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Controlling R&D Projects: Process Proposal and Application to an Industrial Example

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To my family

and to those I love

“Everything is vague to a degree you do not realize

till you have tried to make it precise.”

~ Bertrand Russell

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Δ	delta
AC	Actual Cost
ACWP	Actual Cost for Work Performed
A-o-N	Activity-on-Node
APM	Association for Project Management
AT	Actual Time
BAC	Budget At Completion
BCWP	Budgeted Cost for Work Performed
BCWS	Budgeted Cost for Work Scheduled
CCM	Critical Chain Method
CPI	Cost Performance Index
CPM	Critical Path Method
DSDM	Dynamic System Development Method
EAC	Estimate At Completion
ED	Earned Duration
EDM	Earned Duration Management
EFT	Early Finish Time
EPC	Engineering, Procurement and Construction
ES	Earned Schedule
EST	Early Start Time
ETC	Estimate To Complete
EV	Earned Value
EVM	Earned Value Management
FEED	Front-End-Engineering Design
HSE	Healthy, Safety & Environment
IPMA	International Project Management Association
LFT	Late Finish Time
LST	Late Start Time
MAPE	Mean Absolute Percentage Error
P&ID	Piping & Instrumentation Diagrams
PCS	Project Control Schedule
PERT	Program Evaluation and Review Technique
PM	Project Manager

PMBOK	Project Management Body of Knowledge
PMI	Project Management Institute
PV	Planned Value
R&D	Research & Development
RIES	Ricerca Innovazione e Sviluppo
RUP®	Rational Unified Process
SPI	Schedule Performance Index
TCPI	To Complete Performance Index
TPMS	Tecnimont Progress Measurement System
WBS	Work Breakdown Structure

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Abstract

The present work proposes a new process that can be employed for the control of Research and Development (R&D) projects.
The field of application for R&D projects is very wide, and they may include a large set of activities: for this discussion, the application of the proposed control process is limited to those R&D projects finalized to the validation of a new technology involving the design, construction, operation of an original experimental apparatus (pilot plant) and the execution of experimental campaigns. These projects are strongly characterized by uncertainties whose associated risks are difficult to quantify.

This work starts from the consideration that in literature there is a lack of detailed guidelines applicable for the control of R&D projects: although in the last twenty/thirty years new strategies for the management and control of R&D projects (*flexible methods* and *frameworks*) have been proposed, nevertheless they were originally conceived for Projects finalized to the marketing of products characterized by rapid, if not frantic, evolution (typically, commercial software), and in fields where innovation is mainly meant as incrementation and optimization of existing features. Given that this is not the case for the R&D projects here considered, these flexible strategies cannot be adopted straight forward.

The formalization of a new control process followed a deductive approach. General research on all theories and methods for project management and control was carried out in order to understand applicability conditions, strengths, weaknesses; the effect of the control actions over the project activities are analysed and discussed.
The new control process does not propose an original control metric; it is instead focused on the improvement of the planning phase, and in particular on the fine-tuning of the Project baseline: risks are identified and prioritized; for each project phase, the duration initially allocated for the execution of project activities – associated to specific risks – is characterized by a timespan devoted to test unconventional technical solutions; this process is iterated before moving to the subsequent milestone.

Interviews to Maire Tecnimont senior project managers allowed to validate, at least theoretically, the new proposed control process; this was then retroactively applied to an industrial project: the forecasts accuracy and the deviation from the planned schedule with respect to the actual one were quantitatively studied by comparing the MAPE (Mean Absolute Percentage Error) indicator.

The results obtained confirm that, adopting the proposed control process, it is possible to achieve better control of R&D Projects by means of the introduction of more reliable reference values.

Keywords: Project Control, R&D management, Theory of Constraints, Flexible Methods, Flexible Frameworks.

Sommario

Il presente lavoro di tesi propone un nuovo processo che può essere impiegato per il controllo di progetti di Ricerca e Sviluppo (R&D).

Il campo di applicazione dei progetti R&D è molto esteso in quanto questi possono includere nella loro definizione un vasto insieme di attività: per gli scopi di questa discussione, l'applicazione del processo di controllo proposto si limita ai progetti R&D finalizzati alla validazione di una nuova tecnologia e che prevedono la progettazione, la costruzione, l'esercizio di un apparato sperimentale originale (un impianto pilota) e l'esecuzione di campagne sperimentali sullo stesso impianto. Questa tipologia di progetto è fortemente caratterizzata da incertezze i cui rischi associati sono quantificabili con difficoltà.

Questo lavoro trova la sua motivazione dalla constatazione che, in letteratura, non sono presenti linee guida dettagliate in merito al controllo dei progetti R&D: sebbene negli ultimi venti/trent'anni siano state proposte nuove strategie per la gestione ed il controllo dei progetti R&D (*metodi* e *processi flessibili*), ciononostante queste sono state concepite originariamente per progetti finalizzati alla vendita di prodotti caratterizzati da una rapida – se non frenetica – evoluzione (tipicamente, i software commerciali), e in ambiti in cui l'innovazione è intesa primariamente come incremento e ottimizzazione di caratteristiche già esistenti. Non essendo questo il caso dei progetti R&D qui considerati, queste strategie flessibili non possono essere applicate tal quali.

La formalizzazione del nuovo processo di controllo è il risultato dell'adozione di un approccio deduttivo. È stata condotta una ricerca generale sulle teorie e sui metodi per il controllo e la gestione di progetto volta a comprendere le condizioni di applicabilità, i punti di forza e di debolezza degli stessi; gli effetti delle azioni di controllo sulle attività progettuali sono state analizzate e discusse.

Il nuovo processo di controllo non propone una metrica di controllo originale, piuttosto si concentra sul miglioramento della fase di pianificazione, in particolare sul perfezionamento della costruzione della baseline di progetto: i rischi sono identificati e prioritizzati; per ogni fase progettuale, i tempi assegnati originariamente alle attività – con i relativi rischi specifici – sono incrementati con lo scopo di permettere di testare soluzioni tecniche non convenzionali; questo processo è iterato prima di proseguire con le fasi di progetto successive.

Il nuovo processo di controllo è stato validato, per quanto riguarda il punto di vista teorico, da Project Managers afferenti al gruppo Maire Tecnimont; il processo è stato successivamente applicato in modo retroattivo ad un progetto R&D industriale: l'accuratezza delle previsioni è stata studiata quantitativamente attraverso l'indicatore MAPE (Mean Absolute Percentage Error).

I risultati ottenuti confermano che, adottando il nuovo processo proposto in questa sede e facendo riferimento a valori di pianificazione più affidabili, è possibile garantire un controllo migliore per i progetti R&D.

Parole chiave: Controllo di Progetto, gestione di progetti R&D, Theory of Constraints, Metodi Flessibili, Processi Flessibili.

Executive summary – Controlling R&D Projects: Framing a Process

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Abstract

The control process is one of the elements that assure a positive outcome for a project and due to this reason, it should provide accurate results to allow the realistic description of project progress. The control process is made more complex when dealing with R&D projects: uncertainty in the identification of all the project activities complicates the process of assigning variances and, consequently, the schedule becomes less robust. In order to increase the control reliability, a new control process is proposed and validated theoretically and quantitatively. Differently from more sophisticated approaches such as stochastic and fuzzy logic, the new control process is presented as a simple and pragmatic solution that can be adopted for R&D projects aimed at the development of an industrial technology, that may include the construction of a pilot plant and the execution of experimental campaigns. A strong emphasis is given to planning phase: as the schedule serves as a reference for control, Goldratt's Theory of Constraints – contaminated with elements belonging to flexible methods and frameworks – is adopted to guarantee the baseline a stronger adherence to reality.

Keywords: Project Control, R&D management, Theory of Constraints, Flexible Methods, Flexible Frameworks.

1 Introduction

A project is a temporary endeavor undertaken to create a unique product, service, or result under a defined timed and budget (Rose, 2013). Project features – namely unicity, temporariness and multidisciplinarity – are also shared by R&D projects which, additionally are aimed at producing a highly innovative result. The focus of the present paper is on those R&D projects whose objective is validating a new technology and verifying its potential applicability on an industrial scale. Such validations may include the construction of pilot plants and the execution of experimental campaigns.

R&D projects have some peculiar characteristics that differentiate them from non-R&D ones: the first are by their nature high-risk projects with many unknowns and great technical uncertainties (Cooper, 2007). The risk factors that affect R&D projects the most is the degree of unfamiliarity and the lack of experience concerning certain design conditions (Dey et al., 1994).

The case studies examined in this paper refer to the R&D projects developed in a large EPC (Engineering Procurement & Construction) firm where project management and project control are every day's tools.

Tecnimont S.p.A, an international leader in the field of Engineering, Procurement & Construction of large scale projects worldwide mainly in petrochemical, fertilizers, oil & gas, refining and power plants, is a subsidiary of Maire Tecnimont S.p.A., a technology-driven multinational Group working for the transformation of natural resources into innovative products.

