessor – if it is the first activity on the network, it will be 0). The earliest finish time is calculated taking the earliest finish time of the predecessor plus the duration mean of the activity. The latest start time is calculated by subtracting at its latest finish time its mean duration and the latest finish time (calculated by looking forward at the latest finish time of the next activity). It is a forward process pass through the network when starting from the start node and it is a backward process pass through the network when starting from the end node. The float of an activity (the amount of time an activity can be delayed without delaying the successor activity), is the difference between the earliest-start-time and the latest-finish-time, this is equal to subtracting the earliest-finish-time with the latest-finish-time. The activities which float is 0 consist of the critical ones and the network of critical activities is the critical path. Delaying the start or finish time of critical activities, will delay the entire project of the same amount while the non-critical activities can be delayed by an amount equal to their floats and it will not impact on the project.

An example of AON relationship is presented in the figure 32.

Figure 32: AON relationship

Some considerations:

- D1 and A1 are the identification code (ID) to identify each activity.

- The mean duration is the number represented in the box, corresponding to the expected time value of such activity.

- The arrow indicates that activity D1 is the immediate predecessor of activity A1.

- The earliest start time is the number in the upper box corner at the left of each box.

- The earliest finish time is the number in the upper box corner at the right of each box.

- The latest start time is the number in the lower box corner at the left of each box.

- The latest finish time is the number in the lower box corner at the right of each box.

First of all, the network for each department is computed to show the sequence of department activities as illustrated in figure 33 and then, the overall project network is outlined to show the interdependences between department activities and figuring the logical flow sequence of project activities as shown in figure 34. Figure 33 shows only the logical sequence, while figure 34 shows even the data about time bolding the critical path.
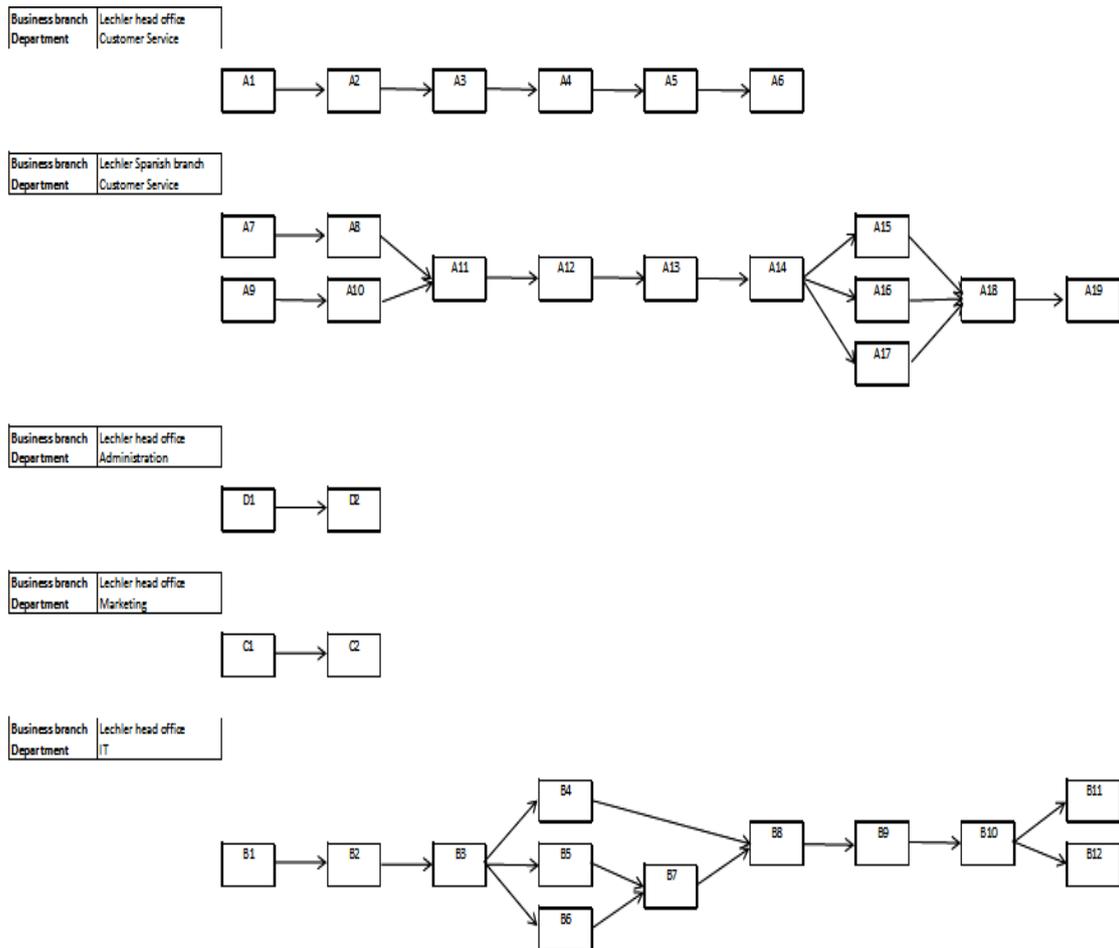
Figure 33: Network for each department

The overall project is graphically represented in a diagram by a network of project activities logically sequenced and created using the information of work packages gathered in *WBS*. An activity is derived from cost, time, technical requirements, and resources of the work packages it is composed of.
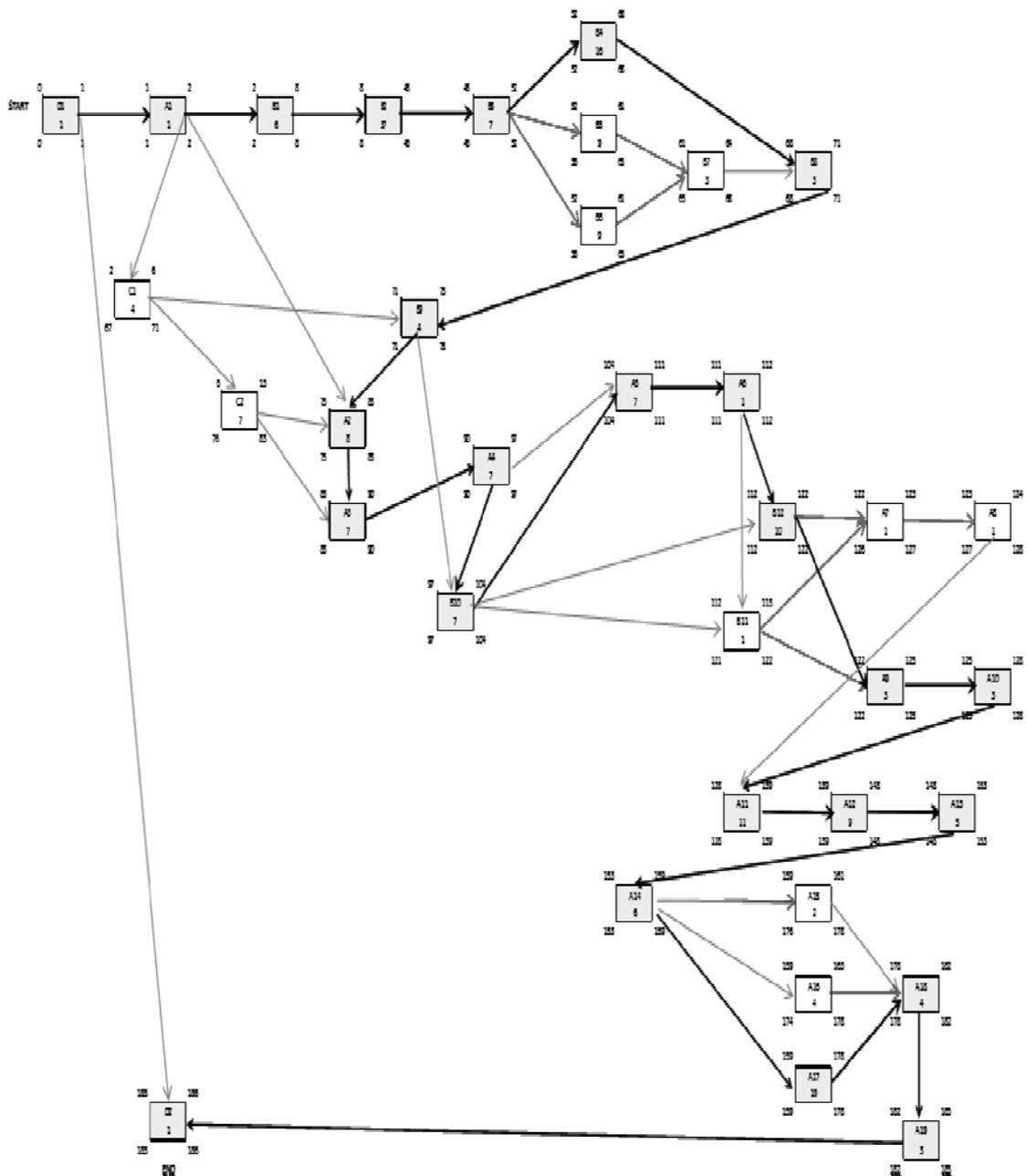
Figure 34: Project network

The network of figure 34 demonstrates a logical flow sequence of activities, and their dependences, that needs to be completed in an orderly way, helping the project manager to easily manage the project, having the start and finish date of the overall project network structured and identifying the critical path. The network follows some rules:

- It goes from left to right.

- An activity cannot start before the previous connected one is completed.

- The critical path cannot be delayed.

- It is a project plan so *what if* scenarios are not considered in the network.

- Each activity occurs once but if it needs to occur again it requires another ID number.

It has to be noted that the duration mean of an activity corresponds to its expected value calculated through three points estimating in time.

Having outlined the path of the project, the scope template can be updated assigning the data to for the expected milestones as illustrated in figure 35.

Milestones	• *Web system bet: #71 labour days with the end of activity B8*
	• *Web System released version: #122 labour days with the end of activity B12*
	• *Web system implementation: #161 labour days with the end of activity A15 if not delayed*
	• *Web system adoption: #186 labour days with the end of the last activity D2*

Figure 35: *Project scope statement* updating.

The average time of the entire project is known as critical time (t_{crit}) that is the sum of the expected values of time (the mean) of the k activities on the critical path[91].

$$t_{crit} = \sum_{i=1}^{k} \bar{t}_i$$

Figure 36 illustrates the floats of each project activity identifying these in the critical path with 0 slack.

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[91] The critical path of the project contains k activities of the n activities of the project network, so that $k < n$.

Activity ID	Earliest start time	Latest start time	Float
D1	0	0	0
A1	1	1	0
B1	2	2	0
B2	8	8	0
B3	45	45	0
B4	52	52	0
B5	52	56	4
B6	52	56	4
B7	61	65	4
B8	68	68	0
C1	2	67	65
B9	71	71	0
A2	75	75	0
C2	6	76	70
A3	83	83	0
A4	90	90	0
B10	97	97	0
A5	104	104	0
A6	111	111	0
B11	112	121	9
B12	112	112	0
A7	122	126	4
A8	123	127	4
A9	122	122	0
A10	125	125	0
A11	128	128	0
A12	139	139	0
A13	148	148	0
A14	153	153	0
A15	159	176	17
A16	159	174	15
A17	159	159	0
A18	178	178	0
A19	182	182	0
D2	185	185	0

Figure 36: Activities float.

The critical path is so composed:

D1→A1→B1→B2→B3→B4→B8→B9→A2→A3→A4→B10→A5→A6→B12→A9→A10 →A11→A12→A13→A14→ A17→A18→A19→D2.

This critical network is graphically represented in figure 37. The sum of the expected time values of each activity in this network is the critical time, the duration of the entire project (figure 38).
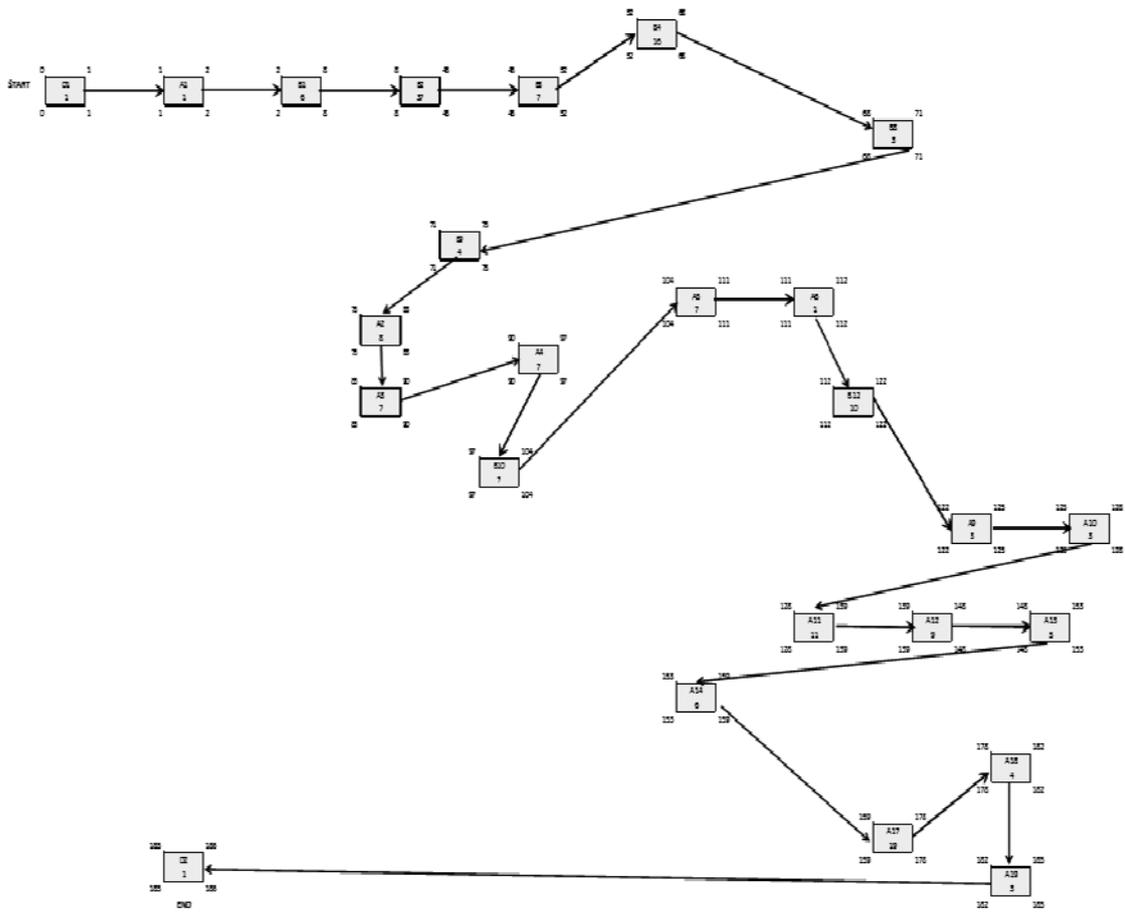
Figure 37: Critical path.

Activity ID	expected time (mean)
D1	1
A1	1
B1	6
B2	37
B3	7
B4	16
B8	3
B9	4
A2	8
A3	7
A4	7
B10	7
A5	7
A6	1
B12	10
A9	3
A10	3
A11	11
A12	9
A13	5
A14	6
A17	19
A18	4
A19	3
D2	1
Critical time	**186**

Figure 38: Critical time.

3.6. Scheduling resources, *crashing costs* and obtaining a project budget baseline

Once a network with a start and finish date is created, and estimation is done, the project manager needs to schedule resources and obtain a project budget baseline. Scheduling resources is another important point in the project because a project manager needs to assess the resources for each activity that employs a certain amount of resources in a certain amount of time. Therefore, he needs to make a realistic evaluation of resource availability, which has been already estimated. The limit of scheduling the project network is in its failure to deal with the availability of resources because the duration of each activity and thus the overall project, has been made independently by the resource availability considering only the logical sequence of the activities and assuming resources are available to perform each work. However, resources and activity network are not independent of each other. The availability of resources can deeply affect the project network, altering its logical sequence and in turn affecting its duration delaying it. "*One research study of more than 50 projects by Woodworth and Willie found that planned project network durations were increased 38 percent when resources were scheduled*".[92] There can be resource conflicts for parallel activities, they can be over committed ignoring peak demands or under committed ignoring troughs. Allocating them seldom is costly, and corrective actions are difficult once the project is carried out. It emerges that the relation between time and resource availability is a complex issue for each kind of project network because there are constraints on the network presented by the demand of resources at the time.

Demanding is to make sure that resources are allocated equally to the amount of time available. It means if resources allocated are above what is available, they are over-allocated. Instead there is under-allocation of resources if the opposite occurs. Resources allocation has to be adjusted such that the number of resources required is equal to the number of resources available. When resources are adequate to the

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[92] Larson et al. (2011).

requirements but the demand for resources vary extensively along the project presenting peaks, it can be smoothed by delaying non-critical activities to lower the peak demand and increase resource utilisation (resource smoothing process). When resources are not adequate but they present demand peaks, the latest finish time of an activity has to be delayed, increasing the duration of the overall project (resource constrained scheduling process), hence the network changes. To resolve scheduling problems and get a better project scheduled, splitting tasks is used as a scheduling technique to increase resource utilisation by interrupting the work in an activity and sending the resources to another activity for a certain period. However it is done in situation in which the project manager knows that the cost of the splitting a certain activity is small (e.g. interrupting people's work incurs high start-up and shutdown costs). To present the scheduled information, the Gantt chart is normally used by project managers. It figures the activities on the vertical axis and the dates on the horizontal axis, placed according to early start and early finish date (EST and EFT). Horizontal bars further demonstrate activity durations and the float of each activity is represented by a dotted line. The critical activities have no continuum of dotted lines while the non-critical activities have it, clearly showing their float. The resources needed are added to each bar. Moreover, a histogram of the resources needed for each activity is used by project managers as a tool to visualise the resources requirements during the time. Particularly, it is a bar chart used to display the specific amount of time a particular resource is scheduled to be worked on. It allows a project manager to view in a chart, what resources are utilised over a specific range of time and how long those resources will be employed. It helps to track the peaks and troughs in demand for resources. Moving from a peak into a trough, the net result is a smoother histogram and a histogram perfectly levelled means a fully utilised resource without any possible further savings. An example of Gantt chart is introduced in figure 39 regarding the activities for *Lechler* project. It is obtained through *Project Libre* that is an open software for Project Management.

Figure 39: GANTT chart.

The chart has been obtained working with the data available of the project, assessing the resources estimated to each activity through an open software for project management: *Project Libre*.

There is also the possibility to reduce project duration. There are several reasons behind reducing the duration of a project but nowadays companies normally tend to reduce the duration for time-to-market reasons. There are also financial advantages in doing so. There are different methods in reducing project activities both when resources are constrained (e.g. compromising quality of the deliverables) and when they are not constrained (e.g. adding additional resources to activities). The challenge is employing a method to balance the benefits of cutting down project duration with the increasing crashing cost without incurring on unnecessary costs. The aim is to reduce the project duration finding the minimum time at which the project can be reduced at a minimum extra-cost, before project starts or when it is on progress. In practice, having n project activities, it is needed to calculate the crash cost per day concerning each activity i to satisfy this condition.

$$Crash\ cost\ per\ day_i = \frac{extra\ cost_i}{\max reduction\ by\ crashing_i}$$

The extra cost of each activity i, expressed in euro, is the difference between the cost of crashing that activity and the normal cost of the same activity. While the maximum reduction of each activity by crashing it, expressed in time, is the difference between the normal duration of an activity and the duration of the same activity crashed. The result of the division is the crash cost per day for each activity and the lower the value, the lower the impact over the direct cost of the same activity, which in turn has less impact over the total direct cost of the project.

Simultaneously, one needs to make a list of all the paths in the project network.

The point now is to find the activity (or a combination of activities) on the critical path, choose the cheapest one to crash and reduce a common activity in the different paths (such that finding a combination of path that covers that activity). This process reduces those paths within which the activity crashed and it occurs until the critical path is of the same length of another non-critical path. In this case the latter becomes critical. The role to keep in mind is to not reduce the critical path under the other paths. Reducing project duration increases the cumulative crashing costs impacting on the total cost of the project. This is because the crash cost per day of an activity impacts on the direct cost of the activity, in turn impacting over the increasing total direct costs of the project. Conversely, total indirect costs decrease because they are essentially overhead costs such as administrative, interest, supervision, and so on, that cannot be associated directly with the activity. They increase with a corresponding time increase, which in turn influences the total cost of the project. Moreover, the project manager has to look at possible bonuses on completing the project before or penalties on completing the project over time. These factors have to be considered in addition to total project costs in order to find the project duration that minimizes the total project costs. This work does not consider the possibility of reducing project duration for the reason that data about extra costs and maximum reduction are not available.