Typically, in the context of large EPC firms, R&D projects represent a small share of effort in the company's development portfolio (Cooper, 2007) but they are vital to the company's long-term growth, prosperity and sometimes even survival (Cooper, 2007; Kivisaari, 1991). Besides the consideration that R&D projects are one of the primary ways to acquire knowledge, they enhance innovativeness (Cuervo-Cazurra et al., 2018), play a predominant role in improving the competitiveness of firms (Gunasekaran, 1997) and shorten the response times to capture opportunities (Gunasekaran, 1997; Wang et al., 2018).

Seen the relevance of the R&D project outcomes, it appears that adequate project management tools and techniques are necessary to maximize the success probability of these projects. Some authors believe that the application of traditional management techniques to non-traditional projects may not be adequate (Cooper, 2007), others believe that current methods should take into consideration R&D projects peculiarities by extending and integrating other existing methods (Cassanelli & Guiridlian Guarino, 2014), others again believe that more importance should be given to some tools such as risk analysis (Wang et al., 2018) for example, during the planning phase (Dey et al., 1994); hence many researchers are studying on the mitigation strategies of the schedule risks in the project management (Y. Zhang & Yang, 2014). In this article, the attention will be focused particularly on project control, the process by which managers assure that resources are obtained and used effectively and efficiently in the accomplishment of the organization's objectives (RN, 1965). Project control includes the set of activities and tools used to verify whether the project proceeds according to the time and costs trends forecasted. It also allows to make predictions about future trends and to select the best strategies to allocate resources or – whenever a deviation is present – to apply corrective actions. It has been suggested that an organization undertaking several projects should adopt a common project management approach for all projects in the program, regardless of the type of project, its size, or the type of resource used (Turner, 1988); advantages are reported in Turner et al. (1999) (H Payne & Rodney Turner, 1999). On the basis of the results of a survey submitted to management people (H Payne & Rodney Turner, 1999), the use of procedures regardless of project peculiarities is less successful compared when the procedures were tailored to the project, hence a customized control process is proposed. The construction of an accurate baseline implicitly turns into a more realistic estimate also of the project budget which could discriminate a project undertaking: an inaccurate budget evaluation can discard the possibility of undertaking a new project with all the related consequences outlined before.

Project control is strictly bond to planning (Omta et al., 1994): only by constructing a reference (baseline) it is possible to compare real trends with planned ones. Planning methodologies were largely studied for those projects related to consolidated technologies where a lot of recorded historical data are available, but the same cannot be said for Research and Development (R&D) projects (Golenko-Ginzburg et al., 1996). Besides the lack of historical data and technological uncertainties, estimating activities duration for R&D projects is not straight forward. Similarly, there are uncertainties related to the lack of experience about the technology and the technical solutions for the process. It follows that R&D projects should be carried out with a kind of “creativity”, making some non-conventional choices (Wingate, 2014).

To face the problems related to the baseline construction, it must be reported that several approaches have been studied and adopted. Literature offers many examples of models for variance computation by probability-based or fuzzy set-based methods (Cooper, 2007; Weglarz, 1999): the first way to proceed is associating a probability distribution function to the unknown variable; for fuzzy set-based methods, fuzzy logic is used and its reliability can be improved by experts' judgment and project managers' experience (Long & Ohsato, 2008). Academics, companies 'specialists and managers can benefit from the results of this study which provides a control process which can suit the R&D project characteristics previously mentioned. Uncertainties can be better managed and corrective actions can be more focused and efficient. The paper is organized into six sections. Firstly, a literature review concerning project control and its interfaces is reported, with reference to Tecnimont best practices. Then, the new control process is proposed addressing all the issues reported in the previous section; it will be followed by a theoretical validation of the process, done by three senior managers of Maire Tecnimont Group involved in the R&D projects. In the fifth and sixth sections, the process quantitative validation is provided: the MAPE (Mean Absolute Percentage Error) index was used to this purpose. One of the R&D projects examined was also chosen as the subject of the quantitative validation (Section 5.2). In the conclusions, the most relevant results and limitations are summarized and discussed, and highlights on further research are provided.

2 Literature Review

A wide number of studies and researches concerning the calculation of activities parameters are offered by literature but a little investigation has been undertaken in the area of planning and control of R&D projects (Golenko-Ginzburg et al., 1996; Ouchi, 1979).

Historical developments of the last years of 1900 showed the need to develop methods and frameworks that could better adapt to new project characteristics (Wingate, 2014), requiring speed in taking decisions and related to innovations. Flexible methods and frameworks – originally born, and still mainly used for the software field – represented the new approach to manage R&D projects. To mention the most known, Spiral Development, Agile Method and Scrum method share some common points: iteration is the key feature to add value to the product and to solve any new problem encountered along the way. Other methods and frameworks exist: their peculiar characteristics are not discussed in this context and more details are included in the Agile Manifesto (Beck et al., 2001). Flexible methods and frameworks are more focused on getting the added value as soon as possible: to do that, activities are not detailed straight at the beginning of the project, many loops are introduced and a lot of importance is given to the project team and the communication between each other. It is the authors' opinion that the application of the flexible methods and framework shows some limitations and is not applicable straight forward to plant construction projects: flexibles characteristics better suit field where innovation is meant as incrementation of features or in contexts where modifications can be easily applied.

Despite existing flexible methods and frameworks, R&D projects are tried to be controlled using deterministic techniques (Golenko-Ginzburg et al., 1996): an example is provided by Tecnimont (a company of Maire Tecnimont Group), an international Engineering, Procurement, and Construction (EPC) contractor.

Tecnimont S.p.A. chooses as control method the Earned Value Management method, which has been proven itself to be one of the most effective performance measurement and feedback tools for managing projects (Institute, 2011). As indicated in the Company procedures, the work is differentiated for its duration and its tangibility in:

- discrete effort, if work is directly related to a product realization or a tangible service;
- apportioned effort, if the work for the project is not easily separated in discrete efforts but can be express proportionally to the work related to discrete efforts;
- level of effort, if work cannot be divided into discrete elements (such as project support and project control (Kerzner, 2017)).

Measured the progress, some indicators are computed. They are based on three fundamental parameters (Rose, 2013) that are defined in the following:

- Planned Value (PV): is the planned value for times and costs. PV is also known as Budgeted Cost for Work Scheduled (BCWS);
- Earned Value (EV): it is the value that represents the progress at a specified time. It represents the work actually performed. EV is also known as Budgeted Cost for Work Performed (BCWP);
- Actual Cost (AC): it represents the number of resources that have been employed in a certain timespan to complete activities. AC is also known as Actual Cost for Work Performed (ACWP).

Based on these three main parameters, the EVM allows the computation of the project performance and to make forecasts about future project behaviour. According to the project complexity, different monitoring strategies are adopted: in fact, monitoring is more structured in an EPC project rather than in FEED or service projects. R&D projects discussed in this paper have been treated – from the control point of view – as service projects. Project control (FEED+ EPC) is represented in Fig.1. As it is possible to see, EPC control process is more structured and the tools used to build the baseline and trace the progress are more advanced. Planning should be considered as nothing more than a predictive model that can be used for resource efficiency calculations, time and cost risk analysis, project control and performance measurement, etc. (Vanhoucke, 2012).

Taking Tecnimont as best practice EPC contractor, the Work Breakdown Structure (WBS) is used to integrate all the project information, to organize and define the project scope. Each activity, ordered hierarchically, is divided into sub-activities and/or deliverables. Activities pertaining to the same area and sharing the same objectives are organized in work packages that are assigned a percent value: their sum must close to 100%. Once activities are identified, times and costs are estimated according to estimates by analogy (making references to similar past projects), parametric estimates (exploiting the countable variable and regression model that describe the project performance in their functions), bottom-up estimates (summing all the milestones costs starting from the most specific task).

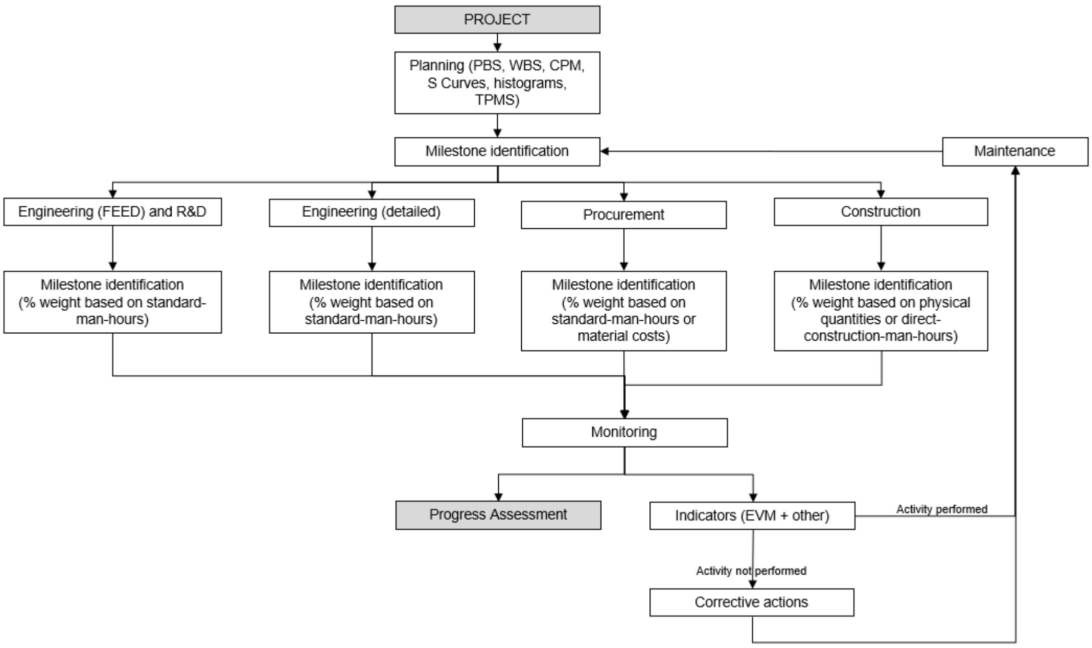

FIGURA 1: FEED AND EPC CONTROL PROCESS DIAGRAM

Many examples of stochastic methods are offered in literature (Acebes et al., 2015) to estimate time and cost variance. Although the related simulations allow the modelling of multiple scenarios covering customized range for the variable values, the strongest limitation is the confidence that the project manager can associate to probability distribution functions: for R&D projects, the lack of historical data and records in databases could lead the project manager to characterize incorrectly the random variables (Dodin, 2006). Fuzzy set-based methods provide viable alternatives in the R&D environment but, even if they have been proposed for many project scheduling (Bonnal et al., 2004; Chanas & Kamburowski, 1981; Long & Ohsato, 2006, 2008; Lootsma, 1989; Lorterapong & Moselhi, 1996), however, it seems that they are not currently applied in many industry fields for example, in Tecnimont. In Tecnimont, the risk is considered by modelling the time and cost variance with stochastic models such as Monte Carlo simulation.

When all time durations and costs are defined, activities are linked with Activity-on-Node (A-o-N) diagrams to trace the Critical Path which can be more than one according to the variance estimated for the milestone completion. When the critical path is traced, ancillary activities are organized consequently, producing the baseline, which is the reference for control.

Gunasekaran (1997) (Dey et al., 1994) points out that a simplified process control to be applied R&D projects turns out to be inadequate: hence, the need to tune a new control process, based on proven management standards and integrated with new methodologies, suitable for R&D projects (Cassanelli & Guiridlian Guarino, 2014).

3 A proposal for a new control process

The new control process, that is inspired either by flexible methods and frameworks, and by Goldratt’s Theory of Constraints (TOC), is focused on the planning.

Planning has a strong interface with control: it is essential to define project objectives and requirements and, therefore, is the basis for reliable project control [22]. Higher the planning accuracy, higher the probability to perform a more effective control.

The proposed process is shown in Fig.2.

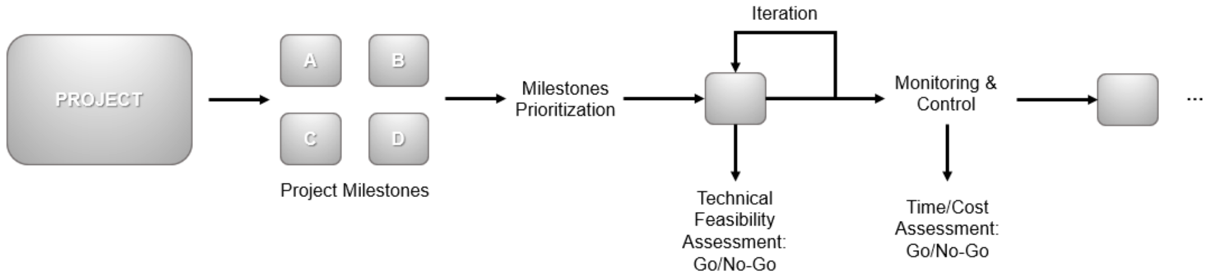

FIGURE 2: NEW CONTROL PROCESS PROPOSAL

The application of TOC requires the prioritization of all the most complex and difficult activities; uncertainties, related to lack of information about them, are managed through the introduction of buffers positioned at the end of the critical path and at the end of sequences of activities influencing the critical path. TOC does not explicitly refer to projects with a high level of uncertainty; the capacity of the buffer is estimated based on the variances associated with the activities described in the schedule. This approach provides good results, however, in case of occurrence of creeps during the project execution, the adherence and accurateness of the control metric are likely to fail.

R&D projects are characterized by a high level of uncertainty. Uncertain events, potentially leading to adverse outcomes, are likely to generate project creeps: it is therefore of paramount importance to early identify these events and outline possible solutions to be implemented in order to mitigate their effects on the overall performance. To this purpose, risk analysis methodology is applied. As, for each activity characterized by uncertainty, the magnitude of the risk can be computed, risk analysis allows the prioritization of these activities. Differently from TOC method, for the new control process, a dedicated buffer is directly associated with any activity characterized by important uncertainty. For each of these activities, the capacity of the buffer is computed based on the magnitude of the risk. Each buffer can be exploited for the implementation of possible recovery/mitigation actions up to the finalization of a suitable solution (iteration) should an adverse event occur.

In addition, based on the results of the risk analysis, the original project schedule is re-modelled in order to anticipate, whenever possible, the activities characterized by high risk. In such a way, for any uncertain event, a timely decision about whether to continue with the execution of the project or to leave it can be taken (go/no-go) based on the efficacy of the mitigative actions that have been tried.

The distribution along the schedule of these buffers, associated with the possible anticipation of high-risk activities, enables a better control of the project. In fact, if an adverse event occurs and none of all the identified mitigative actions is effective, the decision to leave the project can be timely taken; on the other hand, if the mitigation action is effective, the project will progress; the presence of the buffer (that has been used for the implementation of the mitigating action) prevents the introduction of further delays in the planned schedule.

4 Theoretical validation

The theoretical validation of the process for Control is performed by consulting three senior managers of Maire Tecnimont Group involved in R&D projects (the "project managers" as henceforth indicated). Robustness and completeness were tested adopting the "interview" methodology: by this means, all the interviewed managers evaluated the control process referring to their experience in past and ongoing R&D projects.

4.1 Methodology

The interview approach has already been used in other researches as a tool to verify the effectiveness of prototypes (Park et al., 2017), to collect data from interviewees experience (DiCicco-Bloom & Crabtree, 2006; Qu & Dumay, 2011; Zhu & Mostafavi, 2017), evaluate the effectiveness of a model (Drechsler & Breth, 2019; Yali Zhang et al., 2018) and to ascertain and theorize prominent issues (Jamshed, n.d.). The validity of interviews is based on the assumption that interviewees are competent and truth-tellers (Qu & Dumay, 2011).

Interviews consisted of structured conversations (Gillham, 2000; Jamshed, n.d.) aimed at collecting information and project managers' points of view on the control process proposed.

In the present research, semi-structured interviews were employed. This kind of interview contains open and closed questions (Gillham, 2000) – organized in thematic sections (Qu & Dumay, 2011) – whose objective is guiding the interviewee through all topics of interest.

The selected sample of people that was submitted with the interview was not so numerous (three people): this is because – in Maire Tecnimont Group – there are only little examples of R&D Projects with the characteristics described in the Introduction.

Interviews were conducted with face-to-face meetings (when possible), on the telephone and through virtual meetings. A questionnaire for straightforward questions (Gillham, 2000) was also employed.

The interview re-elaborations were submitted to interviewees to check the content consistency and correctness.

4.2 Results and Content Analysis

Interviews were oriented to collect the project managers' opinions and experiences about the salient features of the new control process, namely uncertainties, risks and the choice of control metrics. As expected, there is a wide convergence on the themes discussed. All interviewed judged the risk analysis as an important step: for all projects, risks were evaluated even if a formal analysis was performed only in one project. Since the qualitative risk analysis is already a step for the project, in some cases, implementing this tool would not add substantial costs to the planning phases: this is the demonstration that PMs are aware of the importance of risks while planning and carrying out the project.

An interesting aspect that emerged from interviews is that qualitative risk analyses are already performed to make preliminary considerations about project feasibilities: project managers agree on the use of risk analysis as a first Go/No-Go Gate: hence, if no corrective actions are detected for the occurrence of a possible undesired event, then it would be worth evaluating if the project has to be continued.

Considering the level of uncertainty characterizing the projects, all the respondents share the conviction that re-planning (using, for example, the Rolling Wave Breakdown Structure) is a useful tool that can be used to update the baseline.

For what concerns the introduction of time span to test activities, only one project manager asserts that testing should be even more anticipated to the Engineering phases: as much as it is possible, this conservative approach is not in conflict with the present control process proposal.

Finally, all project managers are aware that changing control metric is not a simple process when there are consolidated procedures or imposed rules so, the first divergence is not affecting the process validation: the new control process proposal is not going into the substance of selecting a more suitable metric, but is instead focusing on improving the accurateness of the baseline by considering some time to be devoted to iteration and testing.

According to the material and information collected with interviews, the new control process proposal can be considered theoretically validated.