Once resources are scheduled, it is possible to plan the cost for each activity[93] and time-phase it in order to obtain the planned cost value of an activity i at time t $(PV_{i,t})$[94]. It is possible to create a matrix where planned costs are broken up for activities (the planned cost for each activity i, PV_i that corresponds to the estimated expected cost for such activity obtained through the three points estimating, such that $PV_i = \bar{c}_i$) and in time. Time-phasing costs means that the planned values of each activity i are scheduled over time obtaining a planned cost for each activity at each time. In this work, the planned value for each activity i is divided by the number of the labour days that such activity i spends. It allows obtaining the cost per day for such activity i assuming that it employs in each day the same project labour hours, the same materials, equipments and human staff[95]. Having obtained the cost per day for each activity, the sum of the costs of all the activities in a specific day gives the planned value at that time t, PV_t. Then, $PV_t = \sum_{i=1}^{n} PV_{i,t}$ is the sum of the values of the matrix lines (that correspond to the activities planned cost values) by fixing the values of the matrix columns (that correspond to the time planned cost values). While, $PV_i = \sum_{t=1}^{T} PV_{i,t}$ is the sum of the values of the matrix columns (that correspond to the time planned cost values) by fixing the values of the matrix lines (that correspond to the activities planned cost values). Gathering these values in a matrix, as in figure 40, it is possible to disclose a project budget baseline, named Budget at Completion (BAC). It represents the value of the total project costs estimated during the scheduling phase. The Budget at Completion is the sum of all the planned cost values for each activity i that in turn is equal to the sum of all the planned cost values time-phased. Considering a project of n activities that takes a time $T(= t_{crit})$:

$$BAC = \sum_{i=1}^{n} PV_i = \sum_{t=1}^{T} PV_t = \sum_{i=1}^{n}\sum_{t=1}^{T} PV_{i,t} = \sum_{t=1}^{T}\sum_{i=1}^{n} PV_{i,t}$$

Having time-phased the planned cost values, the sum of PV_t at the checking time k correspond to the Budget Cost of Work Scheduled/Planned at that time k ($BCWP_k$).

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[93] It has to be pointed out that the expected cost for an activity is obtained through a three point estimation leveraging on the resources scheduled, after that the project network is created.
[94] For more details, see chapter 2.
[95] Clearly, it is an assumption because the data about staff and hourly rate are not available.

The latter is the cumulative project budget baseline moving along the timeline of the project. It means that is the cumulative planned cost at a specific time of the project. At the end of the project, budget at completion and the budget cost of work scheduled coincide. So, the budget cost of work scheduled at the time $t = k$ is:

$$BCWS_k = \sum_{t=1}^{k} PV_t$$

The budget cost of work scheduled at the end of the project ($t = T$) is:

$$BCWS_T = \sum_{t=1}^{T} PV_t = BAC$$

So, the Budget at Completion can be also seen as the planned cost value at the end (finish date) of the project obtained by cumulating the cost scheduled over time.

Having the data[96] of the project budget baseline as in figure 40, the cumulative project budget graph can be developed (figure 41).

Activity ID	Activity duration	EST	EFT	Planned Value	Cost month 1	Cost month 2	Cost month 3	Cost month 4	Cost month 5	Cost month 6	Cost month 7	Cost month 8	Cost month 9	Cost month 10	Deliverable	Deliverable Planned Value
D1	1	0	1	499,63	499,63											
A1	1	1	2	414,24	414,24											
B1	6	2	8	3176,45	3176,45											
B2	37	8	45	18404,77	5969,12	9948,53	2487,13									
B3	7	45	52	3682,06			3682,06									
B4	16	52	68	8185,82			4092,91	4092,91								
B5	9	52	61	4387,17			3899,70	487,46								
B6	9	52	61	4387,17			3899,70	487,46								
B7	3	61	64	1444,62				1444,62								
B8	3	68	71	1444,62				1444,62							Web system beta	46026,54
C1	4	2	6	1875,00	1875,00											
B9	4	71	75	1875,00				1875,00								
A2	8	75	83	3750,00				2343,75	1406,25						Integration web - ERP	7500,00
C2	7	6	13	1300,00	1300,00											
A3	7	83	90	1300,00					1300,00							
A4	7	90	97	1300,00					1300,00							
B10	7	97	104	1300,00					557,14	742,86						
A5	7	104	111	1300,00						1300,00					Test	6500,00
A6	1	111	112	240,00						240,00						
B11	1	112	113	240,00						240,00						
B12	10	112	122	1920,00						1536,00	384,00				fine-tuning	2400,00
A7	1	122	123	53,79							53,79					
A8	1	123	124	125,50							125,50					
A9	3	122	125	268,94							268,94					
A10	3	125	128	268,94							268,94					
A11	11	128	139	968,18							968,18					
A12	9	139	148	788,88							87,65	701,23				
A13	5	148	153	394,44								394,44				
A14	6	153	159	537,88								537,88				
A15	2	159	161	179,29								89,65	89,65		web implementation	3585,83
A16	4	159	163	173,60								43,40	130,20			
A17	19	159	178	744,00								39,16	704,84			
A18	4	178	182	148,80									74,40	74,40		
A19	3	182	185	124,00										124,00		
D2	1	185	186	49,60										49,60	web adoption	1240,00
BUDGET AT COMPLETION				67252,38												
Planned Value (time-phased)					13234,44	9948,53	18061,51	12175,82	4563,39	4058,86	2157,00	1805,75	999,09	248,00		
BUDGET COST OF WORK SCHEDULED					13234,44	23182,96	41244,47	53420,29	57983,68	62042,54	64199,54	66005,29	67004,38	67252,38		

Figure 40: Planned Value of each activity time-phased per month.

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[96] There is a lot of data associated with many labour days but they are grouped for month such that it is possible to illustrate them in a figure.
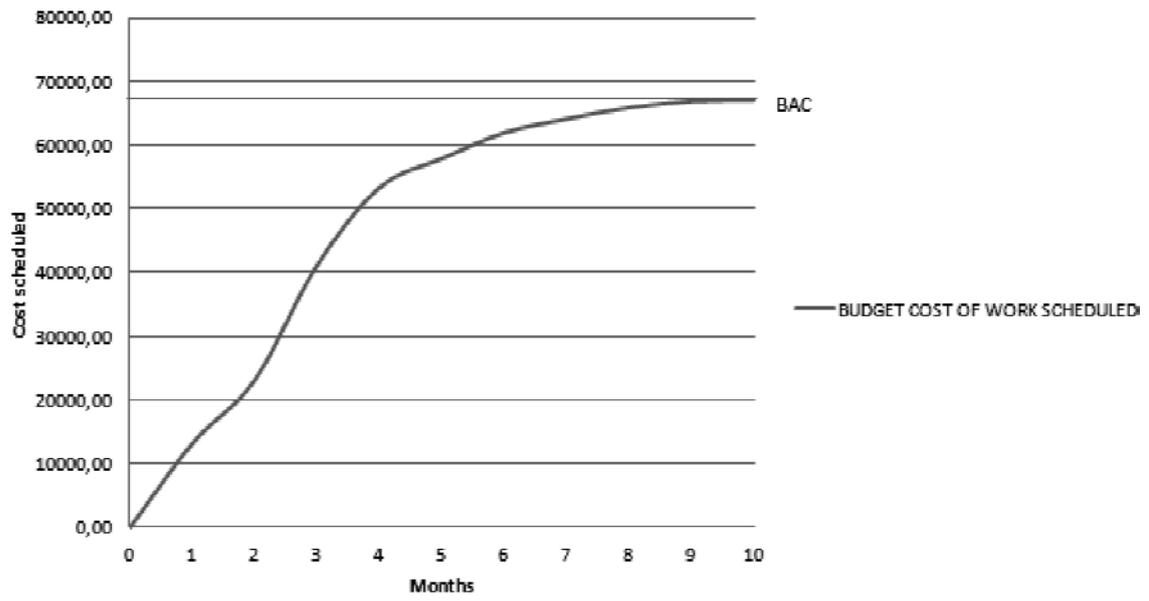
Figure 41: Project budget baseline.

3.7. *P.E.R.T.* analysis

Having time-phased the costs and planned the duration of the entire project, the last question is: can the project manager trust on these estimations? The work assumes that there is no certainty over the project activities such that project time and in turn project cost, will be subject to errors. Three points estimation has been used to rely on different values for time and for cost in three different case scenarios (most likely, optimistic and pessimistic). *PERT* analysis (*Programme Evaluation and Review Technique*) is a technique really useful for large-scale projects, when uncertainty overpasses most of all activities. This technique is computed automatically by project management software. By the way, this work will illustrate it both for cost and time.

Thanks to the optimistic, most likely and pessimistic values obtained for cost and time for each activity, the project manager can calculate through Excel an approximation of the error for each activity i.

It is represented by an approximation of the standard deviation for each activity i both for time, $SD(t)_i$ and for cost, $SD(c)_i$:

$$SD(t)_i = \frac{Pt_i - Ot_i}{6}$$

$$SD(c)_i = \frac{Pc_i - Oc_i}{6}$$

Figure 42 and 43 illustrates the standard deviation values both for time and for cost respectively, obtained by the three points estimating.

Activity ID	Optimistic time	Most Likely time	Pessimistic time	expected time (mean)	Standard Deviation (S.D.)
D1	1	1	2	1,00	0,162829494
A1	1	1	1	1,00	0
B1	4	6	10	6,33	1,035201801
B2	23	34	59	36,66	5,998095571
B3	5	7	12	7,33	1,199978678
B4	10	15	26	16,30	2,667750942
B5	6	8	14	8,74	1,429772868
B6	6	8	14	8,74	1,429772868
B7	2	3	5	2,88	0,470798893
B8	2	3	5	2,88	0,470798893
C1	3	4	5	3,75	0,416666667
B9	3	4	5	3,75	0,416666667
A2	5	8	10	7,50	0,833333333
C2	5	7	8	6,83	0,5
A3	5	7	8	6,83	0,5
A4	5	7	8	6,83	0,5
B10	5	7	8	6,83	0,5
A5	5	7	8	6,83	0,5
A6	1	1	1	1,00	0
B11	1	1	1	1,00	0
B12	8	10	11	9,60	0,533333333
A7	1	1	1	1,00	0
A8	1	1	2	1,47	0,023333333
A9	3	3	3	3,00	0
A10	3	3	3	3,00	0
A11	11	11	12	11,34	0,18
A12	9	9	10	9,24	0,146666667
A13	4	5	5	4,62	0,073333333
A14	6	6	7	6,30	0,1
A15	2	2	2	2,00	0
A16	4	4	5	4,48	0,093333333
A17	18	19	20	19,20	0,4
A18	4	4	4	4,00	0
A19	3	3	3	3,00	0
D2	1	1	1	1,00	0

Figure 42: Expected time value and standard deviation time value for each activity of the project.

Activity ID	Optimistic cost	Most Likely cost	Pessimistic cost	Expected cost	Standard Deviation (S.D.)
D1	315,42	467,07	814,09	499,63	83,11043506
A1	261,51	387,24	674,95	414,24	68,905875
B1	2005,32	2969,44	5175,61	3176,45	528,3813772
B2	11619,11	17205,34	29988,18	18404,77	3061,511286
B3	2324,52	3442,10	5999,43	3682,06	612,4857834
B4	5167,79	7652,35	13337,73	8185,82	1361,657133
B5	2769,66	4101,26	7148,32	4387,17	729,77593
B6	2769,66	4101,26	7148,32	4387,17	729,77593
B7	912,00	1350,47	2353,81	1444,62	240,3022937
B8	912,00	1350,47	2353,81	1444,62	240,3022937
C1	1250,00	1875,00	2500,00	1875,00	208,3333333
B9	1250,00	1875,00	2500,00	1875,00	208,3333333
A2	2500,00	3750,00	5000,00	3750,00	416,6666667
C2	1200,00	1300,00	1400,00	1300,00	33,33333333
A3	1200,00	1300,00	1400,00	1300,00	33,33333333
A4	1200,00	1300,00	1400,00	1300,00	33,33333333
B10	1200,00	1300,00	1400,00	1300,00	33,33333333
A5	1200,00	1300,00	1400,00	1300,00	33,33333333
A6	200,00	240,00	280,00	240,00	13,33333333
B11	200,00	240,00	280,00	240,00	13,33333333
B12	1600,00	1920,00	2240,00	1920,00	106,6666667
A7	52,50	53,81	55,01	53,79	0,4175
A8	122,50	125,55	128,35	125,50	0,974166667
A9	262,50	269,03	275,03	268,94	2,0875
A10	262,50	269,03	275,03	268,94	2,0875
A11	945,00	968,49	990,09	968,18	7,515
A12	770,00	789,14	806,74	788,88	6,123333333
A13	385,00	394,57	403,37	394,44	3,061666667
A14	525,00	538,05	550,05	537,88	4,175
A15	175,00	179,35	183,35	179,29	1,391666667
A16	168,00	173,60	179,20	173,60	1,866666667
A17	720,00	744,00	768,00	744,00	8
A18	144,00	148,80	153,60	148,80	1,6
A19	120,00	124,00	128,00	124,00	1,333333333
D2	48,00	49,60	51,20	49,60	0,533333333

Figure 43: Expected cost value and standard deviation cost value for each activity of the project.

If $SD_i = 0$ for time and/or for cost, it means that the activity i is perfectly computed with no risk involved in performing such activity. That is, for such activity, optimistic value will be equal to pessimistic value, which in turn is equal to the most likely value. Knowing the value of the standard deviation for each activity i, the variance for each activity i about time ($tVar_i$) and cost ($cVar_i$) is:

$$Var(t)_i = SDt_i^2$$
$$Var(c)_i = SDc_i^2$$

Figure 44 and 45 show the values for the variance of each activity about time and cost.

Activity ID	Standard Deviation (S.D.)	Variance (Var.)
D1	0,162829494	0,026513444
A1	0	0
B1	1,035201801	1,07164277
B2	5,998095571	35,97715048
B3	1,199978678	1,439948827
B4	2,667750942	7,116895087
B5	1,429772868	2,044250455
B6	1,429772868	2,044250455
B7	0,470798893	0,221651597
B8	0,470798893	0,221651597
C1	0,416666667	0,173611111
B9	0,416666667	0,173611111
A2	0,833333333	0,694444444
C2	0,5	0,25
A3	0,5	0,25
A4	0,5	0,25
B10	0,5	0,25
A5	0,5	0,25
A6	0	0
B11	0	0
B12	0,533333333	0,284444444
A7	0	0
A8	0,023333333	0,000544444
A9	0	0
A10	0	0
A11	0,18	0,0324
A12	0,146666667	0,021511111
A13	0,073333333	0,005377778
A14	0,1	0,01
A15	0	0
A16	0,093333333	0,008711111
A17	0,4	0,16
A18	0	0
A19	0	0
D2	0	0

Figure 44: Variance for activity time values.

Activity ID	Standard Deviation (S.D.)	Variance (Var.)
D1	83,11043506	6907,344416
A1	68,905875	4748,01961
B1	528,3813772	279186,8798
B2	3061,511286	9372851,357
B3	612,4857834	375138,8348
B4	1361,657133	1854110,147
B5	729,77593	532572,908
B6	729,77593	532572,908
B7	240,3022937	57745,19235
B8	240,3022937	57745,19235
C1	208,3333333	43402,77778
B9	208,3333333	43402,77778
A2	416,6666667	173611,1111
C2	33,33333333	1111,111111
A3	33,33333333	1111,111111
A4	33,33333333	1111,111111
B10	33,33333333	1111,111111
A5	33,33333333	1111,111111
A6	13,33333333	177,7777778
B11	13,33333333	177,7777778
B12	106,6666667	11377,77778
A7	0,4175	0,17430625
A8	0,974166667	0,949000694
A9	2,0875	4,35765625
A10	2,0875	4,35765625
A11	7,515	56,475225
A12	6,123333333	37,49521111
A13	3,061666667	9,373802778
A14	4,175	17,430625
A15	1,391666667	1,936736111
A16	1,866666667	3,484444444
A17	8	64
A18	1,6	2,56
A19	1,333333333	1,777777778
D2	0,533333333	0,284444444

Figure 45: Variance for activity cost values.

Knowing time and cost of the overall project ($t_{crit} = T$ and $BAC = C$), it is time to obtain the variance of the entire project for its duration and cost such that it is possible to calculate the error approximation regarding time and cost for the entire project. For time, it is the sum of the variance of the k activities on the critical path, i_{crit}:

$$Var(T) = \sum_{i_{crit}=1}^{k} Var(t)_{i_{crit}}$$

While, for cost it is the sum of the variance of the n project activities:

$$Var(C) = \sum_{i=1}^{n} Var(c)_i$$

The values are presented in figure 46 and 47.

Activity ID	Variance (Var.)
D1	0,026513444
A1	0
B1	1,07164277
B2	35,97715048
B3	1,439948827
B4	7,116895087
B8	0,221651597
B9	0,173611111
A2	0,694444444
A3	0,25
A4	0,25
B10	0,25
A5	0,25
A6	0
B12	0,284444444
A9	0
A10	0
A11	0,0324
A12	0,021511111
A13	0,005377778
A14	0,01
A17	0,16
A18	0
A19	0
D2	0
Critical Var.	**48,23559109**

Figure 46: Critical variance time value.

Activity ID	Variance (Var.)
D1	6907,344416
A1	4748,01961
B1	279186,8798
B2	9372851,357
B3	375138,8348
B4	1854110,147
B5	532572,908
B6	532572,908
B7	57745,19235
B8	57745,19235
C1	43402,77778
B9	43402,77778
A2	173611,1111
C2	1111,111111
A3	1111,111111
A4	1111,111111
B10	1111,111111
A5	1111,111111
A6	177,7777778
B11	177,7777778
B12	11377,77778
A7	0,17430625
A8	0,949000694
A9	4,35765625
A10	4,35765625
A11	56,475225
A12	37,49521111
A13	9,373802778
A14	17,430625
A15	1,936736111
A16	3,484444444
A17	64
A18	2,56
A19	1,777777778
D2	0,284444444
Project cost Var.	**13351489**

Figure 47: Project cost variance.

By obtaining this data, it helps the project manager to obtain the standard deviation for the entire project representing its approximate errors for time and for cost (the values are presented in figure 48 and 49):

$$SD(T) = \sqrt{Var(T)}$$

$$SD(C) = \sqrt{Var(C)}$$

CRITICAL PATH				
D1-A1-B1-B2-B3-B4-B8-B9-A2-A3-A4-B10-A5-B12-A9-A10-A11-A12-A13-A14-A17				
critical tim	critical SD	critical Var.		
186	6,945184742	48,23559109		

Figure 48: Critical path, critical time, critical standard deviation time value, critical variance time value.

Project cost Var.	13351489
Project cost S.D.	3653,968937
Project expected cost	67252,38

Figure 49: Project cost variance, project cost standard deviation, project expected cost.

Once obtaining the data, the project manager may question whether he could rely on these time and cost estimations.

In other terms he needs to compute the probability that the total project time is bigger than limited project time imposed in the project charter an reported in the *project scope statement* (the beginning of September 2014 = about 200 labour days from the beginning of September 2013) that in turn is lower than the pessimistic project time: $P(T) = \sum_{i=1}^{k} Pt_i$= 244 labour days.

$$\Pr(project\ duration > x_t) = \Pr\left(\frac{project\ duration - t_{crit}}{S.D._{\cdot t_{crit}}} > \frac{x_t - t_{crit}}{S.D._{\cdot t_{crit}}}\right) =$$

$$= \Pr\left(\frac{project\ duration - t_{crit}}{S.D._{\cdot t_{crit}}} \le \frac{t_{crit} - x_t}{S.D._{\cdot t_{crit}}}\right)$$

$$= \Pr\left(\frac{project\ duration - t_{crit}}{S.D._{\cdot t_{crit}}} \le Z_t\right) = N(Z_t)$$

Where:

- $\frac{project\ duration - t_{crit}}{S.D._{\cdot t_{crit}}}$ is a random variable whose distribution is approximated by a normal distribution with average 0 and variance 1, denoted by $N(0,1)$.

- $Z_t = \frac{t_{crit} - X_t}{S.D._{\cdot t_{crit}}}$.

The probability the project manager is looking for is obtained as illustrated in figure 50.

critical tim	critical SD	critical Var.
186	6,945184742	48,23559109
x	200	
z	-2,013208654	
Pr	2,20%	

Figure 50: Probability that the project takes more than limit project time obtained from *PERT* analysis.

At the opposite side, if the project manager is searching for the probability that the total project time is lesser than x_t it will simply be:

$$\Pr(project\ duration < x_t) = 1 - N(Z_t)$$

It will result 97,8%.

In the same way, he needs to compute the probability that the total project cost is bigger than limited project cost imposed in the project charter and reported in the *project scope statement* that in turn is lower than the pessimistic project cost $P(C) = \sum_{i=1}^{n} Pc_i$ = 99741,25€.

$$\Pr(project\ cost > x_c) = N(Z_c)$$

The probability the project manager is looking for is obtained as illustrated in figure 51.

Project expected cost	67252,38
Project cost Var.	13351489,00
Project cost S.D.	3653,97
X	75000
Z	-2,12
Pr	1,70%

Figure 51: Probability (obtained from *PERT* analysis) that the project cost is bigger than the limited project cost.

At the opposite side, if the project manager is searching for the probability that the total project cost is lesser than x_c it will simply be:

$$\Pr(project\ cost < x_c) = 1 - N(Z_c)$$

It will result 98,3%.

3.8. Earned Value Management technique[97]

Once the project starts, its progress needs to be measured. The project manager needs to evaluate its performance progress over cost and time. *Earned Value Management* is used as a technique to evaluate project progress over time and cost and it is employed by the most project management software. It is a technique that quantifies time in monetary terms in order to compare cost with time using the same scale of measurement.