5 Quantitative validation

The new control process accuracy and adherence to reality were challenged to be better than the control process applied in an industrial example of an R&D project. Through a What-if analysis, a new project schedule was produced accordingly to the new control process proposal; process performances are successively compared.

5.1 Methodology

To tune the Control Process proposed before, the "What-if analysis" tool was used.

What-if analysis is a simulation whose goal is to inspect the behaviour of a complex system (i.e., the enterprise business or a part of it) under some given hypotheses(Golfarelli et al., 2006). It measures how changes, in a set of independent variables, impact on a set of dependent variables with reference to a given simulation model that is a simplified representation of the business(Golfarelli et al., 2006). This methodology has already been applied to evaluate beforehand the impact of a strategical or a tactical move(Golfarelli et al., 2006; Lee et al., 2006; Micheli et al., 2009) and for the validation of simulation models(Golfarelli et al., 2006). In the present case, the answer to be replied in the analysis is "is the new control process more efficient than the one effectively applied to a selected industrial R&D project?". To provide an answer to the previous question, a structured approach was adopted.

As done by Chen et al. (2014) and Andrade et al. (2018) (Chen, 2014; de Andrade et al., 2018), accuracy for each node was computed using the Mean Absolute Percentage Error (MAPE). MAPE is probably the most widely adopted unit-free measure and can be used when data have a meaningful zero (ratio-scaled data)(Armstrong & Collopy, 1992). It is defined as:

$$MAPE = \frac{100}{n}\sum_{n=1}^{n}\left|\frac{\widehat{y_t} - y_t}{y_t}\right|$$

where:

- y_t is the actual value for time *t* to perform an activity or a set of activities;
- $\widehat{y_t}$ is the predicted value for y_t to perform an activity or a set of activities;
- n is the number of phases to which is related to the computation for accuracy.

As accuracy will be computed considering single phases for a single project, n assumes the unitary value.

5.2 Case Study

A R&D Project developed in Tecnimont S.p.A was chosen to quantitatively assess the features of the new control process. The Project, started in 2013 and successfully completed in 2018, was aimed at validating a new technology for the natural gas sweetening based on an innovative cryogenic distillation process. The scope of work included the design and construction of a laboratory scale pilot plant and the execution of two experimental campaigns for the validation of the process. The Project was divided into two different phases. The first phase – which is not included in the following study – was devoted to the theoretical studies and simulations of the new technology, to the assessment of the technical feasibility of a laboratory pilot plant and, in perspective, of a future industrial plant based on the new technology, as well as to the assessment the economic competitivity of the process. The second phase included the development of the detailed design, the pilot plant construction, and the execution of the first experimental campaign, with the possibility to run a second experimental campaign should the results of the first were not sufficient to validate or confute the theory at the basis of the new process. For the present discussion, the focus is on the second phase that was planned to last 34 months (including the Second Experimental Campaign).

The second phase of the Project lasted, actually, 45 months, due to the occurrence of unexpected adverse events that enlarged the scope of the project: major modifications were applied to the pilot plant to improve its operative conditions and a second experimental campaign was performed.

For the sake of the discussion, R is the real Project and W is the what-if project.

Table 1 and Table 2 report respectively the original and the actual data related to project R second phase.

TABLE 1: DATA FOR PROJECT R ORIGINAL SCHEDULE

Original Schedule – Project R	***Start date***	***End date***	***Days (calendar)***
Pilot Plant Detailed Design – Planning of operations	19-Feb-15	15-Apr-15	56
Pilot Plant Construction	16-Apr-15	19-Nov-15	219
Pilot Plant Handover	20-Nov-15	30-Jan-16	73
Pilot Plant Tuning	01-Feb-16	25-Mar-16	53
First Experimental Campaign tests	26-Mar-16	02-Dec-16	251
Analysis of 1st experimental campaign results	03-Dec-16	01-Feb-17	62
Second experimental campaign tests	02-Feb-17	27-Nov-17	300
TOTAL			**1014days 34 months**

TABLE 2: DATA FOR PROJECT R ACTUAL SCHEDULE

Actual Schedule – Project R	***Start date***	***End date***	***Days (calendar)***
Pilot Plant Detailed Design – Planning of operations	19-Feb-15	15-Apr-15	56
Pilot Plant Construction	16-Apr-15	06-Mar-16	329
Pilot Plant Handover	7-Mar-16	18-May-16	73
Pilot Plant Tuning	19-May-16	23-Sep-16	130
First Experimental Campaign tests	24-Sep-16	31-May-17	251
Analysis of 1st experimental campaign results	01-Jun-17	31-Jul-17	62
Pilot Plant modification (revamping)	1-Aug-17	28-Nov-17	121
Second experimental campaign tests	29-Nov-17	30-Oct-18	337
TOTAL			**1359 days 45 months**

For what concerns Project W, the original schedule was assembled mainly referring to project R activities durations:

- one day is assigned to the prioritization phase (which includes a qualitative risk analysis and the reorganization of activities precedences). This amount of time was established following the experts' opinions. It is assumed that the baseline is defined according to new precedences: no extra time for scheduling is considered since prioritization only involves the insertion of times – related to test and iterate the considered phase – and some activity order change;
- construction is planned to be three months longer as the pilot plant vendor was proved to be able to provide the accurate estimation of the delay caused by the decision to test some unit functionality;
- once construction is concluded, a new planning ad risk analysis session is done in Project W: here the plant is assumed to be the element to be tested and iterated before the experimental campaign starts. One day is assigned to this planning session;
- the experimental campaign is unique because plant tuning is meant as a testing phase for the plant functionality. Only after the plant is declared to be operative and stable experiments can start;
- in addition to the time used for tests, four months are added for one of the pumps troubleshooting. Since at the early stage of risk evaluation it is not always clear which could have been the specific problem affecting the project success, general considerations are done: the process pump had already been detected as a potential criticality for the project so – to be conservative – the complete failure of the pump is considered to compute the amount of time to be added to ordinal activities. According to qualified pump constructors, pumps that are likely to suit the project purposes are built in three or four months: as the success of a brand-new pump is not assured, four months are taken as timespan. In this way, it is accounted for any further iteration to solve the pump instability;
- for what concerns the experiments, the duration of the single campaign was assumed to be equal to Project R Second Experimental Campaign – which was performed once the plant was proved to be stable.

Project W actual schedule was modelled on the considerations made for its original schedule and considering the actual times of Project R. Days devoted to Project W actual Plant Tuning are increased because, in order to guarantee the plant efficiency obtained for Project R Second Experimental Campaign, a revamping must be included (121 additional days).

Finally, since the number of Project W's experiments is equal to Project R' Second Experimental Campaign, the experimental phase is assumed to last as Project R actual Second Experimental Campaign. Table 3 and Table 4 report respectively the original and the actual data related to project R second phase.

TABLE 3: DATA FOR PROJECT W ORIGINAL SCHEDULE

Original Schedule – Project W	***Start date***	***End date***	***Days (calendar)***
Pilot Plant Detailed Design – Planning of operations	19-Feb-15	16-Apr-15	57
Pilot Plant Construction	17-Apr-15	21-Feb-16	312
Pilot Plant Handover	22-Feb-16	05-May-16	74
Pilot Plant Tuning	06-Mar-16	28-OCt-16	177
Experimental Campaign tests	29-Oct-16	23-Aug-17	300
Analysis of the Experimental Campaign results	24-Aug-17	23-Oct-17	62
TOTAL			**982 days 32 months**

TABLE 4: DATA FOR PROJECT W ACTUAL SCHEDULE

Actual Schedule – Project W	***Start date***	***End date***	***Days (calendar)***
Pilot Plant Detailed Design – Planning of operations	19-Feb-15	16-Apr-15	57
Pilot Plant Construction	17-Apr-15	07-Mar-16	329
Pilot Plant Handover	08-Mar-16	20-May-16	74
Pilot Plant Tuning	21-May-16	13-Mar-17	298
Experimental Campaign tests	14-Mar-17	12-Feb-18	337
Analysis of 1st experimental campaign results	13-Feb-18	15-Apr-18	62
TOTAL			**1157 days 38 months**

5.3 Results and Content Analysis

For what concerns accuracy evaluation, MAPE was expected to demonstrate that the "What-if" project is more accurate than project R; in fact, the project W schedule was widened because of the introduction of tests on the cooling system and of the elongation of troubleshooting times: a longer duration better resembles the actual project development.
Start and End dates are included in the computation of timespans. As it is dealt with time extensions, calendar days are considered.
For Project R actual Experimental Campaign, the First and the Second Campaign days are summed to represent the effective number of days needed for the technology validation. The Plant Modification sections include the days devoted to Plant Tuning and the revamping.
In Tab. 5, values for MAPE are reported.

TABLE 5: RESULTS FOR MAPE COMPUTATION

Phase	**R:** $\hat{y}_t$	**R:** y_t	$MAPE_R$	**W:** $\hat{y}_t$	**W:** y_t	$MAPE_W$
Pilot Plant Detailed Design – Planning of operations	56	56	0	57	57	0
Pilot Plant Construction	219	329	33,43	312	329	5,17
Pilot Plant Handover	73	73	0	74	74	0
Pilot Plant Modifications	53	251	78,88	177	298	40,60
Experimental Campaigns	551	588	6,29	300	337	10,98

The new control forecasts result in being more or equally accurate than the real project ones in the majority of the cases. Colin (1982) (Colin David Lewis, 1982) allows the interpretation of the results obtained; for a MAPE<10, a forecast is highly accurate. This result was obtained the project phases which were related to project planning: hence, planning is less likely to accumulate delay because there is not the chance to physically verify if planned technical solutions are effective once constructed and installed.
In the real project Construction, Plant Modifications and Experimental Campaign were subjected to deviations which complicated the progress measure. The best improvement can be observed for the construction phase because it is assumed that the expert and qualified pilot plant vendor can envisage how much time has to be devoted to, doing specific tests on units (which corresponds to reality). As far as Plant Tuning is concerned, it is very complex to know in advance which could be the specific problem/s affecting the plant reliability: only

the exact knowledge about the technical anomaly enables the project manager to consider possible corrective actions and their temporal quantification.

Only the results related to Experimental Campaigns suggests that Project R forecasts are more accurate than Project W's. This trend can be explained by the fact that, in this analysis, the days related to both Project Experimental Campaigns have been added up. As already highlighted, the possibility to perform Project R Second Experimental Campaign was taken into account in the original planning but represents an extension of the original work scope. Project R Second Experimental Campaign execution can be assumed to be an alternative way to Iterate the First Experimental Campaign and, due to this, its consideration for MAPE computation improves the index value. Nevertheless, if Project R Second Experimental Campaign were not used in the computation, the MAPE index would result in being equal to 53,31, which is a more unsatisfactory result than Project W's. Anyway, although Project R shows a better result for the Experimental Campaigns, this does not compensate for the worse results obtained for the other phases analyzed. These considerations demonstrate that the iterative planning and tasks execution should be incentivized – which is a concept strongly supported in the new control process proposal.

According to the results, it can be stated that the process introduced improves forecasts accuracy and, consequently, the overall control process is improved.

6 Conclusions

In previous sections, three R&D projects were described and analyzed; their characteristics make their control process peculiar. Although in the last years of twentieth-century (Beck et al., 2001; Wingate, 2014) the introduction of flexible methods and frameworks has strongly changed the way to manage new typologies of projects (mainly software ones[10], [20], [21]–[28], [29], [30]), they cannot, however, be applied straight forward to projects that include in their scope the construction of a pilot plant and the subsequent execution of experimental campaigns.

In the present work, it is assumed that the difficulties related to control R&D projects are, essentially, in the planning phase, that is made more complex by the project uncertainties. Although literature offers a good number of examples and attempts to model such uncertainties with stochastic methods (Acebes et al., 2015; Bistline, 2016; Bruni et al., 2011;

Hazır & Ulusoy, 2019; Long & Ohsato, 2008), they cannot provide accurate result since the simulations are run with inaccurate data.

The new control process is proposed as a practical solution for companies dealing with R&D projects: the introduction, detection and classification of risks allow their prioritization in the schedule, and the insertion of buffer times is devoted to test and to verify unconventional technical solutions. In addition, the new control process safeguards the project. As explained in the article, for instance, the early technical tests to verify the functionality of components, which have been evidenced as strongly influencing the schedule, allow to minimize the extent and the impact of the corrective actions to be taken.

A R&D project developed in Tecnimont was selected to test the accuracy of the proposed control process; its schedule was compared to one constructed adopting the new control process (by means of a What-if analysis). From a quantitative point of view, the new control process is demonstrated to be more effective. Although MAPE analysis was applied only to one project, its effectiveness has been acknowledged by three senior managers. This guarantees the applicability of the results also to R&D projects different from the one subject of this discussion.

The project that has been analyzed in detail, was managed following the new control process: although the original planning did not include the early technical tests here above described, however, they have been timely carried out to avoid major disruptions in the schedule.

Also, the key role of technical experts able to identify the tests to be included in the original schedule should be underlined.

The new process shows, however, some limitations. The timespan for testing and iteration is quantified with a conservative approach which does not exclude that the timespan allocated for a specific activity exceeds the actual amount of time needed: in this case the project time advantage could be lost. Although re-scheduling can be done, however, for project activities characterized by scarce flexibility, the benefits are negligible.

Due to this limitation, a deeper study of methods to estimate the duration of iterations could be carried out. Possible methods to be pursued could be the fuzzy-based ones: this solution could compromise the easy application of the control process but would likely improve the quality of the buffer extension.

Another aspect worthy of further investigation is the choice of the control metric. Although in this paper the major problem was assumed to be the baseline strong deviation from reality, it cannot be excluded a priori that some metrics could provide more detailed and accurate information about the project progress.

Additionally, another aspect worth to be considered is the evaluation of a new system for contingency computation. For non-R&D projects, contingencies are usually very accurate and they are computed as a percent value of the overall project budget; due to the limitation mentioned in the Introduction, the same statistical confidence is less likely to be proven for a R&D project.

Finally, keeping into account the continuous developments and changes occurring worldwide, it is fair to think that the impact of these variations would be observed also at the project level: environmental circumstances and constraints could induce new needs and, for this reason, it cannot be excluded that in a next future, also non-R&D projects may be managed differently. In this sense, the control proposal described in the present discussion represents an innovative process that could be tested also on non-R&D projects.

Sommario esteso – Controllo di Progetti R&D: Elaborazione di un Processo

Sommario

Il processo di controllo è uno degli elementi che contribuiscono all'esito positivo del progetto e, per questa ragione, dovrebbe fornire dei risultati quanto più accurati per poter delineare una descrizione realistica dell'avanzamento del progetto. Il processo di controllo è reso più complicato quando si ha a che fare con progetti R&D: l'incertezza nell'identificazione delle attività di progetto complica l'assegnazione delle varianze e, conseguentemente, la schedula risulta meno robusta. Al fine di incrementare l'affidabilità del controllo, un nuovo processo è proposto e validato sia dal punto di vista teorico che quantitativo. A differenza di approcci più sofisticati quali i metodi stocastici e le logiche fuzzy, il nuovo processo di controllo si presenta come una soluzione semplice e pragmatica che può essere adottata in campo industriale per i progetti R&D volti allo sviluppo di una nuova tecnologia; per questo fine può essere necessaria la costruzione di un impianto pilota e l'esecuzione di campagne sperimentali. Grande enfasi è stata attribuita alla fase di pianificazione: dal momento che la schedula funge da riferimento per il controllo, la cosiddetta "Theory of Constraints" di Goldratt – contaminata da elementi appartenenti ai "metodi e processi flessibili" – è stata adottata per garantire che il riferimento (baseline) fosse quanto più aderente alla realtà.

Parole chiave: Controllo di Progetto, gestione di progetti R&D, Theory of Constraints, Metodi Flessibili, Processi Flessibili.

1 Introduzione

Un progetto è un'opera temporanea che viene intrapresa con lo scopo di creare un prodotto, un servizio o un risultato unico entro un tempo e un limite di spesa definito [a]. Le caratteristiche del progetto – ossia l'unicità, la temporaneità e la multidisciplinarietà – sono condivise anche dai progetti R&D che, addizionalmente, hanno lo scopo di produrre un risultato altamente innovativo. Nell'articolo l'attenzione è posta sui progetti R&D il cui obiettivo è la validazione di una nuova tecnologia e la verifica della sua applicabilità su scala industriale. Questa validazione, in mancanza di esempi e applicazioni pregresse, può richiedere la costruzione di un impianto pilota e l'esecuzione di campagne sperimentali.

I progetti R&D hanno alcune altre caratteristiche che li differenziano dai progetti non R&D: i primi sono per natura intrinseca progetti ad alto rischio con molte incognite e grandi incertezze tecniche [b]. I fattori di rischio che influenzano maggiormente i progetti R&D sono lo scarso grado di familiarità e la mancanza di esperienza relativa ad alcune condizioni di progettazione [c].

I casi studiati nel presente articolo si riferiscono a progetti R&D sviluppati in grandi aziende che, come Tecnimont S.p.A., sono specializzate nell'EPC (Engineering, Procurement & Construction) e in cui la gestione dei progetti e il loro controllo sono all'ordine del giorno.

Tecnimont S.p.A. è leader internazionale nel campo dell'ingegneria, approvvigionamento e costruzione di impianti di larga scala nel mondo, soprattutto nel settore degli idrocarburi (petrolchimico, fertilizzanti, raffineria); la Società appartiene al Gruppo Maire Tecnimont, una multinazionale di alto livello tecnologico che lavora alla trasformazione delle risorse naturali in prodotti innovativi.

In questo contesto, i progetti R&D rappresentano una porzione minore del portfolio tipico di una società [b] ma risultano di vitale importanza per la crescita a lungo termine della stessa, per la sua prosperità e – talvolta – anche per la sua sopravvivenza [b], [d].