Earned Value indicates the value of work that has been done until that time (EV_t) expressing it in proportion (%) of the value that should have been done at that point (PV_t). Then, $EV_t = \%PV_t$. There are different rules for calculating EV_t of an activity that is ongoing. However, a single rule should be set just from the beginning of the project. The alternative used in this work is the *0/100* rule that consists on imputing the activity completion at 0% of its planned value until it is completed. In other words, when the activity starts EV_t for such activity is zero ($EV_t = \frac{0 \cdot PV_t}{100} = 0$). When the task ends, EV_t becomes equal to PV_t ($EV_t = \frac{100 \cdot PV_t}{100} = PV_t$).

- Earned Value is used to measure the project performance over time by comparing it with the planned cost. At time t, if the project is on time, it needs to produce (the earned value) how effectively scheduled (the planned cost). If delays occur, the project will not produce as effectively planned because the activity has not produced the value yet. At time t of verification, being on time scheduled means that the activity has to be finished and yielding a value as planned in time, such that $EV_t = PV_t$. If EV_t is not equal to PV_t, it means the activity at time t has not been completed yet, without producing a value.

- Earned Value is also used to measure the project performance over cost by comparing it with the actual cost. Being on cost scheduled means the activity

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[97] It has to be pointed out that in the Earned Value Management technique applied in this particular project, differences in terminology occur. The variance at completion is named difference at completion, schedule and cost variance are named schedule and cost difference respectively.

119

has to incur a cost (AC_t) equal to the value effectively produced ($EV_t = \%PV_t$). Differences at that time t can represent the gap between costs incurred and planned costs effectively realised (if the activity is completed on time, because $EV_t = \frac{100 \cdot PV_t}{100} = PV_t$). While if the activity is not completed, differences at that time t represent the gap between costs incurred and planned costs not realised yet because $EV_t = \frac{0 \cdot PV_t}{100} = 0$. The latter example is so, because, for every $AC_{i,t}$ it corresponds to $EV_{i,t}$ verified at time t.

So earned value represents the value of what has been actually produced and, at the time of verification t, it can differ both from the planned cost value at that time t (PV_t) both from the cost of the work actually done until that point t (AC_t). EV_t itself does not say much. Thus, project manager must use it in combination with other measures to determine the real state of the project. The *Earned Value Management* technique is used to compare the values of the work done (Earned Values) with the final balance values (actual costs) and scheduled costs (planned costs) upon obtaining the measure of performance of the project examined in terms of time and cost. This technique uses a set of metrics for measuring the performance of the project from two points of view: that of the costs (project cost) and that of the actual progress (project time).

Take the cumulative values of time-phased costs scheduled, of time-phased actual costs and of the time-phased earned values, regarding the work. Then present them in a graph with the timeline of the project on the horizontal axis and the cumulative values in the vertical axis, three cumulative values curves can then be tracked and each one can increase in different ways.

- The budget cost of work scheduled at the time t ($BCWS_t$) is the cumulative values of time-phased planned costs:

$$BCWS_t = \sum_{k=0}^{t} PV_k$$

At the end of the project ($t = T$),

$$BCWS_T = BAC$$

- The budget cost of work performed at the time t ($BCWP_t$) is the cumulative values of time-phased earned values of work performed until time t:

$$BCWP_t = \sum_{k=0}^{t} EV_k$$

- The actual cost of work performed at the time t ($ACWP_t$) is the cumulative values of time-phased actual costs of work performed until time t.

$$ACWP_t = \sum_{k=0}^{t} AC_k$$

At the time t of checking, the difference between cumulative earned values at that time ($BCWP_t$) and cumulative cost scheduled ($BCWS_t$) can provide an indicator: schedule difference at time t (Sd_t).

$$Sd_t = BCWP_t - BCWS_t$$

With a negative sign it will figure that the project is carried out over the time scheduled, if the sign is positive it means the project is carried out under the time scheduled or if it is zero, the project is carried out on time scheduled.

However, it is not enough to know if the work is ahead of or behind the time planned, one should also considered the cost indicator. At the same time of verification t, the difference between cumulative earned value $BCWP_t$ and cumulative actual cost $ACWP_t$ provides cost divergence at time t.

$$Cd_t = BCWP_t - ACWP_t$$

When the value is negative, it shows that the project is carried out over the cost scheduled. While if the value is positive it means the project is carried out under the cost scheduled or if it is zero, the project is carried out on plan costs.

To measure the project performance at time t, two indexes are used: Cost Performance Index CPI_t and Schedule Performance Index SPI_t.

- The cost performance index measures the cost efficiency of budgeted resources expressed by the ratio calculated at the recording date t between

the earned values cumulated on the activities carried out until that date ($BCWP_t$) and the cumulative values of how much has been actually spent until that date ($ACWP_t$).

$$CPI_t = \frac{BCWP_t}{ACWP_t}$$

The index can be less than, equal to or greater than 1 depending on whether the costs are higher, in line or lower than expected ones.

- The schedule performance index measures the schedule efficiency expressed by the ratio calculated at the recording date t between the share of the budget already spent at that date $BCWP_t$ and what was scheduled by the plan $BCWS_t$.

$$SPI_t = \frac{BCWP_t}{BCWS_t}$$

The index can be less than, equal to or greater than 1 depending on whether the project progress is greater than, equal to or less than what has been set in the project plan.

Also in this case, the indexes have a certain meaning if they are considered jointly. The performance of costs must be assessed alongside the performance of the progress and vice versa. By two different indexes and the three possible outcomes, 9 meaningful situations can emerge as illustrated in figure 52.

CPI	SPI	Situation
CPI > 1	SPI > 1	The project is spending less and it is ahead
CPI > 1	SPI = 1	The project is spending less and it is respecting time
CPI > 1	SPI < 1	The project is spending less but there is delay
CPI = 1	SPI > 1	The project is spending the cost planned and it is ahead
CPI = 1	SPI = 1	The project is perfectly respecting cost and time
CPI = 1	SPI < 1	The project is spending the plan but there is a delay
CPI < 1	SPI > 1	The project is spending more but it is ahead
CPI < 1	SPI = 1	The project is spending more but it is on time
CPI < 1	SPI < 1	The project is spending more but there is delay

Figure 52: Cost and time performance indexes.

For the control of the project one needs to make the projection to the end date and determine the actual state of the progress by forecasting. Going on with the project one needs to calculate and distribute the new amount of expected cost remaining to complete the work based on available resources at each time of verification t (It is named *Estimated cost To Complete: ETC_t*). The latter represents an estimation of how much money the project manager will spend to complete the remaining part of the project, considering its cost performance.

$$ETC_t = \frac{(BAC - BCWP_t)}{CPI_t}$$

It is used to calculate the new proper budget of the project. This budget represents the total cost the project will spend. It is named *Estimate at Completion (EAC)* and it could differ from *BAC* (the *budget at completion*) because it considers the cumulative actual costs (and not the planned ones) plus the forecasted costs. Then in this work, it is calculated by adding to the current cumulative cost at time t ($ACWP_t$) the estimated cost to complete (ETC_t).

$$EAC = ACWP_t + ETC_t$$

The differences between the *budget at completion* and the *estimated at completion* can figure the amount of project budget surplus or deficit. At the time of verification t, *Difference at Completion (DAC_t)* is:

$$DAC_t = BAC - EAC$$

With positive sign, it means the project is under planned costs (budget surplus), with negative sign it means the project is above planned costs (budget deficit) while if $DAC_t = 0$, the project is on planned costs.

This technique is applied to the project studied in this chapter.

The trends of figures 55, 56, 57 are tracked by the data reported in figure 54. In turn, they are obtained by time-phasing the cost values as in figure 53 and assuming that:

- The periods of cost and time performance measurement are every twenty labour days within a month, hence these are considered the values of each month. This work assumes the project is started and that it is at the end of

labour day #71, in the fourth month. Labour day #71 is the formal gate to review the project progress and to forecast the new proper budget. It coincides with the first milestone reported in the *project scope statement* updated.

- The different cost values (Earned Value, actual cost and plan cost) of the activities carried out until month 4 are time-phased. Clearly there is no data available for the cost incurred for each activity in each period, hence the actual cost for each activity regarding each month is imputed considering the *most likely scenario*.

Activity ID	Activity duration	EST	EFT	Planned Value	PV month 1	PV month 2	PV month 3	PV month 4 (#71)
D1	1	0	1	499,63	499,63			
A1	1	1	2	414,24	414,24			
B1	6	2	8	3176,45	3176,45			
B2	37	8	45	18404,77	5869,12	9948,53	2487,13	
D3	7	45	52	3682,06			3682,06	
D4	16	52	68	8185,82			4092,91	4092,91
B5	9	52	61	4387,17			3899,70	487,46
D6	9	52	61	4387,17			3899,70	487,46
B7	3	61	64	1444,62				1444,62
D8	3	68	71	1444,62				1444,62
C1	4	2	6	1875,00	1875,00			
D9	4	71	75	1875,00				468,75
C2	7	6	13	1300,00	1300,00			

Activity ID	Activity duration	EST	EFT	Planned Value	EV month 1 (EFT<=20)	EV month 2 (EFT<=40)	EV month 3 (EFT<=60)	EV month 4 (EFT<=71)
D1	1	0	1	499,63	499,63			
A1	1	1	2	414,24	414,24			
B1	6	2	8	3176,45	3176,45			
B2	37	8	45	18404,77	0,00	0,00	18404,77	
B3	7	45	52	3682,06			3682,06	
D4	16	52	68	8185,82			0,00	8185,82
D5	9	52	61	4387,17			0,00	4387,17
B6	9	52	61	4387,17			0,00	4387,17
D7	3	61	64	1444,62				1444,62
B8	3	68	71	1444,62				1444,62
C1	4	2	6	1875,00	1875,00			
B9	4	71	75	1875,00				0,00
C2	7	6	13	1300,00	1300,00			

Activity ID	Activity duration	EST	EFT	Planned Value	AC month 1 (ML scenario)	AC month 2 (ML scenario)	AC month 3 (ML scenario)	AC month 4 (ML scenario)
D1	1	0	1	499,63	457,07			
A1	1	1	2	414,24	387,24			
B1	6	2	8	3176,45	2989,44			
B2	37	8	45	18404,77	5580,11	9300,18	2325,05	
D3	7	45	52	3682,06			3442,10	
B4	16	52	68	8185,82			3826,18	3826,18
B5	9	52	61	4387,17			3645,56	455,70
D6	9	52	61	4387,17			3645,56	455,70
B7	3	61	64	1444,62				1350,47
D8	3	68	71	1444,62				1350,47
C1	4	2	6	1875,00	1875,00			
D9	4	71	75	1875,00				468,75
C2	7	6	13	1300,00	1300,00			

Figure 53: Time-phased earned values, planned and actual costs.

Tempo (month)	Verifica	BCWS	ACWP	BCWP	Cd	Sd	CPI	SPI	ETC	EAC	DAC
0		0	0	0	0	0	0	0	0	0	0
1	labour day #20	13234,44	12578,87	7265,32	-5313,5	-5969,1	0,577582	0,548971			
2	labour day #40	23182,96	21879,05	7265,32	-14613,7	-15917,6	0,332068	0,313391			
3	labour day #60	41244,47	38763,49	29352,15	-9411,3	-11892,3	0,757211	0,711663			
4	labour day #71	49670,29	46670,75	49201,54	2530,8	-468,8	1,054227	0,990563	17122,34823	63793,10	3459,28
5		57983,68									
6		62042,54									
7		64199,54									
8		66005,29									
9		67004,38									
10		67252,38									

Figure 54: *Earned Value Management* data.

At the times of verification labour day #20, #40 and #60, Cd and Sd remain negative as illustrated in figure 54. It means that the project is carried out over the cost scheduled because the costs incurred are higher than the value gained ($ACWP_t > BCWP_t$) and the project is carried out over the time scheduled because the value gained is lower than the planned costs ($BCWS_t > BCWP_t$). However, it has to be noted that from labour day #40, the values of these indexes start to decrease. While at the time of verification labour day #71, Cd goes positive while Sd remains negative. It indicates that at that time the project is behind the time schedule but it is carried out under the cost scheduled. The trends of the cumulative values are presented in figure 55. These situations are reflected in the performance indexes of cost and time. They are lower than 1 indicating cost and schedule inefficiency until month #3. At month #4, at labour day #71, CPI goes higher that one reflecting the cost efficiency of budgeted resources, while SPI remain lower that one, even if its value increase going near to zero evidencing the project time is reaching the schedule efficiency. The trends of CPI and SPI are illustrated in figure 57. Each trend tends to zero, after a decrease in month #2. In month #4, at labour day #71, CPI is higher than one, but SPI in not even equal to one. Moreover, the graph shows the projection of the trend in the future through Excel, based on the data until labour day #71. As evidence, they will be higher than one. The reason behind the inefficiency of the project in cost and time during the first and third months is that the work is considering the technique *0/100* in order to assign the earned value to activities. It means that the activity B2, that has started at labour day #8 incurring in actual costs, is not considered completed and such it will not produce a value until its finished date (month #3). At month #3, activity B2 terminates

being considered completed and as such producing value (precisely at labour day #45) and it incurs a cost lower than the value produced (that is 100% of the planned cost value for the same activity). Moreover, activities B3, B4, B5, B6 start at month #3 but only activity B3 terminates behind month #3 (precisely at labour day #52) being considered completed and so producing value. It means activities B4, B5, B6 are not considered completed and so they do not produce the value yet (they will produce value in the month #4).

The comparison between cumulative values for each period is presented in figure 56: clearly, in the first thirds months the cumulative earned value is lower than the cumulative actual cost that in turn is lower than the cumulative scheduled costs. Looking over the data, it seems a good project performance in cost, but as already explained it takes a negative Cd and Sd that in turn is reflected by the two performance indexes lower than one. Clearly the reason behind the inefficiency is explained by the technique *0/100*. Sure enough, at the fourth month the values rearrange and $BCWS_{71} > BCWP_{71} > ACWP_{71}$, in turn $CPI_{71} > 1$ and $SPI_{71} \rightarrow 1$.

Providing the first deliverable, at labour day #71, there is an amount of budget surplus because the cumulative actual costs incurred are lower than the cumulative earned values. Here a demonstration of the last sentence. It is known:

$$
\begin{cases}
DAC_t = BAC - EAC \\
EAC = ACWP_t + ETC_t \\
ETC_t = \dfrac{(BAC - BCWP_t)}{CPI_t} \\
CPI_t = \dfrac{BCWP_t}{ACWP_t}
\end{cases}
$$

Then:

$$DAC_t = BAC - EAC = BAC - (ACWP_t + ETC_t)$$

$$= BAC - \left(ACWP_t + \frac{(BAC - BCWP_t)}{CPI_t}\right)$$

$$= BAC - \left(ACWP_t + \frac{(BAC - BCWP_t)}{\frac{BCWP_t}{ACWP_t}}\right)$$

$$= BAC - (ACWP_t + (BAC - BCWP_t) \cdot \frac{ACWP_t}{BCWP_t}$$

$$= BAC - \left(ACWP_t + BAC \cdot \frac{ACWP_t}{BCWP_t} - ACWP_t\right)$$

$$= BAC - BAC \cdot \frac{ACWP_t}{BCWP_t} = BAC \cdot (1 - \frac{ACWP_t}{BCWP_t})$$

Therefore, if $ACWP_t$ is higher than $BCWP_t$ then the ratio $\frac{ACWP_t}{BCWP_t}$ will be higher than one. As a consequence, $1 - \frac{ACWP_t}{BCWP_t}$ will be always negative and the project will present a deficit (DAC_t negative). On the other side, if $ACWP_t$ is lower than $BCWP_t$, the ratio $\frac{ACWP_t}{BCP_t}$ will be lower than one such that $1 - \frac{ACWP_t}{BCWP_t}$ will be always positive and the project will present a surplus (DAC_t positive).
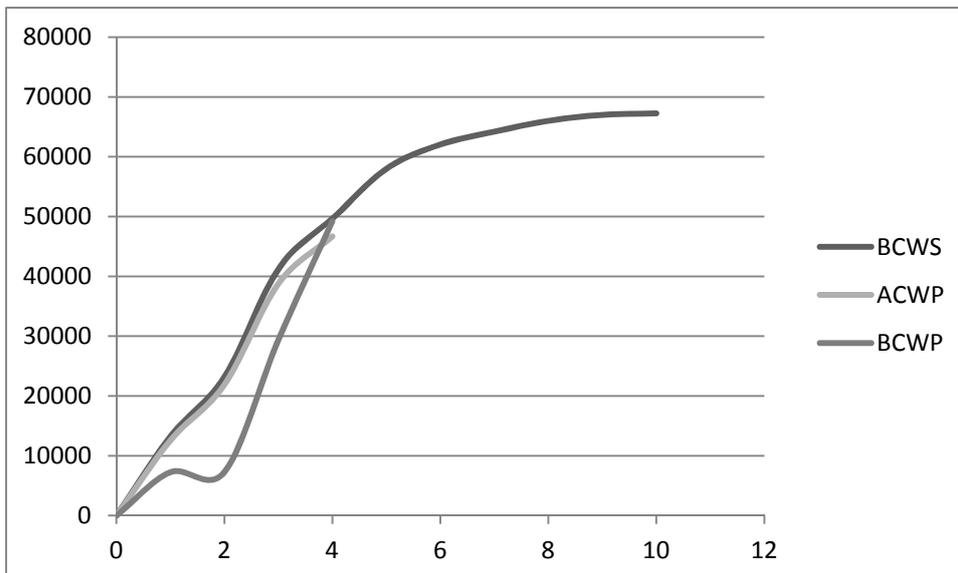
Figure 55: Cumulative values trends for actual costs, earned values and scheduled costs.
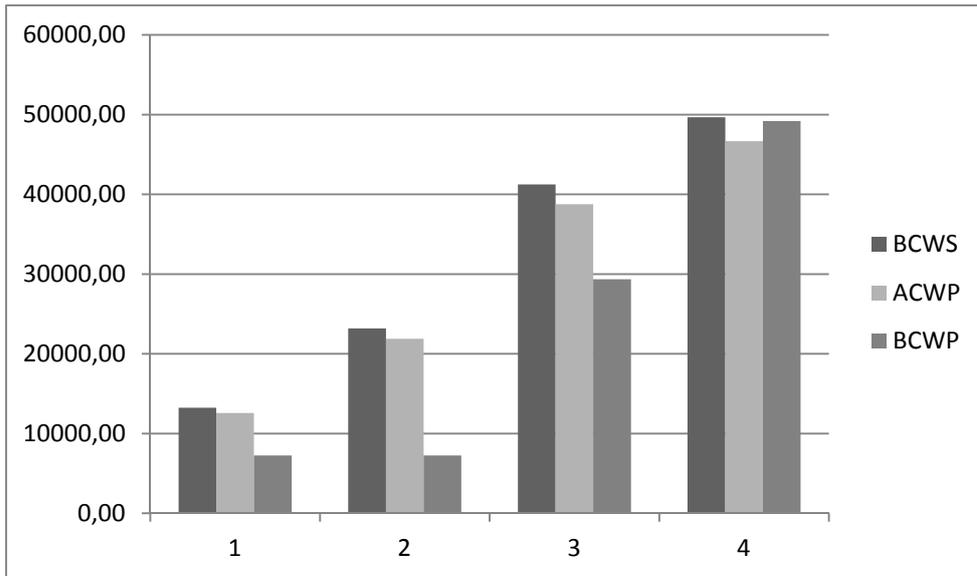
Figure 56: Comparison between scheduled costs, actual costs and earned values for each monitoring period.
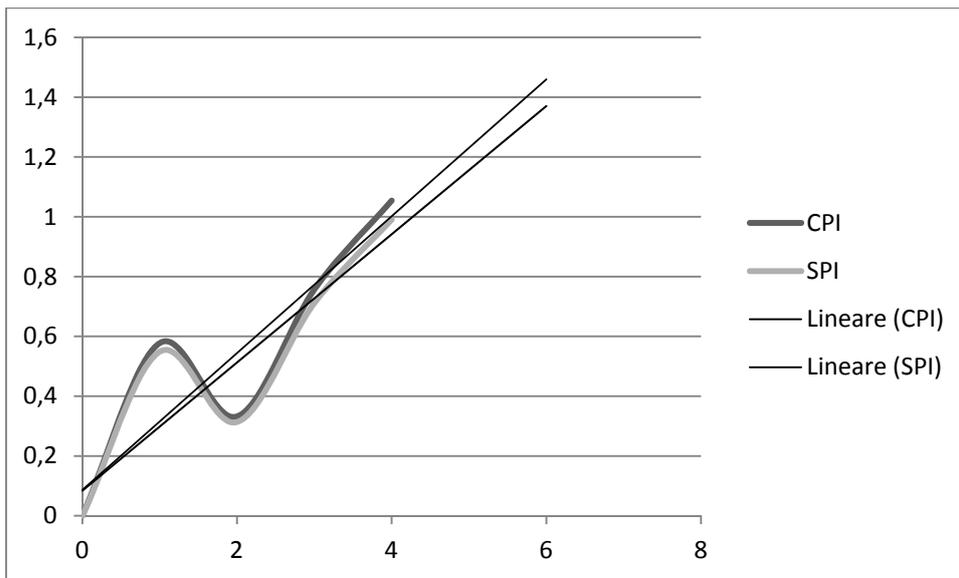

Figure 57: Cost performance index and schedule performance index trends and their trend lines linear prediction.