Aldilà della considerazione che vede i progetti R&D come il mezzo primario per l'acquisizione di maggiori conoscenze, questi progetti accrescono l'innovazione [e], giocano un ruolo predominante nell'aumento di competitività delle aziende [f] e riducono i tempi di risposta nel momento in cui si cerchi di cogliere delle opportunità [f], [g].

Vista la rilevanza dei progetti R&D e dei loro esiti, appare necessario adottare degli strumenti e delle tecniche di gestione di progetto che siano adeguate e che massimizzino la probabilità di successo dei suddetti progetti. Alcuni autori credono che l'applicazione delle tecniche tradizionali di project management a progetti non tradizionali possano essere inadeguate [b], altri pensano che gli attuali metodi dovrebbero prendere in considerazione le peculiarità dei progetti R&D attraverso l'estensione e l'integrazione di altri metodi esistenti [h], altri ancora credono che maggiore importanza dovrebbe essere data all'analisi di rischio [g] per esempio durante la pianificazione [c]; a questo proposito, molti ricercatori stanno studiando strategie di mitigazione dei rischi della schedula nel contesto del project management [i]. In questo articolo l'attenzione verterà particolarmente sul controllo di progetto, il processo attraverso il quale i manager si assicurano che le risorse siano ottenuto ed impiegate effettivamente ed efficientemente per il raggiungimento degli obiettivi dell'organizzazione [j]. Il controllo di progetto include una serie di attività e di strumenti volti a verificare se il progetto procede secondo i tempi e i costi preventivati. Il controllo permette inoltre di fare previsioni sugli andamenti futuri e di selezionare le migliori strategie per stanziare risorse o – qualora siano presenti delle deviazioni – di applicare delle azioni correttive. È stato suggerito che un'organizzazione che intraprende diversi progetti dovrebbe adottare un approccio di gestione comune per ogni progetto in programma, indipendentemente dalla sua tipologia, dalla sua dimensione o dal tipo di risorse utilizzate [k]; i vantaggi di questa scelta sono riportati in Turner et al. (1999) [l]. Sulla base dei risultati di un questionario sottoposto a persone afferenti all'ambito manageriale [l], l'impiego di procedure che non considerino le particolarità del progetto ha meno successo rispetto a quella di personalizzare le già menzionate procedure; per questa ragione, un processo di controllo personalizzato viene qui proposto. La costruzione di una baseline accurata si traduce implicitamente nell'ottenimento di risultati più realistici relativi al budget che può fungere da discriminante nel momento in cui è valutata la possibilità di intraprendere un progetto: una valutazione imprecisa potrebbe escludere la possibilità di dedicarsi ad una nuova iniziativa, con tutte le conseguenze precisate in precedenza.

Il controllo di progetto è strettamente legato alla pianificazione [m]: con il solo confronto con il riferimento (baseline) è possibile comparare gli andamenti reali con quelli pianificati. La fase di pianificazione è stata ampiamente studiata per progetti per i quali si dispone di un vasto numero di dati storici e tecnologie consolidate, ma non si può dire lo stesso per i progetti R&D [n]. Nonostante la mancanza di dati e le incertezze tecnologiche, la stima della durata delle attività per i progetti R&D non è immediata. Similmente, non vi è certezza è certezza dovuta alla mancanza di esperienza riguardo la tecnologia e le soluzioni tecniche per il processo. Ne consegue che i progetti R&D debbano essere condotti con una certa dose di "creatività", prendendo decisioni che potrebbero risultare non convenzionali [o].

Per superare i problemi relativi alla costruzione della baseline, si riporta che diversi approcci sono stati studiati e adottati. La letteratura offre molti esempi di calcolo di varianze modellate attraverso metodi probabilistici o mediante logiche fuzzy [b], [p]: la prima modalità strategia associa una funzione di distribuzione di probabilità alle variabili incerte; i metodi basati su una logica fuzzy sono impiegati in quanto la loro affidabilità può essere incrementata attraverso il giudizio di esperti e la conoscenza soggettiva dei manager di progetto [q].

Coloro i quali possano trarre beneficio da questo studio sono persone dell'ambito accademico, industriale e manager in quanto in questa sede è fornita una proposta di processo che si è dimostrata confacente alle caratteristiche dei progetti R&D. Attraverso questo strumento, le incertezze possono essere gestite in modo migliore e le azioni correttive possono essere più mirate ed efficienti.

L'articolo è organizzato in sei sezioni. Nella prima si riporta una panoramica inerente al controllo di progetto e le sue interfacce con altri processi, con particolare menzione alle procedure di Tecnimont. Successivamente il processo di controllo è proposto ed è evidenziato in che modo lo stesso possa superare le problematiche discusse nelle sezioni precedenti; segue la validazione teorica del processo ad opera di tre project manager afferenti al Gruppo Maire Tecnimont e coinvolti in progetti R&D. Nella quinta e nella sesta sezione il processo è validato quantitativamente: l'indicatore del MAPE (Mean Absolute Percentage Error) è utilizzato a tal scopo. Infine, nelle conclusioni sono stati raccolti i principali risultati e le limitazioni del processo di controllo; le prospettive per future ricerche sono presentate.

2 Stato dell'arte

La letteratura offre un ampio numero di studi e ricerche inerenti al calcolo dei parametri per le attività ma solo un'indagine minore è stata intrapresa per quanto riguarda il campo della pianificazione e controllo di progetti R&D [n], [r].

Gli sviluppi storici degli ultimi anni del 1900 hanno mostrato la necessità di introdurre dei metodi e dei processi che potessero adattarsi meglio alle nuove caratteristiche dei progetti di innovazione e che richiedono velocità nel prendere decisioni [o].

I "metodi e i processi flessibili" – nati originariamente, e ancora primariamente utilizzati nell'ambito dei software – hanno rappresentato il nuovo approccio per gestire i progetti R&D. Alcuni tra i più conosciuti, Spiral Development, Agile Method e il metodo Scrum condividono alcune peculiarità: l'iterazione è la proprietà principale per aggiungere valore al prodotto e per risolvere gli eventuali problemi che si possono incontrare durante l'esecuzione del progetto.

Altri metodi e processi esistono: le loro particolari caratteristiche non saranno discusse in questo contesto e maggiori dettagli sono inclusi nell'Agile Manifesto [s].

I metodi e i processi flessibili sono principalmente incentrati sulla rapida acquisizione del valore aggiunto del prodotto, per questo, le attività non sono definite completamente all'inizio del progetto, sono introdotti molti cicli iterativi ed è attribuita molta importanza al team di progetto e alla comunicazione reciproca.

È opinione degli autori che l'applicazione dei metodi e dei processi flessibili mostrino delle limitazioni e che non possano essere adottati tal quali per i progetti che prevedono la costruzione di un impianto: questi metodi sono più adatti in ambienti in cui l'innovazione è intesa come incremento di caratteristiche o in contesti in cui le modifiche possano essere applicate facilmente.

Sebbene esistano i metodi e i processi flessibili, la tendenza è di controllare i progetti R&D attraverso tecniche deterministiche [n]: un esempio è fornito da Tecnimont.

La Società sceglie come metodo di controllo l'Earned Value Management, metodo che risulta essere lo strumento di feedback più efficiente, anche in termini misurazione della performance di progetto [t]. Come indicato nelle procedure di Tecnimont, il lavoro è differenziato per la sua durata e la sua tangibilità in:

- *discrete effort*, se il lavoro è direttamente associato alla realizzazione di un prodotto o a un servizio tangibile;
- *apportioned effort*, se il lavoro per il progetto non è facilmente separabile in attività discrete ma può essere espresso proporzionalmente al lavoro relativo ad attività discrete;
- *level of effort*, se il lavoro non può essere suddiviso in elementi discreti (come il supporto e il controllo di progetto [u]).

Misurato l'avanzamento, si possono calcolare alcuni indicatori. Questi si basano su tre parametri fondamentali [a] che sono definiti nel seguito:

- *Planned Value* (PV): è il valore teorizzato per i tempi e i costi. Il PV è anche noto come *Budgeted Cost for Work Scheduled* (BCWS);
- *Earned Value* (EV): è il valore che rappresenta il progresso ad un tempo specifico. Rappresenta il lavoro realmente svolto. L'EV è anche noto come *Budgeted Cost for Work Performed* (BCWP);
- *Actual Cost* (AC): rappresenta il numero di risorse che sono state impiegate in un certo arco di tempo per completare le attività. L'AC è anche noto come *Actual Cost for Work Performed* (ACWP).

Sulla base di questi tre parametri, l'EVM consente il calcolo della performance di progetto e di fare previsioni sul comportamento futuro del progetto. A seconda della complessità del progetto, diverse strategie di controllo possono essere adottate: infatti, il monitoraggio è più strutturato per i progetti EPC piuttosto che per i progetti FEED o per i progetti di servizio. I progetti R&D discussi in questo articolo sono stati trattati – dal punto di vista del controllo – come progetti di servizio. Il controllo di progetto (FEED+EPC) è rappresentato in Fig.1. Come è possibile osservare, il processo di controllo per gli EPC è più strutturato e gli strumenti utilizzati per costruire la baseline e per tracciare l'avanzamento sono più avanzati. La pianificazione dovrebbe essere considerata nient'altro che un modello predittivo che può essere impiegato per il calcolo dell'efficienza delle risorse, analisi di rischio e dei tempi, controllo di progetto e misurazione della performance, ecc. [v].