The main benefit of *Earned Value Management* is that this technique provides a picture of how the work is progressing in terms of cost and time, comparable with the same unit of measure. However the technique does not consider an index to measure the quality of the project outcome. Throughout the execution of the project, quality should always be on the radar of the project manager. Performing quality control is a process that belongs to the project quality management knowledge area, and it is

performed throughout the monitoring and controlling phase. Quality control activities are performed internally during project execution to ensure that the deliverable is defect free and all parameters are within the acceptable limits set in the quality control plan. Quality is expressed in the *new project constraints framework* in function of cost and time. It is important because it indicates the health of the deliverable to the end user driving the satisfaction of the stakeholder for whom the project outcome is targeted. Quality control process helps the project manager successfully deliver an outcome that satisfies the major stakeholder for whom the project is targeted. So, quality control helps to create a good quality deliverable, and in turns helping to reach the scope. It has to be noted that quality refers to both technical and non-technical requirements of the deliverables.

3.9. Maximising project scope

According to the principles discussed in chapter 2, the project manager aims at maximising a suitable function s of scope depending on quality, time (denoted as x) and cost (denoted as y) and defined on an admissible set D. Summering, the problem is $\max s(x, y) \, over \, D$.

Firstly, the project manager needs to measure the priorities of the project (in order to determine w_c, w_t and w_q) through the AHP tool and translate them into the function s. It is a sort of assessment of the priorities for the project pillars using an analytical consistency method and the Project Manager is the decision maker. He provides an estimation of the eigenvector $\underline{w}$ by assessing values of the vector weight as in chapter 3.2[98], obtaining:

$$\underline{w} = \begin{bmatrix} w_q \\ w_c \\ w_t \end{bmatrix} = \begin{bmatrix} 0{,}33 \\ 0{,}08 \\ 0{,}59 \end{bmatrix}$$

Secondly he has to leverage on his experience in managing the project, knowing data about it, having an overview about its boundaries, resources, activities and deliverables, in order to quantify the impact of project cost and time over the quality of its outcome. As introduced in chapter 2, quality is described as a Cobb-Douglas function over time and cost, with constant return to scales. In turn, time has an impact α and cost $1 - \alpha$ over quality.[99] The project manager considers the impact of time as well for costs of equal importance, then:

$$\alpha = 0{,}5$$

Translating these parameters in the function s to be maximised, the problem is:

$$Max: s = 0{,}33 \cdot x^{0,5} \cdot y^{0,5} - 0{,}59 \cdot x - 0{,}08 \cdot y$$

Subject to:

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[98] For more details, see chapter 3.2
[99] For more details, see chapter 2.

$$D:\begin{cases} 0 \le x \le \bar{t} \\ 0 \le y \le \bar{c} \\ x^{0,5} \cdot y^{0,5} \ge \bar{q} \end{cases}$$

Note that, being s continuous on a compact domain D a global maximum exist. The project manager is left to find it. The interior of D and its frontier are studied separately. Following the steps developed in chapter 2, the project manager can obtain:

a) The stationary points at the interior of the set D.

After some calculations similar to chapter 2, the following is obtained:

$$\frac{w_q^{\frac{1}{\alpha \cdot (1-\alpha)}}}{w_c^{\frac{1}{\alpha}} \cdot w_t^{\frac{1}{1-\alpha}}} = \frac{1}{(1-\alpha)^{\frac{1}{\alpha}} \cdot (\alpha)^{\frac{1}{1-\alpha}}}$$

Therefore, having assigned a value $\alpha = 0,5$, it becomes:

$$\frac{w_q^2}{w_c \cdot w_t} = 4$$

If the parameters for the vector weights $\underline{w} = \begin{bmatrix} w_q \\ w_c \\ w_t \end{bmatrix}$ satisfy that condition, there will be infinite stationary points characterised by $x = y$. Having obtained $w_q = 0,33$, $w_c = 0,08$ and $w_t = 0,59$, this condition is not verified. Then, there are no points of maximum and minimum at the interior, for $x = y$.

b) The stationary points at the frontier of D.

After some calculations similar to chapter 2 for the function s restricted on the boarder $\overline{AB}$, the following is obtained:

$$\begin{cases} t^* = \bar{q} \cdot \left(\frac{w_t}{w_c} \cdot \frac{1-\alpha}{\alpha} \right)^{\alpha - 1} \\ c^* = \bar{q} \cdot \left(\frac{w_t}{w_c} \cdot \frac{1-\alpha}{\alpha} \right)^{\alpha} \\ q^* = \bar{q} \end{cases}$$

Therefore, having assigned a value $\alpha = 0,5$, it becomes:

$$\begin{cases} t^* = \bar{q} \cdot \left(\dfrac{w_t}{w_c}\right)^{-0,5} = \bar{q} \cdot \dfrac{1}{\left(\dfrac{w_t}{w_c}\right)^{0,5}} = \dfrac{\bar{q}}{\sqrt{\left(\dfrac{w_t}{w_c}\right)}} = \bar{q} \cdot \sqrt{\left(\dfrac{w_c}{w_t}\right)} \\[4mm] c^* = \bar{q} \cdot \left(\dfrac{w_t}{w_c}\right)^{0,5} = \bar{q} \cdot \sqrt{\left(\dfrac{w_t}{w_c}\right)} \\[4mm] q^* = \bar{q} \end{cases}$$

Having obtained the values for $w_q = 0,33$, $w_c = 0,08$ and $w_t = 0,59$ and knowing the quality threshold set in the *project scope statement* $\bar{q} = 75$ it becomes:

$$\begin{cases} t^* = 75 \cdot \sqrt{\left(\dfrac{0,08}{0,59}\right)} \cong 28 \\[4mm] c^* = 75 \cdot \sqrt{\left(\dfrac{0,59}{0,08}\right)} \cong 203,68 \\[4mm] q^* = 75 \end{cases}$$

$c^* = 75 \cdot \sqrt{\left(\dfrac{0,59}{0,08}\right)} \cong 203,68$ is not admissible because the constraint $c \leq \bar{c}$ is not verified.

After some calculations similar to chapter 2 for the function s restricted on the boarder $\overline{BC}$, the following is obtained:

$$\begin{cases} t^* = \bar{t} \\[2mm] c^* = \dfrac{\bar{t}}{\left(\dfrac{1}{(1-\alpha)} \cdot \dfrac{w_c}{w_q}\right)^{\frac{1}{\alpha}}} \\[4mm] q^* = t^{*\alpha} \cdot c^{*1-\alpha} \end{cases}$$

Therefore, having assigned a value $\alpha = 0,5$, it becomes:

$$\begin{cases} t^* = \bar{t} \\[2mm] c^* = \dfrac{\bar{t}}{\left(2 \cdot \dfrac{w_c}{w_q}\right)^{2}} \\[4mm] q^* = t^{*0,5} \cdot c^{*0,5} \end{cases}$$

Having obtained the values for $w_q = 0,33$, $w_c = 0,08$ and $w_t = 0,59$ and knowing the time threshold set in the *project scope statement* $\bar{t} = 200$ it becomes:

$$\begin{cases} t^* = 200 \\ c^* = \dfrac{200}{\left(2 \cdot \dfrac{0,08}{0,33}\right)^2} \cong 850,78 \\ q^* = 200^{0,5} \cdot 850,78^{0,5} \cong 412,5 \end{cases}$$

$c^* = \dfrac{200}{\left(2 \cdot \frac{0,08}{0,33}\right)^2} \cong 850,8$ is not admissible because the constraint $c \leq \bar{c}$ is not verified.

After some calculations similar to chapter 2 for the function s restricted on the boarder $\overline{AC}$, the following is obtained:

$$\begin{cases} c^* = \bar{c} \\ t^* = \bar{c} \cdot \left(\dfrac{1}{\alpha} \cdot \dfrac{w_t}{w_q}\right)^{\frac{1}{\alpha - 1}} \\ q^* = t^{*\alpha} \cdot c^{*1-\alpha} \end{cases}$$

Therefore, having assigned a value $\alpha = 0,5$, it becomes:

$$\begin{cases} c^* = \bar{c} \\ t^* = \bar{c} \cdot \left(2 \cdot \dfrac{w_t}{w_q}\right)^{-2} = \dfrac{\bar{c}}{\left(2 \cdot \dfrac{w_t}{w_q}\right)^2} \\ q^* = t^{*0,5} \cdot c^{*0,5} \end{cases}$$

Having obtained the values for $w_q = 0,33$, $w_c = 0,08$ and $w_t = 0,59$ and knowing the cost threshold set in the *project scope statement* $\bar{c} = 75$ it becomes:

$$\begin{cases} t^* = \dfrac{75}{\left(2 \cdot \dfrac{0,59}{0,33}\right)^2} \cong 6 \\ c^* = 75 \\ q^* = 5,87^{0,5} \cdot 75^{0,5} \cong 20,98 \end{cases}$$

$q^* = 5,87^{0,5} \cdot 75^{0,5} \cong 20,98$ is not admissible because the constraint $t^{0,5} \cdot c^{0,5} \geq \bar{q}$ is not verified, having a quality threshold equal to 75.

The last step is to evaluate the value of the function s at the extreme points A, B and C of its set D. Then the project manager, for this kind of project, calculates the values of the function s in these points and he takes the higher value between the three results obtained in s.

As in chapter 2:

$$s(A) = w_q \cdot \left(\left(\frac{\bar{q}}{\bar{y}^{1-\alpha}} \right)^{\frac{1}{\alpha}} \right)^{\alpha} \cdot \bar{y}^{1-\alpha} - w_t \cdot \left(\frac{\bar{q}}{\bar{y}^{1-\alpha}} \right)^{\frac{1}{\alpha}} - w_c \cdot \bar{y}$$

Having assigned a value $\alpha = 0{,}5$, having obtained the values for $w_q = 0{,}33$, $w_c = 0{,}08$ and $w_t = 0{,}59$ and knowing the cost and quality threshold set in the *project scope statement* $\bar{c} = 75$, $\bar{q} = 75$ it becomes:

$$s(A) = 0{,}33 \cdot \left(\left(\frac{75}{75^{0,5}} \right)^{\frac{1}{0,5}} \right)^{0,5} \cdot 75^{0,5} - 0{,}59 \cdot \left(\frac{75}{75^{0,5}} \right)^{\frac{1}{0,5}} - 0{,}08 \cdot 75 \cong -25{,}5$$

$$s(B) = w_q \cdot \bar{x}^{\alpha} \cdot \left(\left(\frac{\bar{q}}{\bar{x}^{\alpha}} \right)^{\frac{1}{1-\alpha}} \right)^{\alpha} - w_t \cdot \bar{x} - w_c \cdot \left(\frac{\bar{q}}{\bar{x}^{\alpha}} \right)^{\frac{1}{1-\alpha}}$$

Having assigned a value $\alpha = 0{,}5$, having obtained the values for $w_q = 0{,}33$, $w_c = 0{,}08$ and $w_t = 0{,}59$ and knowing the time and quality threshold set in the *project scope statement* $\bar{t} = 200$, $\bar{q} = 75$ it becomes:

$$s(B) = 0{,}33 \cdot 200^{0,5} \cdot \left(\frac{75}{200^{0,5}} \right)^{\frac{1}{0,5}^{0,5}} - 0{,}59 \cdot 200 - 0{,}08 \cdot \left(\frac{75}{200^{0,5}} \right)^{\frac{1}{0,5}} \cong -95{,}5$$

$$s(C) = w_q \cdot \bar{x}^{\alpha} \cdot \bar{y}^{1-\alpha} - w_t \cdot \bar{x} - w_c \cdot \bar{y}$$

Having assigned a value $\alpha = 0{,}5$, having obtained the values for $w_q = 0{,}33$, $w_c = 0{,}08$ and $w_t = 0{,}59$ and knowing the time and cost threshold set in the *project scope statement* $\bar{t} = 200$, $\bar{c} = 75$ it becomes:

$$s(C) = 0{,}33 \cdot 200^{0,5} \cdot 75^{0,5} - 0{,}59 \cdot 200 - 0{,}08 \cdot 75 \cong -83{,}60$$

Finally, having obtained these values for s, $s(A) > s(C) > s(B)$, then the project scope is maximised in A, which point is, as in chapter 2:

$$\begin{cases} t^* = \left(\frac{\bar{q}}{\bar{c}^{0,5}} \right)^2 \\ c^* = \bar{c} \\ q^* = t^{*0,5} \cdot c^{*0,5} = \bar{q} \end{cases}$$

Where $\bar{q}$ is the minimum quality threshold and $\bar{c}$ the maximum cost threshold values set by the project committee and reported in the *project scope statement*. $t^* = \left(\frac{\bar{q}}{\bar{c}^{0,5}}\right)^2$ is the minimum time that is possible to reach in order to obtain the project deliverable. This value that maximises the scope can be explained considering the parameter $\alpha = 0,5$, or rather considering the same impact of time and cost over the quality. Furthermore the project manager obtains this result assuming time is prioritised over the other variables, in fact $w_t > w_q > w_c$.

According to chapter 2, these results have to be normalised between 0 and 1 to provide a better interpretation. Then:

$$\begin{cases} \dfrac{t^*}{\bar{t}} = \dfrac{75}{200} = 0,375 \\[2mm] \dfrac{c^*}{\bar{c}} = \dfrac{75}{75} = 1 \\[2mm] \dfrac{q^*}{q_{max}} = \dfrac{\bar{q}}{\bar{t}^\alpha \cdot \bar{c}^{1-\alpha}} \cong \dfrac{75}{122,48} \cong 0,61 \end{cases}$$

The project manager has to minimize the project time by using 37,5% of the time at its disposal to provide the project outcome qualitatively completed at 61% of its maximum qualitative value achievable (in doing so, he has to maintain the minimum quality threshold of the project outcome). It will be possible by minimising project cost, or rather maximising the use of resources available for the project by using all the budget at his disposal ($100\% \; \bar{c}$).

Finally it has to be pointed out that the negative sign that s can assume is independent of the project's success or rather maximising it. It is a function to describe a concept and as such it can assume different values, negative or positive. What interests the project manager is to reach the project success and obtain the values for quality, cost and time that maximise the scope.

As in chapter 2, having identified the optimal triplet (q^*, c^*, t^*) the project manager can estimate the performance of the real project by computing a distance of a project (q, c, t) by (q^*, c^*, t^*). Supposing the project is completed as planned on the #186

labour day, providing a project outcome with $q = 100$ and $c = \frac{67252,38}{1000}$. The project performance is:

$$P = \sqrt{(q - q^*)^2 + (c - c^*)^2 + (t - t^*)^2}$$

$$= \sqrt{(100 - 75)^2 + (\frac{67252,38}{1000} - 75)^2 + (186 - 75)^2} \cong 114,05$$

Clearly the project manager has not reached the optimal performance and has missed the mark by about 114,05 units, which is far from reaching it. This is because, in the planning phase without knowing the optimal performance values and using the *Earned Value Management* technique, the aim of the project manager was to lean towards the planned values instead of the optimal ones. During the planning phase, had the mathematical tool, *crashing costs* method been applied, the time would have been compressed at the expense of diminishing the quality and increasing the cost. From the planned phase point of view, the project manager has tried to maximise the quality by reducing the costs and increasing time, but in accordance with priority assigned to time this is not the best case.

Moreover, through Excel the project manager can perform a sensitivity analysis in order to judge how the results can vary as the priority assigned to each variable fluctuates or of the impact of time and cost over quality. Different scenarios from the baseline case can emerge if the project committee shifts its priority over the scope[100]

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[100] Suppose the company, before planning the project, faces a financial problem and the project committee has to change its priority (first scenario). Basically the thresholds set for quality, cost and time are confirmed but in this scenario the project manager has to maximise the project scope by carrying out a project at a minimum cost. However the project outcome has to be delivered in the same time threshold respecting the minimum qualitative characteristics. Moreover the condition of the outcome does not change: the project manager faces the same impact of cost and time over quality outcome. In this scenario cost is considered *extremely preferred* over time and *very strongly to extremely preferred* over quality, while quality over time is considered *moderately preferred*.
Considering the second scenario the company, before planning the project, faces a different situation: the market is asking for a qualitative outcome as possible at the expense of time and costs. The priority vector has to be reviewed. Basically the thresholds set for quality, cost and time are confirmed but in this scenario the project manager has to maximise the project scope by carrying out a project deliverable at a maximum qualitative value, exploiting the amount of resources and time at his disposal. Moreover the condition of the outcome does not change: the project manager faces the same impact of cost and time over quality outcome. In this scenario quality is considered *very strongly to extremely*

or if the quality is impacted differently from cost and time[101]. The situations are obtained and reported in the figure 58. The weights are determined through AHP.

Scenarios	Priority	w_q	w_c	w_t	α	Optimal solutions	Max
Baseline	Min t	0,33	0,08	0,59	$\alpha = 0,5$	$\begin{cases} t^* = 37,7\%\bar{t} \\ c^* = 100\%\bar{c} \\ q^* = 61,24\%q_{max} \end{cases}$	A
					$\alpha = 0,9$	$\begin{cases} t^* = 38,5\%\bar{t} \\ c^* = 83,6\%\bar{c} \\ q^* = 41,4\%q_{max} \end{cases}$	$\overline{AB}$
1	Min c	0,14	0,8	0,06	$\alpha = 0,5$	$\begin{cases} t^* = 100\%\bar{t} \\ c^* = 37,51\%\bar{c} \\ q^* = 61,24\%q_{max} \end{cases}$	B
					$\alpha = 0,8$	$\begin{cases} t^* = 83\%\bar{t} \\ c^* = 4,2\%\bar{c} \\ q^* = 45,63\%q_{max} \end{cases}$	$\overline{AB}$
					$\alpha = 0,2$	$\begin{cases} t^* = 98,5\%\bar{t} \\ c^* = 78,6\%\bar{c} \\ q^* = 82,2\%q_{max} \end{cases}$	$\overline{AB}$
					$\alpha = 0,9$	$\begin{cases} t^* = 100\%\bar{t} \\ c^* = 3\%\bar{c} \\ q^* = 70,37\%q_{max} \end{cases}$	$\overline{BC}$
2	Max q	0,73	0,2	0,07	$\alpha = 0,5$	$\begin{cases} t^* = 100\%\bar{t} \\ c^* = 100\%\bar{c} \\ q^* = 100\%q_{max} \end{cases}$	C
					$\alpha = 0,2$	$\begin{cases} t^* = 94\%\bar{t} \\ c^* = 100\%\bar{c} \\ q^* = 98,77\%q_{max} \end{cases}$	$\overline{AC}$
					$\alpha = 0,89$	$\begin{cases} t^* = 100\%\bar{t} \\ c^* = 95,65\%\bar{c} \\ q^* = 99,51\%q_{max} \end{cases}$	$\overline{BC}$

Figure 58: Scenario analysis.

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preferred over time and *strongly preferred* over cost, while cost over time is considered *moderately to strongly preferred*.

[101] Suppose that the company relies on the baseline situation but, before planning the project, after a research over the deliverable, the project manager understands that its quality will be affected differently by both cost and time. It finds that the impact of time is much more relevant in order to obtain a qualitative outcome. The outcome is strongly time oriented. Then the situation change for the parameter of the *Cobb-Douglas quality function* (that now is $\alpha = 0,9$).

Suppose that now, the company relies on the first scenario but the research over the quality of the project deliverable studies three different values for alpha: $\alpha = 0,8$, $\alpha = 0,2$, $\alpha = 0,9$.

Suppose that now, the company relies on the second scenario but the research over the quality of the project deliverable studies different values for alpha: $\alpha = 0,2$, $\alpha = 0,89$.

Emerging from these scenarios, if one considers the same impact of cost and time over quality, the more a variable is prioritised, the more the optimal result tends to maximise (for quality) or minimise (for time and cost) that variable at the expense of the others. Clearly, if the project priority is to quickly deliver the project outcome, time will be compressed as much as possible at the expense of minimising the quality and maximising the cost (tending to their thresholds). On the other side, if the project priority is to cheaply deliver the project outcome, costs will be compressed as much as possible at the expense of minimising the quality and maximising the time (tending to their thresholds). Finally, if the project must deliver an optimal qualitative outcome with no exceptions, the project will use all the time and cost at its disposal (tending to their thresholds). Then, changing from an extreme point to another is seen as a trade-off between the priorities over the project pillars. This trade-off is done by assigning different levels of importance to a specific variable. The more the priority is oriented over one variable, the more the optimal solution tends to rely in the extreme of the function where that variable takes its maximum (for quality) or minimum (for time and cost) value, at the expense of the others with less priority (that vice versa tend to their thresholds).

Things change if the impact of time and costs are considered differently over quality. When time is prioritised but the alpha value tends to its biggest value (time strongly impacts over quality), the more the solution tends to shift from point A to rely in the boarder $\overline{AB}$. When quality is prioritised but the alpha value tends to its smallest value (cost strongly impacts over quality), the more the solution tends to shift from point C to rely in the boarder $\overline{AC}$. When quality is prioritised but the alpha value tends to its biggest value (time strongly impacts over quality), the more the solution tends to shift from point C to rely in the boarder $\overline{BC}$. When cost is prioritised but the alpha value tends to its smallest value (cost strongly impacts over quality), the more the solution tends to shift from point B to rely in the boarder $\overline{AB}$. When cost is prioritised but bigger is the alpha value (time strongly impacts over quality), the more the solution tends to shift from point C to rely in the boarder $\overline{AB}$ but there will be the biggest and specific value that shift the solution from the boarder $\overline{AB}$ to the boarder $\overline{BC}$. The

specific values for alpha that changes the solutions, considering the different scenarios explained before, are presented in figure 59 and illustrated in figure 60.

Scenarios	Priority	w_q	w_c	w_t	$\Delta\alpha$	Max
Baseline	Min t	0,33	0,08	0,59	$0,1 \leq \alpha < 0,8811$	A
					$\alpha \geq 0,8811$	$\overline{AB}$
1	Min c	0,14	0,8	0,06	$\alpha \leq 0,2$	$\overline{AB}$
					$0,2 < \alpha < 0,73$	B
					$0,73 \leq \alpha < 0,85$	$\overline{AB}$
					$\alpha \geq 0,85$	$\overline{BC}$
2	Max q	0,73	0,2	0,07	$\alpha \leq 0,2$	$\overline{AC}$
					$0,2 < \alpha < 0,89$	C
					$\alpha \geq 0,89$	$\overline{BC}$

Figure 59: Scenario analysis for $\Delta\alpha$.

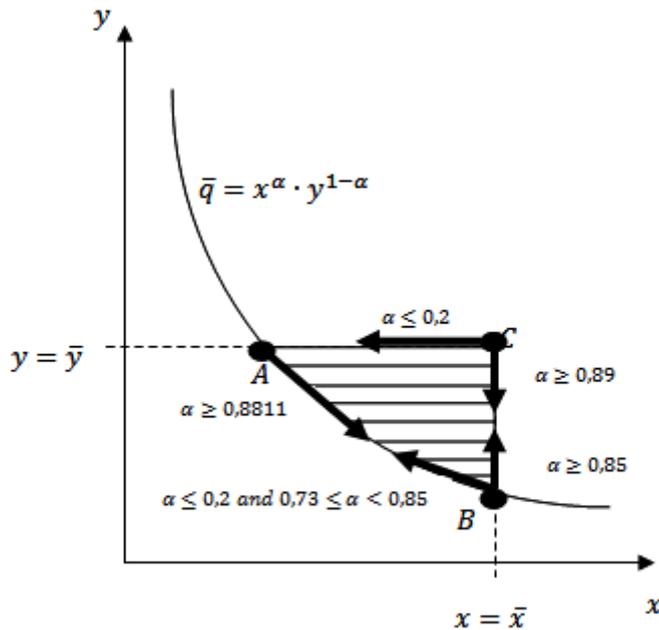

Figure 60: How the optimal solutions shift on varying of α values, considering the situations of the scenario analysis.

4. A Project Risk Management methodology for practices in *Lechler*

"Think of a risk plan as a mini project plan, and you have the idea. If the risk occurs, all that remains to be done is to implement the plan".[102]

As already pointed out, the internationalisation process in a company embodies a series of projects performed in different geographical regions and as such, companies nowadays need to manage more and more projects internationally. Though, most of the time those projects are mismanaged, not relying on suitable project management methodologies. On the background of internationalisation, the project is fast becoming a mode of business in itself in order to compete in a global market influenced by rapid changes, high risk, innovation and time to market. In particular internationalisation involves large-scale projects influenced by uncertainty. Uncertainty produces and exposes one to risks that in project management could lead to over budgeting as well as impacting schedule, quality of the outcome and scope itself. So, considering the *new constraints framework* developed in this work, it deals with facing a set of risks affecting the project pillars that in turn will alter the scope. Most of the time companies, especially SMEs, lack the proper tools to manage the risks related to these international projects without turning internationalisation process into a competitive advantage. *"Many firms ignore risk management because they have not seen the need for it"*.[103] Those are identified as less mature firms that hide the risk instead of managing it, dealing with an inconsistent strategic performance and their organisational culture is marked by *crisis management* and *fire-fighting*. *"These firms are like the mythological character Icarus. They fly high but come crashing down because they ignored easily recognizable risk events"*.[104] As Kendrik (2003) suggests, project manager has to look backward in order to avoid repeating past failures and to

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[102] Grisham (2011).

[103] G. D. Githens, " How to Assess and Manage Risk in NPD: A Team - Based Approach, " in P. Belliveau, A. Griffin, and S. Somermeyer, *The PDMA Toolbook for New Product Development* , Wiley, Hoboken, NJ, 2002, p. 208.

[104] G. D. Githens, " How to Assess and Manage Risk in NPD: A Team - Based Approach, " in P. Belliveau, A. Griffin, and S. Somermeyer, *The PDMA Toolbook for New Product Development* , Wiley, Hoboken, NJ, 2002, p. 208.

look forward in order to eliminate or minimize many potential problems in the future, and it is possible by adopting a suitable methodology of project risk management. A separate chapter was created because the risk must always be on the radar of the project manager as a potential cause for altering the project pillars' quality, cost and time. Consequently, it becomes as important as the same pillars and relying on a methodology of risk management becomes essential for a project manager in order to complete the project on schedule, within the budget, respecting the quality deliverables and finally achieving the scope by providing an outcome that satisfies the customers. This section provides a project risk management model, based on a bibliographic research and interviews with professional project managers[105], and its applicability on the *Lechler* project. Nevertheless, it has to be stressed that projects are different and things go wrong for a set of different reasons, sometimes unique to a particular kind of project. So a general approach can be provided but it has to be shaped to each kind of specific project. There are many ways to capture the effect of project risks as Carbone (2004) stresses. The literature and even the practices are very wide and diversified but the method a project manager chooses should be aligned with the standards provided by the Project Management Institute. For consistency and communication, the method and terminology developed in this chapter are aligned with such standards.

Firstly, one needs to define what project risk means. "*Project risk is an uncertain event or condition that, if it occurs, has a positive or negative effect on one or more project objectives such as scope, schedule, cost, and quality*".[106] Risks exist as a consequence of uncertainty.

Uncertainty is higher at the beginning (and so the potential risks are higher in turn), decreasing during the life of the project once time deliverables are reached. For that reason, it is beneficial to implement the project risk analysis and management in the

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[105] Rodriguez et al. (2010), Project Management Institute (2013), Larson et al. (2011), appendix A where interviews are called, Carbone (2004), Kendrick (2003), Gurau et al. (2014), California. Department of Transportation. Risk Management Task Group (2012), Norris et al. (2000), Schuyler (2001).
[106] Project Management Institute (2013).

earlier stages of the project. Then, it has to be performed during all the life of the project in order to increase the probability of its success.[107]

Each risk has a cause considering each project activity and, once it occurs, it faces a consequence over it, affecting project progress. Really, a single risk may have one or more causes and, if it occurs, one or more effects. It is extremely important to not confuse *cause* of risks, *risks* and *effects* of risks:

- *Causes* are definite events or sets of circumstances which exist in the project or its broader environment, and which give rise to uncertainty.[108] They are not on the radar of the project manager because causes themselves are not uncertain since they are facts.

- *Risks* are uncertain events that, once they occur, will affect the project pillars negatively in form of threats or positively in the form of opportunities. These are on the radar of the project manager that has to manage them proactively through the risk management process. Indeed, risk management is seen as a proactive approach rather than reactive because it is a preventive process set in order to guarantee that those uncertain events are reduced and the related negative consequences are minimized.

- *Effects* are unplanned changes (because of risk occurring) over the project pillars and in turn altering the scope, in positive or negative terms. The effects have not to occur, as a consequence of risk management process.

For example, consider the bridge project construction over the Rhine during the fifth Gallic Campaign, living in unfriendly and cold temperatures (*cause*), most of the military units, the actual team members at that time, when building the bridge, were very sick (*risk*) having no possibility to work on the bridge construction (*effect*). Then, the objective of project risk management is to increase the likelihood and impact of positive events, and decrease the likelihood and impact of negative events in the project.[109] It means adopting a suitable project management risk approach to increase the probability of project success in time, cost and quality that in turn affect the scope.

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[107] For more details, see chapter 1.5.
[108] Risk management Task Group (2012).
[109] Project Management Institute (2013).

Particularly the project risks management will be considered, with negative events having an impact $\bar{X}$ with certain probability P over the project pillars quality, cost and time according to the *new constraints framework* model. It is a proactive approach that must be implemented during throughout the project lifecycle and it interacts with the processes across all the knowledge areas of project management. However it becomes reactive when unknown events occur because the sources of risks can potentially be unlimited internally within the organisation as well externally. However the proactive approach should consider risky events with statistical relevance, whereas the reactive can be considered issues.

The risk attitude of the project manager influences his willingness to accept varying degrees of risk. In particular this attitude is influenced in turn if he is more of a risk taker or averse to risk taking (if it is more optimistic or pessimistic over the events) and his degree of tolerance over the risk (translated in a risk threshold over which accept risks).

In line with the standards of project management, the processes that characterize project risk management in this methodology are:

1. Identifying risks.
2. Performing micro and macro risk analysis.
3. Planning risk responses.
4. Monitoring risk.

Formally, these steps are undertaken in the project gates as suggested by professional project managers[110] but informally it is a process that continues throughout lifecycle of the project. Each step is described in the next pages and developed in the *Lechler* case study.

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[110] For more details, see appendix A where interviews are called.

Identifying risks means defining *what* uncertain events could happen, impacting the project pillars and *how* they could happen. Starting from the list of activities, one needs to perform an initial qualitative risk analysis (in terms of verbal judgement) characterised by the identification of the main risk sources associated with each activity (the causes) and the subjective assessment of each risk, that could affect the project, through its description. The risks are tracked and their characteristics are documented in the *risk register*, a document that will be updated in the following phases. In fact, it is a tool used by the project team during all the project lifecycle to create profiles of risks, where risks are clearly separated from their causes and effects through structuring risk statements: risks are structured by a cause-effect relationship. Risk identification is possible through evaluating them in brainstorming sessions with the stakeholders involved, reviewing historical data and leveraging on the knowledge of experts[111]. For large projects with a large list of activities, this analysis should be done for part of the activity list regarding those with more uncertainty, and those who have surpassed the risk threshold tolerance surpasses defined by the project manager. For each uncertain activity, once a list of risks is created, then they can be grouped by category creating a *Risk Breakdown Structure*, a tool that groups in a graphical manner, the risks per category[112], displaying them from higher to lower (based on verbal judgements). Then, each risk is assigned a team member who is responsible for being its risk owner, and whose duties are to overlook it during the project lifecycle and manage it in case the risk occurs. Taking this phase is important to understand the project, its uncertainty over activities and the possible risks related knowing causes and effects. It is an interactive process throughout the project lifecycle working with all the knowledge areas of the project management because new risks can emerge or

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[111] If an organisation relies on a suitable project risk analysis and management approach having already developed expertise in it, this activity can be carried out in-house. While if such expertise do not exist within an organisation it is better to acquire them from outside consultants.

[112] Risks to the project can be categorized by sources of risk (e.g., using the RBS), the area of the project affected (e.g., using the *WBS*), or other useful categories (e.g., project phase) to determine the areas of the project most exposed to the effects of uncertainty. For more details, see Project Management Institute (2013).

previously identified risks can drop out so the risk *register* should be updated. Risk identification should not be limited to just the project team, instead it is important to create synergies with customers, sponsors, suppliers, and all the stakeholders involved in the project.

In the *Lechler* project, a list of risks for each activity is obtained via interviews with the main project stakeholders and my personal practical knowledge during the implementation phase.[113] The risk owners identified are those responsible for their department's activities. A subjective assessment is performed, of those potential risks impacting the project in a *cause-effect* relationship and which uncertainty surpasses the risk threshold tolerance of the project manager, as follows.

- Activity D1: regarding *project kick-off* activity, no relevant risks impacting over the pillars are revealed. However organisational or administrative traps can be revealed, delaying this activity.
- Activity D2: regarding *Web system evaluation* activity all project activities are effectively performed there are no risks revealed. If all project activities are not effectively performed, the utilisation rate target, in according to the formula provided in the interview[114], is not reached and then the entire system must be reviewed.

- Activity C1: regarding *market research* activity, a possible risk is not finding a means to integrate the customers' ERP and Web system.[115]
- Activity C2: regarding *sample gathering* activity, a risk revealed is to not gather the desired number of samples. Another one revealed is to not choose adequately the cluster of samples in order to effectively test the system.[116]

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[113] For more details, see Appendix A where interviews are called.

[114] $Web\ orders\ utilisation\ rate = (w_o \cdot O + w_c \cdot C) \cdot 100$. For more details, see appendix A where interviews are called.

[115] However intuitive Web system functions are created in order to make the customer feel good with using the Web system.

[116] However this risk has a very low probability of occurrence because the activity wants that the sample be gathered in function of IT competency and technical expertise of ERPs. If this activity is effectively performed by using a matrix, that relates the IT competency with the ERPs technical expertise, a heterogeneous sample can be gathered.

- Activity A1: regarding *virtual meetings with target customers* activity, a relevant risk revealed is that the customers could not gauge the benefit of the new Web system as they struggle to understand its potential benefits. This is because they resist in changing their purchase habits with a totally new purchase tool. Moreover, engaged in their everyday working life and commitments, they could perceive the meeting as a waste of time.

- Activity A2: regarding *ERPs sample test* activity, a risk revealed is that some customers' ERP could provide a file with the wrong size preventing it from being preloaded into the Web system. More effort has to be spent in tailoring the file.

- Activity A3: regarding *test1 over sample partners* activity, if activities B1-A2 are effectively performed, no relevant risks are tracked. Instead, a risk revealed is the possibility to meet easily and resolve Web system errors.

- Activity A4: regarding *errors evaluation* activity, there are no relevant risks revealed. However the time of this activity can be slashed if consistent errors to be evaluated are revealed in the previous activities.

- Activity A5: regarding *test2 over sample partners* activity, a risk revealed is to find easily resolvable de-bugging errors.

- Activity A6: regarding *gathering new customers needs* activity, there are no relevant risks revealed.

- Activity A7: regarding *customers portfolio development* activity, a possible risk revealed is to not choose adequately the cluster of customers in order to effectively implement the system.[117]

- Activity A8: regarding *customers confidence relationship* activity, a possible risk revealed is to have difficulties in over passing the psychological barriers created in activity A1. If A1 is computed effectively there is no cause for that risk.

- Activity A9: regarding *training CSM over SAP and Web system* activity, a possible risk revealed is to inherit a poor competency level regarding the assistant unit.

- Activity A10: regarding *handbooks development* activity, a possible risk revealed is failing to create intuitive and easy-way guides with illustrations, which encourages customers to misinterpret and overlooking them.

- Activities A11-A14: regarding *business trips* activities, there are a number of possible risks revealed. If customers have poor technical competency and natural inclination to pretend they comprehend when in fact they do not understand the system, it is of little use. If customers' ERP create the purchase order with an incorrect file format, they incur possible integration

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[117] However this risk has a very low probability of occurrence because the activity wants that customers have to be categorised in function of their IT competencies and the technical level of their ERPs. If this activity is effectively performed by using a matrix, that relates the customers' IT competencies and customers' ERPs technical level, a heterogeneous portfolio can be created.

problems with the Web system. If there are integration problems, the customer could reject using the web system manually. If there is no data conversion of the product ID, the client's customised IT space must be reviewed. If there are psychological barriers associated with changing their purchase habits, not influenced in the previous confidence activities, the customers' purchase orders through web could not go on.

- Activity A15: regarding *customers conference call* activity, there are no relevant risks revealed.

- Activity A16: regarding *customers post-relationship and problem solving* activity there are no relevant risks revealed.[118]

- Activity A17: regarding *web orders monitoring* activity there are no significant risks revealed.

- Activity A18: regarding *results analysis* activity there are no significant risks revealed.

- Activity A19: regarding *results evaluation* activity If previous project activities are effectively performed there are no risks revealed.

- Activity B1: regarding *database model configuration* activity, a relevant risk revealed is to not create efficiently and effectively a proper database. This would mean engaging in a new effort to provide a better quality technical database.

- Activity B2: regarding *programs development* activity, a relevant risk revealed is to incur programming errors. This would mean engaging in a new effort to correct these technical errors.

- Activity B3: regarding *server development* activity, a relevant risk revealed is to get the incorrect server size. In this case, it would mean engaging in a new effort to resize it.

- Activity B4: regarding *GUI development* activity, a relevant risk revealed is to get an incorrect programming GUI. In this case, it would mean engaging in a new effort to re-programme it.

- Activity B5: regarding *customers info workflow* activity, a relevant risk revealed is to stumble upon structural problems but the cause relies in under-performing activities B1, B2, B3, B4. In this case, it would mean re-engage in activities B1, B2, B3, B4.

- Activity B6: regarding *organisational info workflow* activity, a relevant risk revealed is to stumble upon structural problems but the cause relies in under-performing activities B1, B2, B3, B4. In this case, it would mean re-engage in activities B1, B2, B3, B4.

- Activity B7: regarding *logistic IT link development* activity, there are no relevant risk revealed. Instead, contingent programming errors can be easily corrected.

- Activity B8: regarding *access customised development* activity, there are no relevant risks revealed. Instead, contingent interfacing errors can be easily corrected.

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[118] In this activity an email box has been created to service the customers IT issues.

- Activity B9: regarding *preloaded ERP format* activity, a risk revealed is that some customers' ERP could provide a file with the wrong size that could not be preloaded in the Web system.

- Activity B10: regarding *errors resolution* activity, a risk revealed is the possibility to meet easily and resolvable programming errors.

- Activity B11: regarding *logistic coordination programming* activity, a risk revealed is to incur fewer but easily resolvable programming errors.

- Activity B12: regarding *database programming* activity, a risk revealed is to incur errors associated with the database and programming development but the probability of occurence is so low that is overlooked.

2. *Performing micro and macro risk analysis*

In project management standards this step is named qualitative and quantitative risks analysis but these definitions can be misleading. At first impression, qualitative risk analysis can lead thinking to analyzing risks on verbal judgements while a quantitative one on analysing them in numerical terms. However, both qualitative and quantitative risk analysis are used to identify the assessment of risk rating in numerical terms. Qualitative is not only referring to the verbal judgement of risk but, as in The Project Management Institute (2013), it deals with the process of prioritizing risks for further analysis or action by assessing and combining their probability of occurrence and impact. And one tool in doing so, starting by verbal judgements, is the *severity matrix*[119] by rating the risks assigning numerical values to its probability of occurrence and impact on an objective of the project. In other terms it considers examining the rating risk per risk, overlooking the impact of a single risk over the project pillars. This step answers the question: which of these risks are most important?[120] So let's look over their rating. On the other side the quantitative analysis of risks is defined in The Project Management Institute (2013) as the process of numerically analyzing the effect of identified risks on overall project objectives. Clearly here, as in definition, it means analysing via probability the effect of identified risks on the overall project objectives and answering the question: how could these affect the overall outcome of the project in probability terms of cost and schedule?[121] It is a sort of examination of the impact on the population of risks over the project pillars. In fact, it is used mostly to evaluate the aggregate effect of all risks affecting the project.[122] To avoid confusion, these two steps are named as micro and macro risk analysis, where micro refers to the analysis of the risk rating risk per risk impacting over the project pillars and macro to the analysis

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[119] It has to be noted that this work names the probability and impact matrix defined by the standards of The Project Management Institute (2013) as the *severity matrix*. It is similar but not identical to the *risk severity matrix* developed in Larson et al. (2011) or *risk matrix* developed in Risk Management Task Group (2012). The techniques and terminologies are different even if inspired by the same standards. The meaning of the combined probability and impact value varies. For more details, see note 124.
[120] Risk Management Task group (2012).
[121] Risk Management Task Group (2012).
[122] Project Management Institute (2013).

of the probability in overall terms of the population of risks over the project pillars. Moreover, the standards, as already mentioned, are written in generic and confusing terms regarding the impact of risk over the project objectives, such as scope, time, quality, etc. However, for consistency with the *new constraints framework* developed in chapter 2, here is considered the impact of risks upon the three clearly defined project pillars quality, cost and time, in turn affecting in aggregate terms the project scope as in function.

2.1. Micro risk analysis

Once the list of risks for each activity is obtained, has been categorised, and prioritised by verbal judgements, they are selected for further actions through a quantitative assessment. The easiest and most commonly used method[123] for assessing the severity rating to each risk is combining the level of probability P and its impact $\bar{X}$, giving a value as such:

$$Risk\ severity^{124} = P \times \bar{X}^{125}$$

The project manager needs to define which is the probability scale (that will be reported in the matrix) and he needs to know the organisation's thresholds for low, moderate and high impact (they will be reported in the matrix as well, determining if the risk is considered as high, moderate or low for that objective).

The first step is to create a matrix[126] used as a template to compare the values of severity obtained for each risk, according to its impact over the project and its likelihood of occurrence. It consists of a $n \times n$ chart that relates the probability and the impact of the risk event, plotted in the same chart in order to show the value in the single square that corresponds to the severity rating. The risk severity matrix adopted

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[123] For more details, see Larson et al. (2011).