Utilizzando Tecnimont come riferimento nel mondo degli EPC contractor, la *Work Breakdown Structure* (WBS) è utilizzata per integrare le informazioni di progetto, per organizzare e definire lo scopo di progetto. Ogni attività, ordinata gerarchicamente, è divisa in sub-attività e/o *deliverables*. Le attività che concernono lo stesso ambito e che condividono gli stessi obiettivi sono organizzate in work packages ai quali è assegnato un valore percentuale: la loro somma deve chiudere a 100%. Terminata l'identificazione delle attività, i tempi e i costi sono stimati per analogia (facendo riferimento a progetti passati), attraverso considerazioni parametriche (che sfruttano delle variabili quantificabili e modelli di regressione che descrivono la performance di progetto in funzione delle suddette variabili), e attraverso valutazioni bottom-up (sommando tutti i consti delle milestone a partire da quelle contenenti attività più specifiche).

La letteratura offre molti esempi di metodi stocastici [w] per la stima della varianza dei tempi e dei costi.

Sebbene le relative simulazioni permettano di modellare scenari multipli che riescono a coprire intervallo personalizzato di valori variabili, la maggiore limitazione è la confidenza statistica che il project manager può associare alla funzione di distribuzione di probabilità: per i progetti R&D, la mancanza di dati storici conservati all'interno di banche dati può portare lo stesso manager a caratterizzare le variabili casuali in modo incorretto [x].

I metodi basati su logiche fuzzy costituiscono una valida alternativa nel panorama della ricerca e sviluppo ma, sebbene siano proposti per la schedulazione di molti progetti [q], [y]–[cc], sembra che non siano correntemente applicati in molti ambiti industriali, per esempio in Tecnimont.

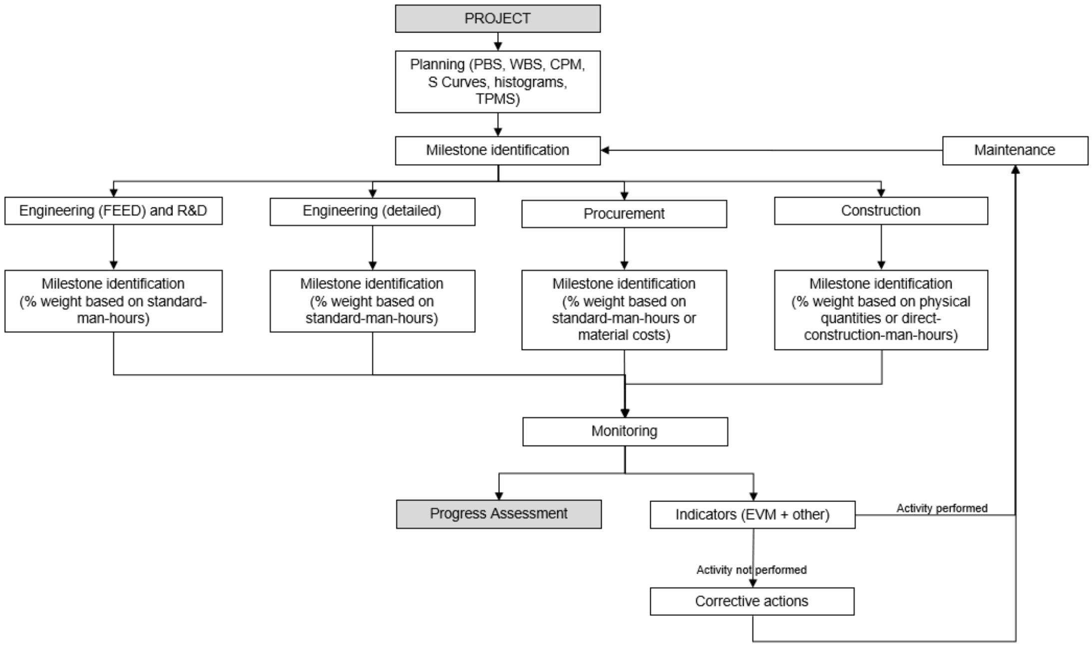

FIGURA 3: DIAGRAMMA DEL PROCESSO DI CONTROLLO PER PROGETTI FEED ED EPC

In Tecnimont, il rischio è considerato attraverso il calcolo della varianza dei tempi e dei costi attraverso il modello stocastico del Metodo Monte Carlo. Quanto tutte le durate e i costi sono definiti, le attività sono collegate attraverso gli *Activity-on-Node (A-o-N) diagrams* che tracciano il *cammino critico*, o i cammini critici, a seconda della varianza stimata per il completamento della milestone.

Quando il cammino critico è tracciato, le attività secondarie sono organizzate conseguentemente, arrivando alla costruzione della baseline, che è il riferimento per il controllo di progetto.

Gunasekaran (1997) [c] evidenzia che l'applicazione di un processo di controllo semplificato a progetti R&D risulterebbe inadeguato: da qui, la necessità di mettere a punto un nuovo processo di controllo, basato su standard di gestione acquisiti e consolidati ma integrati con nuove metodologie, confacenti ai progetti R&D [h].

3 Una proposta per un nuovo processo di controllo

Il nuovo processo di controllo, ispirandosi ai metodi e ai processi flessibili e alla Theory of Constraints (TOC) di Goldratt, è incentrato sulla pianificazione.

La pianificazione ha una stretta relazione con il controllo: essendo essenziale definire gli obiettivi e i requisiti di progetto, il planning pone le basi per svolgere un controllo che risulti affidabile [v]. All'aumentare dell'accuratezza della pianificazione, la probabilità di svolgere un controllo più efficiente aumenta.

Il processo proposto è mostrato nella Fig.4.

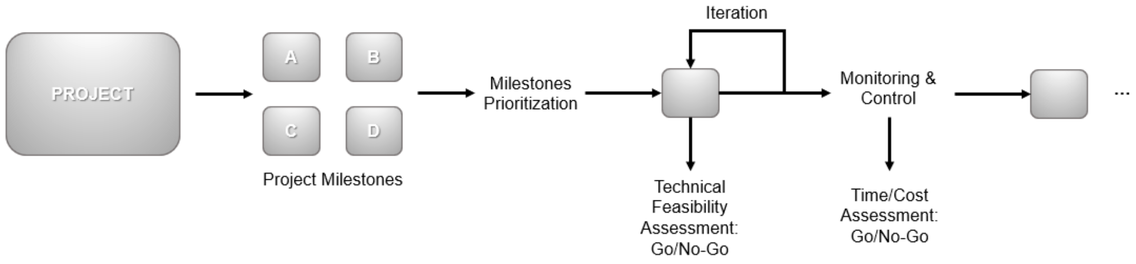

FIGURA 4: NUOVA PROPOSTA DI PROCESSO DI CONTROLLO

L'applicazione della TOC richiede la prioritizzazione delle attività più complesse; le incertezze relative alla mancanza di informazioni inerenti alle suddette attività sono gestite attraverso l'introduzione di buffer posizionati alla fine del cammino critico e alla fine delle sequenze di attività che influenzano il cammino critico. La TOC non fa esplicito riferimento a progetti con elevato grado di incertezza; la capacità dei buffer è stimata sulla base delle varianze associate alle attività presenti nella schedula. Questo approccio fornisce risultati soddisfacenti, tuttavia, se durante l'esecuzione del progetto si verificano delle deviazioni, l'aderenza alla schedula e l'accuratezza della metrica di controllo vengono meno.

I progetti R&D sono caratterizzati da un elevato livello di incertezza. Gli eventi incerti, che possono portare ad esiti indesiderati, sono gli elementi che hanno la maggiore probabilità di produrre delle deviazioni: risulta quindi di estrema importanza identificare precocemente questi eventi e definire delle soluzioni che possano essere implementate per mitigare gli effetti delle deviazioni sull'intera performance del progetto. A questo scopo è applicata la metodologia dell'analisi di rischio. Dal momento che, per ogni attività caratterizzata da incertezza, la magnitudo può essere calcolata, l'analisi di rischio permette la prioritizzazione di queste attività. A differenza del metodo descritto nella TOC, i buffer del nuovo processo di controllo sono direttamente associati alle attività ad alto livello di incertezza. Per ognuna di queste attività, la capacità del buffer è calcolata sulla magnitudo del rischio. Nel caso in cui un evento avverso si verifichi, i buffer possono essere sfruttati per l'implementazione di

eventuali azioni correttive/di mitigazione, per arrivare alla finalizzazione di una soluzione tecnica innovativa (iterazione).
In aggiunta, sulla base dell'analisi dei rischi, la schedula originale è riorganizzata al fine di anticipare, ove possibile, le attività caratterizzate da alto rischio. In questo modo, per ogni evento incerto, è possibile prendere una decisione tempestiva riguardo al proseguimento o all'abbandono del progetto: questo è possibile tramite l'adozione di uno schema go-/no-go basato sull'efficienza delle azioni correttive applicate.
La distribuzione lungo la schedula dei buffer, insieme all'anticipazione delle attività ad alto rischio, permettono un migliore controllo di progetto. Infatti, se un evento avverso si presenta e nessuna delle azioni mitiganti identificate è effettiva, la decisione di abbandonare il progetto può essere presa prontamente; d'altro canto, se l'azione mitigante è efficace, il progetto proseguirà; la presenza del buffer evita l'accumulo di ulteriori ritardi nella schedula pianificata.