[124] As Carbone (2004) explains, the meaning of the combined probability and impact value varies. Depending on the authors' preference for naming these two risk attributes, the combination has been called the expected value (Lukas, 2002; PMI Risksig Lexicon, 2003; Pritchard, 2000), risk score (PMI, 2000), risk severity (Graves, 2000), P-I score (Hillson, 2000), risk exposure (Githens, 2002), or risk event status (Wideman, 1992). Royer (2000) identifies an "intersecting matrix" for the probability and severity factors. Price (1998) defines risk as the probability times multiple consequences using a probability fault tree approach. Datta and Mukerjee (2001) developed a nine-segment matrix for immediate project risk analysis based on weighted probability. Pyra and Trask (2002) describe a quantitative priority ranking based on a table of probability and impact. Other models, as discussed by Kerzner (2002, p. 707), use a mathematical function that defines the risk factor as the multiplication of a number of probability and consequence factors. For more details, see Carbone (2004).

The same Carbone (2004) develops a model (RFMEA) leveraging on the Failure Mode and Effects Analysis (FMEA). For more details, see Carbone (2004).

In particular, the latter is commonly used in the practices for technical projects (for more details, see appendix A where interviews are called). It combines the probability and impact value with a detection value that represents the possibility to detect errors by team. There can be certainty the control team detects errors (minimum value) it is also true that the team cannot have the possibility to detect them (maximum value).

[125] The level of probability for each risk and its impact on each objective is evaluated during the brainstorming sessions. For more details, see Project Management Institute (2013).

[126] For more details, see note 124.

in this work and its scale values for probability and impact level are that of the Project Management Institute (2013) as in figure 61.

0,9	0,045	0,09	0,18	0,36	0,72
0,7	0,035	0,07	0,14	0,28	0,56
0,5	0,025	0,05	0,1	0,2	0,4
0,3	0,015	0,03	0,06	0,12	0,24
0,1	0,005	0,01	0,02	0,04	0,08
Pr./Impact	0,05	0,1	0,2	0,4	0,8

Figure 61: Severity matrix.

Each value in the square can vary from 0,005 (lowest severity) to 0,72 (highest severity). According to The Project Management Institute (2013) the following can be noted: for impact equal to 0,05 corresponds a *very low* impact level. For an impact equal to 0,1, this corresponds to a *low* impact level. For an impact equal to 0,2 corresponds a *moderate* impact level. For an impact equal to 0,4 corresponds a *high* impact level and for impact equal to 0,8 corresponds a *very high* impact level. The project manager needs to identify the level of attention by assessing two thresholds: $\bar{\lambda}max$ and $\bar{\lambda}min$ in order to obtain three levels of attention:

- *Critical* if the severity of risk is higher or equal to $\bar{\lambda}max$
- *Moderate*, if the severity is between $\bar{\lambda}max$ and $\bar{\lambda}min$
- *Minor*, if the severity is less or equal than $\bar{\lambda}min$.

He needs to compare the severity of risk obtained with the level of attention, in order to plan possible responses. For a particular *risk severity*, the risk is positioned into one of the three colour zones in the risk matrix. Each one indicates the priority of the risk:

- Red zone implies high attention.
- Yellow implies medium attention.
- Green implies low attention.

According to The Project Management Institute (2013) $\bar{\lambda}max = 0,18$ and $\bar{\lambda}min = 0,06$. Then, each risk is reported by a priority scale in the *Risk Assessment Form* that defines for each risk its risk severity, at which stage the risk may occur (in terms of

which activity), its category and its risk owner.[127] The micro risk analysis is used in The *Lechler* project to analyse the risks related to project pillar of quality (as in figure 62) because for measuring that variable the project manager does not leverage on the *three point estimating* without the possibility of performing a *macro risk analysis*.

Activity ID	Activity description	Risk description	Impact	Pr	Risk Severity	Test for G zone	Test for Y zone	Test for R zone
D1	Project kick-off	Organisational/administrative tramps	0,05	0,5	0,025	G		
A1	Virtual meeting with target customers	Psychological barriers over Web system	0,2	0,5	0,1		Y	
B1	Database model configuration	Not create a proper database	0,4	0,3	0,12		Y	
B2	Programs development	Programming errors	0,2	0,9	0,18			R
B3	Server development	Get wrong the server sizing	0,2	0,3	0,06		Y	
B4	GUI development	Get wrong GUI programming	0,2	0,9	0,18			R
B5	Customer Info workflow	Structural problems	0,4	0,3	0,12		Y	
B6	Organisation Info workflow	Structural problems	0,4	0,3	0,12		Y	
B7	logistic IT link development	Contingent programming errors	0,2	0,3	0,06		Y	
B8	Access customised development	Contingent inter-face errors	0,2	0,3	0,06		Y	
C1	Market research	No ERPs-Web system integration	0,4	0,3	0,12		Y	
B9	Preloadable ERPs format	ERPs unpreloaded file	0,1	0,3	0,03	G		
A2	ERPs sample test	Wrong file structure	0,1	0,3	0,03	G		
C2	Sample gathering	Ineffective sample's cluster	0,2	0,1	0,02	G		
A3	Test1 over sample partners	Web system errors	0,1	0,3	0,03	G		
A4	Errors evaluation	Activity slack	0,05	0,1	0,005	G		
B10	Errors resolution	Easily-resolvable programming errors	0,1	0,3	0,03	G		
A5	Test2 over ERP partners	Debug errors	0,1	0,5	0,05	G		
A6	Clustering new customers needs	None	0,05	0,1	0,005	G		
B11	logistic coordination programming	Easily-resolvable programming errors	0,05	0,3	0,015	G		
B12	Database programming	Database and programming errors	0,8	0,1	0,08		Y	
A7	Customer portfolio development	Ineffective customers' cluster	0,4	0,1	0,04	G		
A8	Customers confidence relationship	Psychological barriers over Web system	0,2	0,5	0,1		Y	
A9	CSM training over SAP and Web system	Inadequate IT competences	0,2	0,1	0,02	G		
A10	Handbooks development	No intuitive ad easy-way guides	0,2	0,1	0,02	G		
A11 - A14	Business trips	Leaving web system utilisation	0,8	0,5	0,4			R
		No continuativeness of customers' purchase orders through web	0,8	0,5	0,4			R
		Reviewing customers' IT space	0,8	0,5	0,4			R
		Integration problems	0,8	0,5	0,4			R
A15	Customers conference call	None	0,05	0,1	0,005	G		
A16	Customers post-relationship and problem solving	None	0,05	0,1	0,005	G		
A17	Web orders monitoring	None	0,05	0,1	0,005	G		
A18	Results Analysis	None	0,05	0,1	0,005	G		
A19	Results evaluation	None	0,05	0,1	0,005	G		
D2	Web system evaluation	Utilisation rate<75%	0,4	0,1	0,04	G		

Figure 62: Quality risk assessment.

2.2. Macro risk analysis

Performing *macro risk analysis* is a way to estimate numerically, the probability that the project will meet its budget and schedule, as determined in the *project scope statement*. The impacts of all identified (and already quantified singularly) risks are simultaneously evaluated in order to get a probability distribution of the project's cost and time. It represents the degree of uncertainty in each schedule and cost activity. The information needed depends upon the type of probability distributions that will be used.[128] These practices determine the probability distribution by leveraging on the *three point estimating*[129] that set the optimistic, most likely, and the pessimistic values for time and cost. As already outlined in chapter 3.7, knowing such distribution it is possible to answer if the project manager can rely or not on such cost and time estimations used in the planning phase to create the project network and to obtain the project budget baseline. This implies an understanding if the contingency reserves are adequate (if allowed), to perform risk-based budget analyses and forecasting cost at completion, to ask for supplemental funds. The techniques to perform *macro risk analysis* take a more macro perspective than the micro risk analysis by looking at overall cost and schedule risks. Here, the focus is not on individual events, instead on the probability that the project will be completed on schedule and within the budget.[130] However, in some cases, it is not possible to perform *macro risk analysis* process due to lack of sufficient data to develop appropriate models[131] and this is the case for project quality. The tool that leverages on the *three point estimating* and already applied in the *Lechler* case study is the *PERT* analysis.[132] Leveraging on the values obtained for the pessimistic (maximum uncertainty considered) and optimistic (minimum uncertainty considered) scenarios, the project manager has identified a quantified but simplified measure of the risk: the standard deviation. It is a standardised measurement, which expresses the severity of the risk for each

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[128] Project Management Institute (2013).
[129] For more details, see chapter 3.4.
[130] For more details, see Larson et al. (2011).
[131] For more details, see Project Management Institute (2013).
[132] For more details, see chapter 3.7.

activity.[133] Here the project manager needs to define what he means by risk tolerance by defining two thresholds: $\bar{S}max$ and $\bar{S}min$. These are used to obtain three levels of attention: critical (if $SD \geq \bar{S}max$), moderate (if $\bar{S}max > SD > \bar{S}min$) and minor (if $\bar{S}min \geq SD$). He needs to compare the severity of risk with the level of attention, in order to plan possible adequate responses. Performing this analysis, it is really helpful to know which activities contribute the most to the possibility of overrunning schedule or cost targets. Then, simulations can be performed leveraging on *PERT simulation* or *Montecarlo simulation* for example, as well sensitivity analysis or EMV[134] analysis but they do not enter on the objective of the chapter.[135] From *PERT analysis* developed in chapter 3.7, the project manager has found that for this project the probability that the total project cost is bigger than the cost threshold decided by the project committee is:

$$\Pr(project\ cost > x_c) = N(Z_c) = 1,7\%$$

On the other side the probability that the total project time is bigger than the time threshold decided by the project committee is:

$$\Pr(project\ time > x_t) = N(Z_t) = 2,2\%$$

As in the previous results the project faces a low probability to overrun cost and time planned values. The probability is computed over these values because they are those obtained through the *three point estimating* technique in which the *PERT* analysis leverages on. Furthermore, knowing the standard deviation for each activity associated with time and cost, the project manager can study which ones contribute the most to the possibility of overrunning schedule or cost planned values. Figure 63 and 64 show the standard deviation for cost and time (respectively) associated with each activity and obtained from the *PERT analysis[136]*, which in turn leverages on the *three point estimating* technique[137]. Moreover, a test is computed through Excel to evaluate the level of attention for each one, assuming $\bar{S}min = 100$ and $\bar{S}max = 1000$ for cost and

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[133] This technique is useful to get the overall project risk assuming a normal distribution. It deals with the calculation of the probability that project cost and time take more than the preset budget and schedule.
[134] EMV stands for Expected Monetary Value.
[135] For more details, see Project Management Institute (2013).
[136] For more details, see chapter 3.7.
[137] For more details, see chapter 3.4.

for time. It has to be pointed out that the risk associated for each activity will impact project pillars differently, in terms of quality, cost and time. In fact, the risk associated with each activity changes the level of attention according to its impact over the variable. The first difference that can be noted between figure 63 and 64 is the standard deviation. It is obtained through the *three point estimating* in turn provided by the interviews with the main stakeholders. Activities C2, A3, A4, B10 shift from no critical zone (the green one) for costs, to a more critical zone (the yellow one) for time. It means that if some risks occur, they will impact more on time than on costs for those activities. Moreover more differences are tracked considering the impact of some activity risks over quality as in figure 62. The level of attention is low for activities B9, B10, A2-A5 and C2, moderate for activity A1, A8 and high for activities A11-A14.

Activity ID	Activity description	Risk description	SD (c)	Test for G zone	Test for Y zone	Test for R zone
D1	Project kick-off	Organisational/administrative tramps	83,11	G		
A1	Virtual meeting with target customers	Psychological barriers over Web system	68,91	G		
B1	Database model configuration	Not create a proper database	528,38		Y	
B2	Programs development	Programming errors	3061,51			R
B3	Server development	Get wrong the server sizing	612,49		Y	
B4	GUI development	Get wrong GUI programming	1361,66			R
B5	Customer info workflow	Structural problems	729,78		Y	
B6	Organisation info workflow	Structural problems	729,78		Y	
B7	logistic IT link development	Contingent programming errors	240,30		Y	
B8	Access customised development	Contingent inter-face errors	240,30		Y	
C1	Market research	No ERPs-Web system integration	208,33		Y	
B9	Preloadable ERPs format	ERPs unpreloaded file	208,33		Y	
A2	ERPs sample test	Wrong file structure	416,67		Y	
C2	Sample gathering	Ineffective sample's cluster	33,33	G		
A3	Test1 over sample partners	Web system errors	33,33	G		
A4	Errors evaluation	Activity slack	33,33	G		
B10	Errors resolution	Easly-resolvable programming errors	33,33	G		
A5	Test2 over ERP partners	Debug errors	33,33	G		
A6	Ghatering new customers needs	None	13,33	G		
B11	logistic coordination programming	Easly-resolvable programming errors	13,33	G		
B12	Database programming	Database and programming errors	106,67		Y	
A7	Cusotmer portfolio development	Ineffective customers' cluster	0,42	G		
A8	Customers confidence relationship	Psychological barriers over Web system	0,97	G		
A9	CSM training over SAP and Web system	Inadequate IT competences	2,09	G		
A10	Handbooks development	No intuitive ad easy-way guides	2,09	G		
A11 - A14	Business trips	Leaving web system utilisation	7,51	G		
		No continuativeness of customers' purchase orders through web	6,12	G		
		Reviewing customers'IT space	3,06	G		
		Integration problems	4,17	G		
A15	Customers conference call	None	1,39	G		
A16	Customers post-relationship and problem solving	None	1,87	G		
A17	Web orders monitoring	None	8,00	G		
A18	Results Analysis	None	1,60	G		
A19	Results evaluation	None	1,33	G		
D2	Web system evaluation	Utilisation rate < 75%	0,53	G		

Figure 63: Cost risk assessment.

Activity ID	Activity description	Risk description	SD (t)	Test for G zone	Test for Y zone	Test for R zone
D1	Project kick-off	Organisational/administrative tramps	0,16	G		
A1	Virtual meeting with target customers	Psychological barriers over Web system	0,00	G		
B1	Database model configuration	Not create a proper database	1,04		Y	
B2	Programs development	Programming errors	6,00			R
B3	Server development	Get wrong the server sizing	1,20		Y	
B4	GUI development	Get wrong GUI programming	2,67			R
B5	Customer info workflow	Structural problems	1,43		Y	
B6	Organisation info workflow	Structural problems	1,43		Y	
B7	Logistic IT link development	Contingent programming errors	0,47		Y	
B8	Access customised development	Contingent inter-face errors	0,47		Y	
C1	Market research	No ERPs-Web system integration	0,42		Y	
B9	Preloadable ERPs format	ERPs unpreloaded file	0,42		Y	
A2	ERPs sample test	Wrong file structure	0,83		Y	
C2	Sample gathering	Ineffective sample's cluster	0,50		Y	
A3	Test1 over sample partners	Web system errors	0,50		Y	
A4	Errors evaluation	Activity slack	0,50		Y	
B10	Errors resolution	Easily-resolvable programming errors	0,50		Y	
A5	Test2 over ERP partners	Debug errors	0,50		Y	
A6	Ghatering new customers needs	None	0,00	G		
B11	Logistic coordination programming	Easily-resolvable programming errors	0,00	G		
B12	Database programming	Database and programming errors	0,53		Y	
A7	Customer portfolio development	Ineffective customers' cluster	0,00	G		
A8	Customers confidence relationship	Psychological barriers over Web system	0,02	G		
A9	CRM training over SAP and Web system	Inadequate IT competences	0,00	G		
A10	Handbooks development	No intuitive ad easy-way guides	0,00	G		
A11 - A14	Business trips	Leaving web system utilisation	0,18	G		
		No continuativeness of customers' purchase orders through web	0,15	G		
		Revewing customers'IT space	0,07	G		
		Integration problems	0,10	G		
A15	Customers conference call	None	0,00	G		
A16	Customers post-relationship and problem solving	None	0,09	G		
A17	Web orders monitoring	None	0,40	G		
A18	Results Analysis	None	0,00	G		
A19	Results evaluation	None	0,00	G		
D2	Web system evaluation	Utilisation rate < 75%	0,00	G		

Figura 64: Time risk assessment.

3. Planning risk responses

When a risk event is identified and assessed, a decision must be made [..].[138] Once the risks are quantified, the project manager uses the information at his disposal to plan adequate responses to each risk identified with a certain level of attention. The main objective is to decrease the probability risks occurring or reduce its impact by implementing pre-identified preventive measures. As in The Project Management Institute (2013), this process consists of developing options and actions to reduce threats to project objectives. The literature has developed different frameworks but the standard of responses provided by The Project management Institute (2013) are considered in this work and re-elaborated in a decision-tree. Basically they are:

- Accepting: the project manager decides to accept the risk without taking any actions except documenting and periodically monitoring the threat. He takes this decision because the risk severity is not troubling without altering the progress of the project once occurring and it is not cost-effective to intervene. Its chance of occurrence is slim and if it occurs the budget or the contingency reserves set up can absorb it.

- Transferring: the project manager shifts in advance before the impact of the risk to a third party by outsourcing. It gives it to another part the responsibility of managing it and be responsible over its impact with an insurance. It consists on a payment of a risk premium but the possible negative effects are eliminated.

- Avoiding: the project manager isolates the project from the risk impact, eliminating it by changing the plan. Scope, cost, quality and time can vary, but the risk can be avoided.

- Mitigating: the project manager reduces the risk severity taking actions in advance, before its occurrence, to decrease its probability of happening and its impact. The severity decrease is within certain threshold limits but it means

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[138] Larson et al. (2011).

higher costs. Taking actions in advance is more effective than trying to repair the damage once the risk occurs.

Using the standards of responses, provided by Project Management Institute (2013), this work has elaborated a framework for risk responses through decision trees. In the planning phase, the project manager faces three possible scenarios:

- Not taking actions: it means the project manager accepts the risk in advance because its severity is lower than his *risk tolerance threshold* and if it occurs the project progress will be not altered. It is not effective intervening and in the case of occurrence the budget or the contingency reserves (if set up) can absorb the impact.

- Taking actions in advance: it means facing two possibilities. One of transferring the ownership of risk (and its negative consequences) to another part. It implies to eliminate the risk severity (then $risk\ severity = 0$) but at the same time it implies an increasing in costs. Another possibility is reducing its severity immediately in-house, at the increasing of costs, by taking action to mitigate or avoid all together. In the last case, $risk\ severity \rightarrow 0$.

- Waiting: It means the project manager decides to wait until the risk occurs. This decision clearly should be done according to the probability of occurrence of the risk considered. Going on with the project, if the uncertain event will not occur the project continues as planned, if the event will occur, the project manager needs to intervene by taking another plan. This plan is named in literature as *contingency plan*[139] and it can be costly. As in Larson et al. (2011), it refers to an alternative plan used if an unforeseen event occurs. It consists of actions to be taken in order to reduce the negative impact of the risk. Risk response plan differs from contingency plan. The first one considers responses as part of the actual plan taking actions in advance (before the risk occurs). The second one is not part of the initial plan, then it takes effect after the risk is recognized taking actions a posterior (after the risk occurs).

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[139] For more details, see Larson et al. (2011).

In each scenario, the decisions are taken according to the level of attention planned by the project manager, in turn depending by his *risk tolerance threshold*, comparing it with the risk rating. Then, a link between the three possible scenarios and the attention level, marked by three different colour zones, is needed. In this project risk management framework:

- Actions are not taken if the level of attention is green.
- Waiting is taken if the level of attention is yellow.
- Action is taken immediately if the level of attention is red.

The scenario is presented in a decision tree as in figure 65.
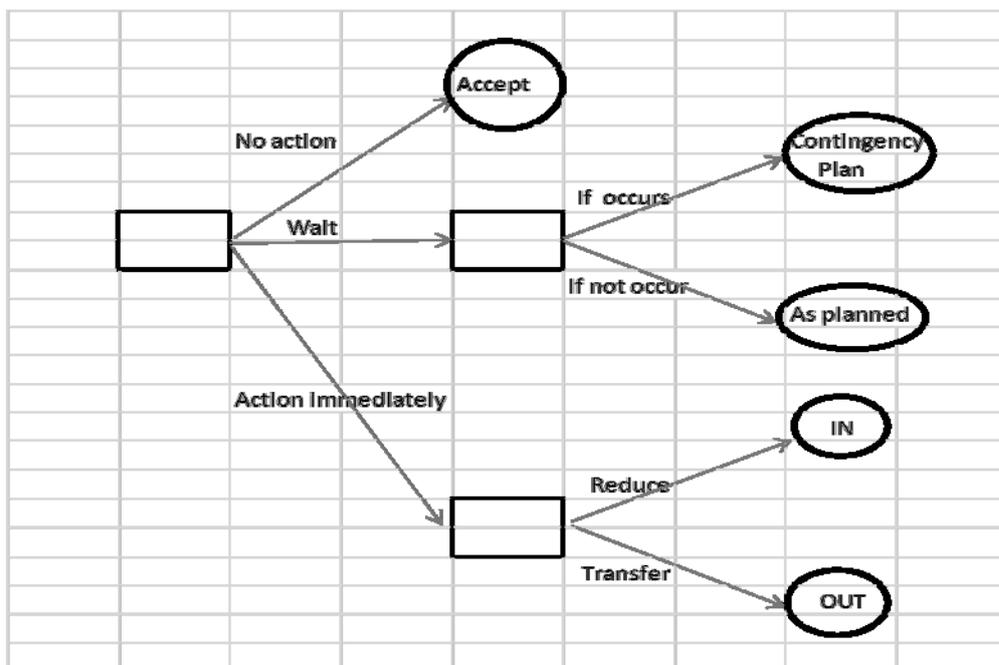
Figure 65: Risk responses decision tree.

Figure 66 presents the responses developed for each risk. It has to be pointed out that if the level of attention of a specific risk changes according to its impact over the variables, then the level of attention in order to prepare adequate responses will be the higher one.

Activity ID	Risk description	Level of attention for COST	Level of attention for TIME	Level of attention for QUALITY	Response
D1	Organisational/administrative tramps	G	G	G	No actions
A1	Psychological barriers over Web system	G	G	Y	Wait
B1	Not create a proper database	Y	Y	Y	Wait
B2	Programming errors	R	R	R	Action immediately
B3	Get wrong the server sizing	Y	Y	Y	Wait
B4	Get wrong GUI programming	R	R	R	Action immediately
B5	Structural problems	Y	Y	Y	Wait
B6	Structural problems	Y	Y	Y	Wait
B7	Contingent programming errors	Y	Y	Y	Wait
B8	Contingent inter-face errors	Y	Y	Y	Wait
C1	No ERPs-Web system integration	Y	Y	Y	Wait
B9	ERPs unpreloaded file	Y	Y	G	Wait
A2	Wrong file structure	Y	Y	G	Wait
C2	Ineffective sample's cluster	G	Y	G	Wait
A3	Web system errors	G	Y	G	Wait
A4	Activity slack	G	Y	G	Wait
B10	Easily-resolvable programming errors	G	Y	G	Wait
A5	Debug errors	G	Y	G	Wait
A6	None	G	G	G	No actions
B11	Easily-resolvable programming errors	G	G	G	No actions
B12	Database and programming errors	Y	Y	Y	Wait
A7	Ineffective customers' cluster	G	G	G	No actions
A8	Psychological barriers over Web system	G	G	Y	Wait
A9	Inadequate IT competences	G	G	G	No actions
A10	No intuitive and easy-way guides	G	G	G	No actions
A11 - A14	Leaving web system utilisation	G	G	R	Action immediately
	No continuativeness of customers' purchase orders through web	G	G	R	Action immediately
	Reviewing customers' IT space	G	G	R	Action immediately
	Integration problems	G	G	R	Action immediately
A15	None	G	G	G	No actions
A16	None	G	G	G	No actions
A17	None	G	G	G	No actions
A18	None	G	G	G	No actions
A19	None	G	G	G	No actions
D2	Utilisation rate< 75%	G	G	G	No actions

Figure 66: Risk response plan.

Then for the risks associated with activities D1, D2, B11, A6, A7, A9, A10, A15-A19 no actions are taken because those risks are accepted as in the green zone for each pillar. If they occur the project progress will be not altered so it is not effective to intervene. However, for the risks associated with activities A1-A5, A8, B1, B3, B5-B10, B12 the project manager waits for their occurrence. If they occur he has to rely on a contingency plan. If the risks associated with activities B1 and B3 occur, the IT staff has to correct the database errors and modify its size in order to effectively re-perform activities B5 and B6. If the risks associated with activities B7 and B8 occur the IT related errors can be resolved. Clearly, the contingency plan has to contain the possible cost and time slacks. If the risk associated with activity B9 occurs, other IT tools in supporting the customers have to be provided but for that reason they are already

created in the previous activities.[140] If the risk associated with activity B10 occurs, the technical errors can be easily resolved but it will cost more time then is needed to provide for such activity. If the risk associated with activity B12 occurs, the IT staff must be changed. Regarding activity A1, the risk associated for quality is considered of moderate attention. It implies that If it occurs the project team must intensify the relation and the service with the customers. Regarding activity A2: the risk associated for time and cost is considered of moderate attention. It implies that if it occurs more effort has to be spent in structuring the file. Regarding activity A3: the risk associated for time is considered of moderate attention. It implies that If It occurs more time has to be spent in adjusting errors. Regarding activity A4: the risk associated for time is considered of moderate attention. It implies that If It occurs the activity will require more time. Regarding activity A5: the risk associated for time is considered of moderate attention. It implies that If It occurs easily and resolvable errors must be resolved taking more time for that activity. Then activities A11-A14 are considered of high attention regarding the impact of their risks over the quality (in non-technical terms) of the project. Then the project manager has to pay attention immediately to that risk. In fact, during the project implementation the Customer Support Manager provided a discount considering the customers' web utilisation kick off and its continuation. Furthermore, a clear explanation of the web system was provided, to increase the probability that the customers understand the system and its potential benefits. Moreover, activity A10 was created ad-hoc to prevent that risk. That is not all: a closer working relationship between the IT specialist and the customers was created and funded by the company in order to resolve possible integration problems between ERPs and the Web system. Finally, the IT staff uploads, prior to the visits of the customers and their personal IT space in order to codify different products ID. Activities B2 and B4 are considered of high attention above all the pillars. Two possible solutions exist: outsourcing the activity to a specialist or mitigating the risk in-house. In the real case project, the company chooses the second option in order to reduce it.

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[140] A filter for the insert of the orders via Web is provided and a file .txt generated from a general ERP is planned to be uploaded. Moreover another function is provided: the possibility of the insertion of the orders by the sales forces responsible over customer service.

A continuous monitoring of the risks identified performed by the project risk owner in turn supervised by the project manager is an effective way to implement the adequate risk responses and tracking their effects over the project progress. Moreover this process ensures that new risks are identified and managed during all the project lifecycle. Risks and responses must be reviewed and updated when conforming to the project phase. It is a way of continuously monitoring the risk variable and its impact over project time, quality and cost and in turn over the scope. It is also in accordance with the *new constraints framework*. This process has to be implemented in order to manage all the identified and possible risks, with the aim to reduce the gap between optimal values found in the optimisation problem and the actual values provided by performing project activities. Project risk management is an essential tool in order to guarantee the success of the project over its scope and the three pillars related, benefiting in turn the stakeholders involved, who have a stake in its success. Clearly this process requires resources involving costs and it affects time, because managing risk means spending cost and time and, then, it depends upon the scale of the project. Companies, in particular the smaller ones, when performing international development should not leave the management of risk with the following sentence "*it is a question of chance*". Instead, project risk management is a *knowledge area* that must really be considered in performing a project. When carrying out international projects, it is better to be ready for *what* is known, than leave the success to chance.

Conclusions

This work has discussed the concept of *International Project Management* debating how project management is a discipline that can help companies in breaking their value chain globally. We have addressed this issue by embodying a *methodology of project management* that can be applied to non-ordinary international operations in order to frame them by analytical rules, as in the project-case studied. Moreover, we tried to clarify the concept of project success and performance by unifying the project management pillars of scope, quality, cost and time through a *mathematical model*. As discussed in this work, Project Management is a concept already awarded in the ancient times and throughout history, experts worked on improving and refining the project management practices. However, there are still companies that do not consider this discipline as a key function. Project Management is the future for the business and we aim at showing how this scientific discipline is really useful and needs to be considered by companies, especially those ones that want to go abroad for business facing complexity, uncertainty and large-scale effort.

Our methodology involves all the functional area of a business by creating a dedicated teamwork oriented toward the objectives. It tracks tangible results by gathering fundamental project info, by monitoring the pillars of the project (quality requirements, time and cost), by coordinating the various project stakeholders over the same objective. Moreover project management is essential to efficiently allocate the resources without waste, to create a teamwork in order to effectively reach the objective, to define the alternative paths or solutions in case of problems. Objectives are clear and they have to be monitored: it is essential to reach them and this discipline is helpful. Furthermore, it really helps to improve these non-ordinary operations by managing the possible risks related through a clear and analytical model. In doing so, the project manager is who orchestrate the overall project, being

responsible over its success and performance. For that reason, its figure is more than ever essential whenever a company needs to implement a non-ordinary operation.

In the real-case project, studied in chapter 3, *practices for project management* have been applied though a clear methodology based on project management standards and analytical rules. Moreover a model for *project risk management* has been implemented in order to manage the risk related. This methodology has leveraged on the *new constraints framework*, developed in chapter 2, and which tries to unify in a mathematical function the pillars of the project management that in turns impact over the scope. It helps to clarify the concept of project performance and success, because different frameworks have been applied in the discipline and the standards provide a vague definition. The project success has been linked to the concept of scope and through an optimisation problem the values for the project pillars that influence the scope (quality, cost and time) are maximised. In turns the project success can be maximised by tending the planned and cost values to the optimal ones. In doing so a function that describes *quality concept* has been provided. Furthermore the *Analytical Hierarchy Process* has been applied as analytical and consistent method in order to obtain a quantified measure of the priority of the three variables over the project scope in order to clearly manage it, without leaving anything to chance. It urges at applying the multi-criteria decision analysis whenever decision-making situations arise.

We have played the role of project manager by creating a methodology applied for *Lechler* project by using *Excel*. We have drafted the *project scope statement* by having a clear description of the scope of the project, its boundaries, constraints, exclusions, its main deliverables, acceptance criteria and milestones. Then the priorities of the main stakeholders have been translated into quantified measures through *Multi-Criteria Decision Analysis*. The *Analytical Hierarchy Process* has been applied as analytical and consistent method in order to obtain those quantified measures translated as weights in the mathematical project scope function. It urges at applying the multi-criteria decision analysis whenever decision-making situations arise. The *Work Breakdown Structure* has been employed to map the project detailing a structure

of the scope (broken down into major deliverables and sub-deliverables) and it has been linked to the *Organisational Breakdown Structure* to assign the project activities to each organisational department. Once a structure of the project has been designed, helping us to have its overview, it has been estimated the time and cost of the overall project. Under uncertainty we have adopted the *three-point estimating* technique to evaluate time and cost for each activity in the optimistic, pessimistic and most likely scenarios. Knowing the activities network for each department and having also the estimation about time and cost, we have scheduled the logical sequence of activities of the entire project figuring its network path and obtaining the *Critical Path*. So it has been possible to track the duration of the entire project. We have shown that it is important to schedule resources in order to obtain *project budget baseline*. Through *Project Libre* we have created the *GANTT* chart to present the schedule information. Furthermore, we have also illustrated how to reduce the project duration by adopting *crashing costs* technique. Once time-phased the costs and planned the duration of the entire project we, as project manager, have obtained the probability that these estimations (over time and cost) are reliable by leveraging on *PERT* analysis. Moreover we evaluated its performance progress over cost and time by leveraging on *Earned Value Management* technique. Then, the results we obtained through the new *mathematical model* applied in the project have helped to clarify project management literature about *project management pillars, success* and *performance* because different frameworks have been applied in the discipline and the standards provide a vague definition. They confirm that the success consists on reaching project scope (the mainstay of the project), by managing time, cost and quality requirements according to their priorities and respecting their thresholds. Then through an optimisation problem the values for the project pillars that influence the scope (quality, cost and time) are maximised. In turns the project success can be maximised by tending the planned and actual values to the optimal ones. Having provided a *Cobb-Douglas function* for quality, the quality variable of a project will be influenced according to the impact that time and cost have over it. If one considers the same impact of cost and time over quality, the more the priority is oriented over one variable, the more the optimal solution

tends to rely in the extreme of the function where that variable takes its maximum (for quality) or minimum (for time and cost) value, at the expense of the others with less priority (that vice versa tend to their thresholds). Then, changing from an optimal extreme point to another is seen as a trade-off between the priorities over the project pillars. Things change if the impact of time and costs are considered differently over quality. Considering *Lechler* time-to-market project, its priority has been to quickly deliver its outcome: time needs to be compressed as much as possible at the expense of minimising the quality (but respecting an identified quality threshold to satisfy the customers) and maximising the cost (by using the entire budget at the disposal). However different scenarios have been examined at changing of the priorities and of the impact. Finally a methodology for *project risk management* has been developed and applied to this project. *Risk Register* has been used to identify risks, *Risk Assessment* has been adopted to perform micro risk analysis, *PERT* analysis has been employed to perform macro risk analysis and *Decision Trees* has been used for planning risk responses.

Appendix A

Zulian, S. (interviewer) & Dr. Colombo, A. (interviewee) – Lechler project IT manager and SAP administrator in *Lechler s.p.a. Lechler* project interview. *Lechler s.p.a.* 12/05/2015 and 26/08/2015.

Zulian, S. (interviewer) & Dr. Voltolina, S. (interviewee) – Lechler project representative and start-up process manager in *Lechler s.p.a. Lechler* project interview*. Lechler s.p.a.* 11/03/2015, 10/05/2015 and 25/08/2015.

In the first interview occurred with Dr. Voltolina on 11/03/2015 it has been outlined how Lechler has carried out the business-IT project between September 2013 and September 2014 in the Spanish market. Lechler headquarter (Lechler s.p.a.) formally authorised to carry out an international project jointly with its Spanish business branch (Lechler Coatings Iberica s.l.) in September 2013 consisting of developing a Web system for business orders with the aim of changing the purchase habits of Spanish customers in the Spanish market. Their purchase habits would have changed from a traditional old-fashioned system of mail and phone based business orders to a new and intuitive system of on-line business orders. A careful feasibility study offered important advantages both for organisation and Spanish customers and the project was authorised after the business case was developed. This project needed to be implemented maximum within a year, being the way to translate in action Lechler organisational strategy to achieve a long-term goal consisting on implementing the Web system in the markets in which the company operates. In particular, this project has presented uncertainty in developing an IT system to change Spanish customers business orders habits facing historical and cultural barriers over the Spanish customers accustomed to rely on an old-fashioned system for business orders in the chemical industry. Clearly part of the objective has been to provide an intuitive, easy and quick system to meet customers' needs on easy-way practices. Furthermore, to provide the possibility of monitoring the business order just in time from their IT tools like PC, smart

phones and tablets. One of the major risks involved, would be to lose the customer who is exposed to such a radically different way of inputting business orders. This IT system would have resolved other practical problems tracked in the possibility of integration between the IT tool and a general ERP software of the Spanish customer. Each ERP generates the business order sent directly to Lechler Coatings Iberica s.l. Customer Service. The ERP should generate a preloaded format text with certain characteristics and fields to be uploaded into the Web system directly, enabling it to be read. Another relevant risk faced by the project was to not meet a solution enabling integration with all customers ERP. This is due to the fact that there is no homogeneity of ERP between Spanish customers. A preloaded text to be imported directly in the Web system was the result of an accurate research.

Then the project scope statement has been drafted as in the following table:

Project name: Web system for business orders	
Project type: business-IT Project	
Industry: Chemistry Industry	
Stakeholders involved	• *Lechler s.p.a. – head-office* • *Lechler Coatings Iberica s.l. – Spanish branch* • *Spanish customers*
Stakeholders needs	• *Changing the ordinarily way to purchase of the Spanish customers by providing an IT system that satisfy their needs (Lechler s.p.a.)* • *Having the possibility to make business orders online and monitoring them (Spanish customers)*
Project scope	• *Creating an easy, intuitive and quick web system order to purchase and monitor the orders online and implementing it in the Spanish market. Without outsourcing activities.*
Project time	• *Reaching the project scope before 200 labour days.*
Project cost	• *The overall project has not to exceed the cost of 75.000€*
Project quality	• *Reaching the technical and non-technical requirements of the project deliverables. The desired quality completion over its maximum is set by the project committee at about 61%.*

Technical requirements	• *The web system must be accessible on Lechler webpage by the customer*
	• *The web system must get inputs:*
	  o *externally by the clients when generating the orders*
	  o *internally by logistic, customer service and sales departments to gather information*
	• *The web system must generate the output in the form of orders and information accessible for customers*
	• *The Web system to be accessed by different IT tools (Smartphone, tablet, PC) and consultable from any place*
	• *Classifying the catalogue of products in function of the product industry (INDUSTRY, REFINISH, DECORATIVE,YACHTING, WOOD)*
	• *The web system can be compatible with a Spanish customer's ERP turning its orders in online orders*

Major Deliverables	1. *Web system for business orders beta version* 2. *Integration Web system beta – ERP* 3. *Market test over Web system beta* 4. *Fine-tuning for realising Web system official version* 5. *Web system implementation in the Spanish market* 6. *Web system adoption by Spanish customers*
Acceptance criteria	1. *Web system features regarding the acceptance criteria of sub-deliverables* 2. *Preloaded format file from ERP at a minimum cost* 3. *Test with no errors over 78% of customer partners* 4. *Resolution of all customer needs* 5. *Meeting the acceptance criteria of each related activity* 6. *Reaching the customer utilisation rate by business orders via Web repetition over 75% of Spanish customers*
Milestones	• *Web system beta* • *Web System released version*

| | | • Web system implementation | | | |
| | | • Web system adoption | | | |

In the interviews occurred on 10/05/2015 with Dr. Voltolina and on 12/05/2015 with Dr. Colombo an organised list of activities has been obtained for the project with their acceptance criteria, description and the major deliverable for each group of activities. For each department has been assigned a number of staff. Then time and cost have been estimated in most likely, pessimistic and optimistic scenario for the major deliverables and weights for each activity are addressed in order to split cost and time for each one (the latter is done later in project planning phase). The preceding activities for each one are identified (then they will be held accountable for each department network in the planning phase). Finally, in the interviews occurred on 25/08/2015 with Dr. Voltolina and on 26/08/2015 with Dr. Colombo, assumptions about potential risks for each activity have been done by describing it and then for each one has been assessed impact level and probability of occurrence (translated then in the planning phase for quality risk assessment. The measure for risk regarding time and cost are calculated leveraging on the standard deviation obtained in the planning phase). All data are summarised in the following tables:

Immediate preceding activities	Activity ID	Department	Assigned Staff	Activity description	Activities deliverable/acceptance criteria	Major deliverable
-	D1	Administration - Lechler head office	Senior Manager #1	Project kick-off	Project documentation	Web system for business orders beta version
D1	A1	Custiomer Service (CS) - Lechler head office	CS Manager #1 - Staff #1	Virtual meeting with target customers	Customer needs	
A1	B1	IT - Lechler head office	IT Manager #1 - Staff #1	Database model configuation	Database model configuration	
B1	B2	IT - Lechler head office	IT Manager #1 - Staff #1	Programs development	Database model development in accordance to the acceptance criteria provided in the project scope statement	
B2	B3	IT - Lechler head office	IT Manager #1 - Staff #1	Server development		
B3	B4	IT - Lechler head office	IT Manager #1 - Staff #1	GUI development		
B3	B5	IT - Lechler head office	IT Manager #1 - Staff #1	Customer info workflow	Database data workflow	
B3	B6	IT - Lechler head office	IT Manager #1 - Staff #1	Organisation info workflow		
B5;B6	B7	IT - Lechler head office	IT Manager #1 - Staff #1	Logistic IT link development	Database order updating just in time	
B4;B7	B8	IT - Lechler head office	IT Manager #1 - Staff #1	Access customised development	Personalised web system access	
A1	C1	Marketing - Lechler head office	Marketing Manager #1 - staff #1	Market research	Possibility of Web-ERP integration at min. cost	Integration Web system beta - ERP
B8,C1	B9	IT - Lechler head office	IT Manager #1 - Staff #1	Preloadable ERPs format	Preloaded ERP format	
A1;B9	A2	Custiomer Service (CS) - Lechler head office	CS Manager #1 - Staff #1	ERPs sample test	Positive test over at least 75% of different ERP models	
C1	C2	Marketing - Lechler head office	Marketing Manager #1 - staff #1	Sample gathering	Sample gathering of at least 20 partners	Market test over Web system beta for errors resolution

Pred	ID	Location	Responsible	Task	Description	Phase
A2;C2	A3	Custimer Service (CS) - Lechler head office	CS Manager #1 - Staff #1	Test1 over sample partners	Web system errors identification	
A3	A4	Custimer Service (CS) - Lechler head office	CS Manager #1 - Staff #1	Errors evaluation	Evaluation of error type identified in Test1	
B9;A4	B10	IT - Lechler head office	IT Manager #1 - Staff #1	Errors resolution	Rosolution of error type identified in Test1	
A4;B10	A5	Custimer Service (CS) - Lechler head office	CS Manager #1 - Staff #1	Test2 over ERP partners	Positive test over at least 78% of partners	
A5	A6	Custimer Service (CS) - Lechler head office	CS Manager #1 - Staff #1	Ghatering new customers needs	New resolvable needs	Fine-tuning for realising Web system official version
B10;A6	B11	IT - Lechler head office	IT Manager #1 - Staff #1	Logistic coordination programming	Lot splitting >= minimum number of peaces for a particular product line	
B10;A6	B12	IT - Lechler head office	IT Manager #1 - Staff #1	Database programming	Database upgrading for wizard, product code and business line	
B11;B12	A7	Customer Service (CS) - Lechler Spanish branch	CS Manager #1 - Staff #1	Cusotmer portfolio development	Spanish customers portfolio	Web system implementation in the Spanish market
A7	A8	Customer Service (CS) - Lechler Spanish branch	CS Manager #1 - Staff #1	Customers confidence relationship	Business relationship solidity and visit date	
B11;B12	A9	Customer Service (CS) - Lechler Spanish branch	CS Manager #1 - Staff #1	CSM training over SAP and Web system	Training level assased by IT manager	
A9	A10	Customer Service (CS) - Lechler Spanish branch	CS Manager #1 - Staff #1	Handbooks development	.pdf documentation for customers	
A8;A10	A11	Customer Service (CS) - Lechler Spanish branch	CS Manager #1 - Staff #1	Business trips central-north area	Assessment by customer support manager	
A11	A12	Customer Service (CS) - Lechler Spanish branch	CS Manager #1 - Staff #1	Business trips Andalucia area		
A12	A13	Customer Service (CS) – Lechler Spanish branch	CS Manager #1 - Staff #1	Business trips Catalunya area		
A13	A14	Customer Service (CS) - Lechler Spanish branch	CS Manager #1 - Staff #1	Business trips Levante area		
A14	A15	Customer Service (CS) - Lechler Spanish branch	CS Manager #1 - Staff #1	Customers conference call		
A14	A16	Customer Service (CS) - Lechler Spanish branch	CS Manager #1 - Staff #1	Customers post-relationship and problem solving	Assessment by customer support manager	Web system adoption by Spanish customers
A14	A17	Customer Service (CS) - Lechler Spanish branch	CS Manager #1 - Staff #1	Web orders monitoring	Web orders utilisation rate $= (w_o \cdot O + w_c \cdot C) \cdot 100$ Where: $O = \dfrac{web\ customers'\ orders}{tot.\ customers'\ orders}$ $C = \dfrac{cust.\ web\ utilisation}{tot.\ customers}$ And w is the weight assigned for each variable with $w_o > w_c$	
A15;A16;A17	A18	Customer Service (CS) - Lechler Spanish branch	CS Manager #1 - Staff #1	Results Analysis		
A18	A19	Customer Service (CS) - Lechler Spanish branch	CS Manager #1 - Staff #1	Results evaluation		
D1;A19	D2	Administration - Lechler head office	Senior Manager #1	Web system evaluation		

Impact	Pr of occurance	Risk description	Activity ID	Optimistic time	Most Likely time	Pessimistic time	Optimistic cost	Most Likely cost	Pessimistic cost	Weights
			1° major deliverable	58	86	148	29057	43027	74994,25	
0,05	0,5	Organisational/administrative tramps	D1							0,010855
0,2	0,5	Psychological barriers over Web system	A1							0,009
0,4	0,3	Not create a proper database	B1							0,069013
0,2	0,9	Programming errors	B2							0,399873
0,2	0,3	Get wrong the server sizing	B3							0,079999
0,2	0,9	Get wrong GUI programming	B4							0,17785
0,4	0,3	Structural problems	B5							0,095318
0,4	0,3	Structural problems	B6							0,095318
0,2	0,3	Contingent programming errors	B7							0,031387
0,2	0,3	Contingent inter-face errors	B8							0,031387
			2° major deliverable	10	15	20	5000	7500	10000	
0,4	0,3	No ERPs-Web system integration	C1							0,25
0,1	0,3	ERPs unpreloaded file	B9							0,25
0,1	0,3	Wrong file structure	A2							0,5
				25	35	40	6000	6500	7000	
0,2	0,1	Ineffective sample's cluster	C2							0,2
0,1	0,3	Web system errors	A3							0,2
0,05	0,1	Activity slack	A4							0,2
0,1	0,3	Easly-resolvable programming errors	B10							0,2
0,1	0,5	Debug errors	A5							0,2
			3° major deliverable	10	12	14	2000	2400	2800	
0,05	0,1	None	A6							0,1
0,05	0,3	Easly-resolvable programming errors	B11							0,1
0,8	0,1	Database and programming errors	B12							0,8
			4° major deliverable	40	42	44	3500	3587	3667	
0,4	0,1	Ineffective customers' cluster	A7							0,015
0,2	0,5	Psychological barriers over Web system	A8							0,035
0,2	0,1	Inadequate IT competences	A9							0,075
0,2	0,1	No intuitive ad easy-way guides	A10							0,075
0,8	0,5	Leaving web system utilisation	A11							0,27
0,8	0,5	No continuativeness of customers' purchase orders through web	A12							0,22
0,8	0,5	Reviewing customers'IT space	A13							0,11
0,8	0,5	Integration problems	A14							0,15
0,05	0,1	None	A15							0,05
			5° major deliverable	30	32	34	1200	1240	1280	
0,05	0,1	None	A16							0,14
0,05	0,1	None	A17							0,6
0,05	0,1	None	A18							0,12
0,05	0,1	None	A19							0,1
0,4	0,1	Utilisation rate < 75%	D2							0,04

The following interviews are wrote out in the original language

Zulian, S. (interviewer) & Dr. Bevilaqua, P. (interviewee) – project manager and operations planning manager in *Carraro Holding s.p.a. Project Management interview*. *Carraro Holding s.p.a.* March 16, 2015.

"Zulian, S.: <*Gentilmente, mi può parlare della disciplina del project management, del project risk management e se utilizza la Multi-criteria decision analysis?*>.

Dott. Bevilacqua, P.: <*Bisogna innanzitutto distinguere tra progetto su commessa e progetto che si sviluppa all'interno dell'azienda. Il primo tipo è commissionato da un'azienda a una società esterna specializzata in project management. Il secondo è sviluppato all'interno della stessa, in quanto ha già abbracciato il project management come funzione chiave. La differenza sta sostanzialmente nei costi da imputare alle attività di progetto e l'attività di ricerca in se viene seguita marginalmente all'interno della commessa. E' un lavoro dall'inizio ben già definito dove sono già definite le particolarità tecniche. Riguardo l'altro tipo, qui il prodotto non è ancora definito e deve essere strutturato per avviare il progetto tenendo conto del ciclo di vita del prodotto. Una volta capita questa distinzione bisogna capire che il project management è una funzione trasversale che copre tutto il processo e tutto le funzioni ed è importante definire i pacchetti di lavoro con tutte le funzioni aziendali. Il progetto ha bisogno di un business plan per capire le potenzialità del mercato e come il prodotto possa avere successo. Si effettua un'analisi SWOT, un'analisi della concorrenza, dei bisogni dei consumatori nel mercato e un'analisi economico-finanziaria. Partendo dall'inizio il project management è un'insieme di attività volte alla realizzazione degli scopi/obbiettivi di progetto. In un'azienda di grandi dimensioni si lavora in un ambiente multi-project ovvero, dove si gestiscono tanti progetti di grandi o piccole dimensioni secondo l'esigenza mentre la commessa lavora su progetti di larga scala che richiedono grandi investimenti. Ora mi preme sottolineare che il project management è anche un approccio culturale diverso che, soprattutto nel Nord-est ma penso anche in tutte le*

aziende, è importante perche porta con se degli aspetti organizzati e culturali innovativi di fatto. Anche se è una metodologia implementata nelle grosse aziende e che esiste da anni, in realtà molte aziende per una questione culturale fanno fatica a ritenerla come funzione chiave. E', di fatto, una metodologia che, se utilizzata nel modo corretto, può effettivamente aiutare nell'ambito gestionale. Quindi, questo è un aspetto importante. Infatti il project management è l'applicazione di conoscenze, tecniche e strumenti che servono per il raggiungimento degli obiettivi ovvero lo scopo di progetto. La storia insegna che nei primi anni di vita del project management, il project manager è nato come figura tecnica che era all'interno di alcune organizzazioni militari (parliamo dei primi anni del XX secolo). Questa figura si è però evoluta negli anni e fondamentalmente è diventata una figura gestionale. Esso deve aver la capacità di definire gli obiettivi con un team di progetto, coordinare il team di progetto e controllare che gli obiettivi di tempo, costo e qualità siano raggiunti (in gergo chiamati q. c. t.: quality, cost and time). Fondamentalmente è importante definire gli obiettivi e avere competenze soft per gestire il team (che devono essere distinte dalle competenze di natura tecnica). Deve avere competenze di carattere gestionale affinché i tecnici possano raggiungere gli obiettivi che li vengono definiti. Deve sapere gestire ed allocare in modo corretto le risorse per raggiungere gli obiettivi di progetto. Costi, tempi e qualità sono i vincoli di progetto ed è questo che differenzia un progetto dalle attività di processo. Costo e tempo devono essere certi e il progetto deve raggiungere delle performance. Per performance di progetto intendo il risultato di un'attività in termini di obiettivi fissati all'inizio in termini di costo, tempo e qualità. Infatti, ci sono i cosiddetti KPI (Key Performance Indicator) che servono per monitorare le attività e il raggiungimento del risultato in termini di tempo, costo e qualità. Quando si parla di qualità, fondamentalmente si parla dei requisiti. Qui ha un ruolo fondamentale la gestione del ciclo di vita del prodotto (PLM). S'identificano i requisiti del cliente (è indispensabile identificare con chiarezza i requisiti di prodotto e non – es. requisiti legislativi). Si può utilizzare la Technical Application Form al fine dell'individuazione. Si determinano le specifiche di prodotto al fine rispondere al cliente, si effettua un'analisi tecnico-economica per capire se si può rispondere al cliente. Se questa fase è effettuata

in maniera adeguata, si riduce al minimo il margine di rischio sulla qualità. Per l'analisi economico-finanziaria è importante il business case per determinare i volumi di vendita e fare un'analisi di prezzo, degli investimenti necessari e del loro ritorno. Questo permette di capire se l'attività è conveniente o meno e capire che tipo di prodotto può rispondere ai requisiti del cliente. E' fondamentale garantire i risultati interni per l'azienda e allo stesso tempo soddisfano il cliente. La customer satisfaction è fondamentale ma deve essere in conformità agli obiettivi aziendali. Inoltre è importante controllare le variabili (riguardo alle modifiche tecniche). Il project manager deve definire gli obiettivi in termini di costo, tempo e qualità e allocare le risorse al fine del loro raggiungimento, gestire il team avvalendosi di competenze anche di natura soft e coordinarlo in funzione degli obiettivi. Deve avere la governance degli obiettivi gestendo i pilastri di progetto (q., c., t.), gestire il budget, organizzare le attività, deve avere l'attitudine del problem solving ed essere looking forward in modo da trovare una soluzione ai possibili problemi, sapere gestire il rischio ed essere un leader. Tutte queste son caratteristiche fondamentali e a supporto ci sono delle tecniche e strumenti al fine di compiere l'attività nel miglio modo possibile. Parliamo di pianificazione: il project manager deve essere in grado di pianificare le attività con i responsabili. Tra gli strumenti principali ci sono il GANTT chart e la WBS (Work Breakdown Structure). La WBS permette di definire il livello dettagliato e aree di attività di un progetto ed integrarle con le varie funzioni. Ci sarà un responsabile per un determinato pacchetto di attività ma sarà il project manager il responsabile del progetto a 360°. E' fondamentale il coinvolgimento delle funzioni. Per ogni attività bisogna allocare delle risorse economico-finanziarie e qui è essenziale adottare la GANTT chart. La collocazione delle risorse è fondamentale in fase di pianificazione per poi individuare il percorso critico a seconda delle risorse disponibili tramite un altro strumento importante, il Critical Path method e per capire dove poter intervenire per risolvere eventuali criticità. Altri strumenti fondamentali sono la PERT analysis per stimare che la probabilità che il costo e il tempo di progetto non sfiori i limiti imposti. È importante una cultura aziendale che abbracci questa funzione, ed è importante un'efficace comunicazione avendo la capacità (con riguardo al project manager) di sapere comunicare gli obiettivi agli enti

coinvolti esterni e interni. Ci sono dei gate formali dove il progetto è monitorato tramite una documentazione formale. Tramite Design FMEA (Failure Mode and Effect Analysis) si può effettuare un'analisi a calcolo per quantificare il rischio ingegneristico in fase di progettazione e di processo. Analisi make-or-buy permette di capire cosa esternalizzare e quali attività effettuare in-house. Action Plan è il piano di azione creato dal project manager che definisce le attività, il responsabile per ogni attività o gruppo di attività, la data delle attività (inizio e fine). I milestones son date pianificate che non si possono sbagliare. La Check-List serve per capire, attraverso delle domande, se si riesce a soddisfare determinati requisiti. La Multi-criteria decision analysis non le ho mai applicate. Riguardo a degli spunti sul project risk management che ti posso dare, la gestione del rischio a livello generale è molto simile per i vari tipi di progetto. Quello che è fondamentale è capire alcuni termini importanti che sono utili per la gestione del rischio. Infatti, da tutte queste analisi, elencate successivamente, si può ottenere una sintesi di rischio. Analisi make-or-buy. APQP (advanced product quality planning) serve per monitorare tutte le attività al fine di garantire le norme di qualità. PCPA (process control plan audit) per capire se il processo/fornitori son omologati o meno. PPAP (production plan approval process). DVPLAN (design validation plan) per sintetizzare le attività di validazione prodotto e i test necessari. FMEA (Failure mode and Effect analysis) legata al mondo della progettazione design o dei processi industriali. In particolare da quest'ultima si possono capire tutti i test necessari per validare il prodotto e il livello di rischio associato. Si fa un'analisi a calcolo per capire se si può assumere il rischio ingegneristico e intraprendere il test tangibile di validazione. In generale, una volta sintetizzati tutti i rischi, si valutano e si capisce quale livello di rischio associare per poi intraprende un piano di gestione del rischio (vedi PMBOK Guide). Il Risk Management? Alla base c'è un lavoraccio incredibile! Per concludere, importanti software che normalmente si utilizzano per il project management possono essere la funzione project management in SAP, Primavera, Microsoft project.>.

Zulian, S. (interviewer) & Eng. Gallo, F. (interviewee) – project manager and strategic marketing director in *Carraro Holding s.p.a. Project Management interview*. *Carraro Holding s.p.a.* March 13, 2015.

"Zulian, S.: <*Gentilmente, mi può parlare della disciplina del project management?*>.

Ing. Gallo, F.: <*Il project management è la tipica funzione trasversale e cross-funzionale che serve a governare un'attività che si chiama progetto, che ha necessariamente un inizio e una fine. Il primo elemento d'attenzione è capire all'interno di ogni azienda quali sono le attività che vanno governate a flusso (per esempio un'attività di produzione che non ha un inizio e una fine certa, ma è una routine quotidiana) e quali a progetto (per esempio un progetto di riallocazione produttiva che ha un inizio e una fine certa, quindi non è una routine quotidiana). Il team di lavoro è formato da persone provenienti da diverse aree funzionali con un obiettivo comune. Questo team di lavoro deve rifarsi al project charter, il documento dove son contenuti i pilastri di progetto: tempi, costo e performance. La qualità e il contenuto tecnico di progetto le considero all'interno delle performance. Il contenuto del progetto stesso è il primo fondamentale pilastro del progetto e il fatto che io ho un deliverable in termini di costo e tempo è del tutto ininfluente se non raggiungo l'obiettivo del progetto in termini di performance (tecniche). Quindi il contenuto è l'obiettivo, che può essere tecnico. Per esempio devo spostare per ragioni di mercato un certo prodotto in un altro mercato e quindi devo prendere questo prodotto, industrializzato in questa fabbrica e duplicarlo in un'altra sede produttiva (mantenendo la produzione in una logica local for local). Se il prodotto medesimo non ha la qualità e quindi le performance tecniche richieste il progetto viene a cadere e tutti gli altri obiettivi come tempi e costi sono in subordine. Al di la di quello che dicono i testi cerchiamo di capire l'intrinseco significato delle cose: è importante innanzitutto che il risultato ci sia. E' tollerabile quello di arrivare con tempi e costi più lunghi ma l'importante è raggiungere l'obiettivo identificato nella performance qualitativa di prodotto. Se non raggiungo quest'obiettivo, viene a mancare la ragione prima per cui io ho fondato questo team di lavoro, o deciso di gestire questa serie di attività, con caratteristiche specifiche, non più a flusso (perché in tal caso non mi*

sarebbe stato garantito il risultato). Altro elemento fondamentale è che ci sono dei ruoli nel project management: un committente che fornisce i tempi, costi ed obiettivi e un capo progetto che va gestire le attività non a flusso di un progetto dando gli strumenti cognitivi ed organizzativi per gestire in maniera corretta la pianificazione e o svolgimento (il project manager). L'azienda gestisce contemporaneamente moltissimi tipologie di progetti e si decide di gestire a progetto un'insieme di attività che se effettivamente annegata nel flusso quotidiano non porterebbe ai risultati richiesti. Tutti questi progetti devono avere una governance interconnessa con le altre governance dei processi e progetti altrimenti andrebbero a competere al fine di stabilire le risorse (umane e non), costi, tempi e performance. Inoltre le risorse sono finite e devono essere governate nella logica dell'insieme dei progetti e il project management ha il compito di dare gli strumenti cognitivi, anche di what-if scenario, per allocare le risorse in maniera corretta. Ci possono essere dei progetti molto semplici che richiedono poche settimane ed altri che richiedono anni.>.

Zulian, S.: <*Che strumenti utilizza per misurare tempo, costo e performance?*>.

Ing. Gallo, F.: <*Performance, tempi e costi vengono definiti in fase di pianificazione. Nella maggioranza dei progetti, gestisco progetti di sviluppo prodotto e si raggiungono determinate performance definite nel project charter (ovvero determinati requisiti). Normalmente vi è una simulazione di performance a livello virtuale per capire se può soddisfare i requisiti. Inoltre si fanno i prototipi per sottoporli ad altri test di laboratorio e alla fine di questo percorso di R&D capiamo se raggiungeremo le prestazioni richieste.*

Il costo del progetto (presente nel project charter) si determina dopo un accurato business case dove si stima il mercato potenziale in valore del prodotto (si determina il prezzo) e i volumi di vendita (si determina la quantità) al fine di individuare il fatturato consuntivo preliminare. Dopo uno studio di fattibilità tecnico, per capire se con determinati requisiti si può raggiungere l'obiettivo, si valutano gli investimenti necessari in R&D e in industrializzazione (per esempio utilizzando il net present value). Infine si realizzerà il budget da fornire al project manager.

I tempi sono già definiti in fase di pianificazione e vengono riportati nel project charter andando a determinare gli obiettivi di tempo entro i quali il team deve raggiungere gli stadi di avanzamento del progetto.

Si monitora il progetto in termini di costo, tempo e performance in determinati gate formali (le quattro project reviews, dove si producono le documentazioni formali che attestano che il progetto è in conformità con gli obiettivi in termini di tempo, costo e performance). Precisamente alla fine di attività rilevanti (start, pianificazione prodotto, progettazione prodotto, end, considerando progetti di sviluppo prodotto). Sarà poi il project manager a determinare non in maniera formale ma in maniera sostanziale il roll-up di tempi, costi e performance del progetto andando a misurare l'avanzamento di progetto mensilmente. La gestione del team è molto importante in quanto ci sono attori che entrano in crisi se vengono spostati da una logica a flusso ad una logica a progetto. Sarà compito del project manager trovare i compromessi tra efficienza ed efficacia in quanto uno andrà a discapito dell'altro. Troverà giorno per giorno dei compromessi virtuosi. Il project manager deve capire il progetto nel suo insieme e quindi avere una robusta conoscenza tecnica-specialistica perché il rischio è non capire il progetto che si governa, che è drammatico!E se il team capisce questo, "lo taglia fuori".>.

Zulian, S.: < *come misura l'impatto dei rischi nel progetto una volta identificati?*>.

Ing. Gallo, F.: <*L'impatto del rischio viene valutato nei quattro gate formali di progetto (project review). Il rating del rischio è comune calcolarlo attraverso la formula* $Risk\ rating = Probabilità \times Impatto$ *ottendo un numero che rientra in una scala tale che si possa dare una priorità al rischio (ovvero il livello di attenzione da porgli). La probabilità e l'impatto vengono stabiliti grazie ai dati storici, prontuari in campo tecnico andando a studiare la letteratura o casi simili (andando a studiare in maniera specifica design FMEA e process FMEA di riferimento per andare a valutare le differenze al fine di fare un'analisi specifica) e da esperti. Mentre i concetti di base sono gli stessi, la declinazione dei concetti base per ottenere il risultato è in funzione al tipo di progetto e possono cambiare. Viene sviluppato un Mitigation plan una volta studiato il risk rating, ovvero vengo effettuate delle azioni preventive al fine di riportare il rischio*

nei limiti accettabili. Ricordo che stiamo parlando di progetti che riguardano lo sviluppo di prodotto e i prodotti sviluppati in questi progetti sono tecnici perciò il tema è molto tecnico.>.

Zulian, S.: <*Conosce la Multi-criteria Decision Analysis e se lo utilizza che ne pensa?>.*

Ing. Gallo, F.:<*Non lo uso, ho letto il tema ma conosco così poco al riguardo che non mi permetto di esprimere un giudizio. Nella vita il magazzino diventa pieno ad una certa età, le cose che utilizzi abbastanza frequentemente ce le hai in mano e puoi dare un giudizio sulla loro validità o meno. Per quelle che non utilizzi, onestamente diventerebbe velleitario per me esprimere qualsiasi giudizio.>.*"

Bibliographic research

Appendix A, where Interviews are called

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