4 Validazione teorica

La validazione teorica del processo di controllo è stata svolta attraverso la consultazione di tre project manager afferenti al Gruppo Maire Tecnimont. La robustezza e la completezza sono state testate impiegando la metodologia dell'intervista: attraverso questo metodo, tutti i project manager intervistati hanno valutato il processo di controllo facendo riferimento alla propria esperienza relativa a progetti R&D conclusi o in corso.

4.1 Metodologia

L'approccio dell'intervista è già stato impiegato in altre ricerche come uno strumento volto a verificare l'efficacia di prototipi [ff], per raccogliere dati relativi all'esperienza degli intervistati [gg]–[ii], valutare l'efficacia di un modello [jj], [kk] e accertare e teorizzare questioni importanti [ll]. La validità delle interviste si basa sull'assunzione che gli intervistati siano competenti e sinceri [ii]. Le interviste si sono costituite di conversazioni strutturate [ll], [mm] aventi lo scopo di raccogliere informazioni e i punti di vista dei project manager riguardo il processo di controllo proposto.
In questa ricerca sono state svolte delle interviste semi-strutturate. Questa tipologia di intervista contiene domande aperte e chiuse [mm] – organizzate in sezioni tematiche – il cui obiettivo è di guidare l'intervistato attraverso tutti gli argomenti di interesse.

Il campione di persone selezionato per lo svolgimento dell'intervista non è stato molto numeroso (tre persone): ciò è dovuto al fatto che – nel Gruppo Maire Tecnimont – ci sono solo pochi esempi di progetti R&D aventi le caratteristiche descritte nell'Introduzione.
Le interviste si sono svolte in riunioni in presenza (quando possibile), al telefono e attraverso riunioni virtuali. Ulteriormente, è stato utilizzato un questionario per domande dirette e chiuse [mm].
Le rielaborazioni delle interviste sono state inviate agli intervistati per la verifica della consistenza dei contenuti e della loro correttezza.

4.2 Risultati ed analisi dei contenuti

Le interviste sono state orientate alla raccolta delle opinioni dei project manager e delle loro esperienze rispetto ai temi salienti del nuovo processo di controllo, vale a dire le incertezze, i rischi e la scelta della metrica.
Come atteso, è presente un'estesa convergenza sui temi discussi. Tutti gli intervistati hanno giudicato l'analisi di rischio un passaggio importante: per tutti i progetti i rischi sono stati valutati, anche se un'analisi formale è stata svolta solo in un progetto. Considerato che l'analisi di rischio qualitativa è già considerata come un passaggio per il progetto (a dimostrazione che i project manager sono consapevoli dell'importanza dei rischi durante la pianificazione e lo svolgimento del progetto), l'implementazione di questo strumento non aggiungerebbe costi sostanziali alla fase di pianificazione.
Un aspetto interessante che è emerso dalle interviste è che le analisi di rischio sono già svolte per fare delle considerazioni preliminari riguardo alla fattibilità del progetto: i project manager sono d'accordo sull'utilizzo dell'analisi di rischio come un primo sistema go/no-go: di fatto, le azioni correttive sono individuate per ogni evento indesiderato e, successivamente si valuta se valga la pena proseguire nel progetto.
Considerato il livello di incertezza al quale il progetto è soggetto, tutti gli intervistati condividono la convinzione che la ripianificazione (usando, per esempio, la Rolling Wave Breakdown Structure) è una strategia che può essere utilizzata per aggiornare la baseline.
Per quanto riguarda l'introduzione dei buffer per testare le attività, solo uno dei project manager ha dichiarato che la fase di test dovrebbe essere anticipata nella fase dell'Engineering: per quanto possibile, questo approccio conservativo non è in conflitto con la proposta di controllo qui proposta.

Infine, tutti i project manager sono consapevoli che una modificazione nella metrica di controllo non è cambiamento immediato da effettuare, soprattutto se si impiegano procedure consolidate o se gli algoritmi sono imposti. Pertanto, nonostante un solo intervistato non abbia escluso la possibilità che una metrica diversa possa rendere il controllo più accurato, questa affermazione non influenza significativamente il processo di validazione: il nuovo processo di controllo non entra nel merito della scelta di una metrica più o meno adatta, ma si concentra sul miglioramento dell'accuratezza della baseline includendo dei buffer per il collaudo di soluzioni tecniche.

Sulla base del materiale e delle informazioni raccolte attraverso le interviste, il nuovo processo di controllo può considerarsi validato dal punto di vista teorico.

5 Validazione quantitativa

L'accuratezza del nuovo processo di controllo è stata messa alla prova per verificare se fosse più performante del processo di controllo applicato in un esempio industriale di progetto R&D. Attraverso un'analisi What-if, è stata prodotta una nuova schedula conformemente alla proposta del nuovo processo di controllo; le performance dei due processi sono state successivamente confrontate.

5.1 Metodologia

Per mettere a punto il processo di controllo proposto in precedenza, lo strumento della What-if analysis è stato utilizzato.

L'analisi What-if è una simulazione il cui obiettivo è di studiare il comportamento di un sistema complesso (per esempio, un'attività commerciale o una sua parte) sotto alcune ipotesi definite [nn]. L'analisi misura in che modo alcuni cambiamenti, applicati ad un insieme di variabili indipendenti, hanno un impatto su un insieme di variabili dipendenti rispetto ad un modello di simulazione che è la rappresentazione semplificata di ciò che si sta studiando [nn]. Questa metodologia è stata impiegata per valutare in anticipo l'impatto di una mossa tattico-strategica [nn]–[pp] e per la validazione di modelli di simulazione [nn]. Nel presente caso, si deve cercare la risposta alla domanda "il nuovo processo di controllo è più efficiente rispetto a quello effettivamente applicato ai progetti R&D?". Per rispondere alla precedente domanda, è stato adottato un approccio strutturato.

Come svolto in Chen et al. (2014) e in Andrade et al. (2018) [qq], [rr], per ogni nodo è stata calcolata l'accuratezza della previsione utilizzando il Mean Absolute Percentage Error (MAPE). Il MAPE è probabilmente l'indice adimensionale maggiormente diffuso e può essere utilizzato quando al valore 0 è associato un significato (ratio-scaled data) [ss]. Il MAPE è definito come:

$$MAPE = \frac{100}{n} \sum_{n=1}^{n} \left| \frac{\widehat{y_t} - y_t}{y_t} \right|$$

dove:

- y_t è il valore attuale al tempo *t* per svolgere un'attività o un set di attività;
- $\widehat{y_t}$ è il valore teorizzato per y_t per svolgere un'attività o un set di attività;
- n è il numero delle fasi rispetto alle quali è calcolata l'accuratezza.

Dal momento che l'accuratezza sarà calcolata considerando delle singole fasi per un solo progetto, n assume il valore unitario.

5.2 Caso studio

Per la validazione quantitativa del processo di controllo è stato scelto un progetto R&D svolto in Tecnimont. Il progetto, iniziato nel 2013 e completato con successo nel 2018, aveva lo scopo di validare una nuova tecnologia per l'addolcimento del gas naturale basata su una distillazione criogenica innovativa. Lo scopo del lavoro ha previsto il design e la costruzione di un impianto pilota su scala di laboratorio e l'esecuzione di due campagne sperimentali per la validazione del processo. Il progetto si è diviso in due fasi diverse. La prima fase – che non è contemplata in questo studio – è stata destinata alla valutazione della fattibilità tecnica dell'impianto pilota e, in prospettiva, di un futuro impianto industriale basato sulla nuova tecnologia, come anche la stima della competitività economica del processo.

La seconda fase ha incluso lo sviluppo del design di dettaglio, la costruzione del pilota, e l'esecuzione della prima campagna sperimentale, con la possibilità di intraprenderne una seconda qualora i risultati della prima non fossero stati sufficienti per validare o confutare la teoria alla base del nuovo processo. Per la presente discussione, l'attenzione è posta sulla seconda fase la cui durata era stimata in 34 mesi (includendo la seconda campagna sperimentale). In realtà, la seconda fase del progetto si è protratta a 45 mesi, a causa dell'accadimento di eventi avversi che hanno esteso lo scopo del progetto: per migliorare le condizioni dell'impianto pilota, infatti, sono state apportate importanti modifiche e, inoltre, si è resa necessaria l'esecuzione della seconda campagna sperimentale. Per gli scopi della trattazione, R è il progetto reale e W è il progetto What-if.

Le Tabelle 6 e 7 riportano rispettivamente le schedule originali ed effettive relative alla seconda fase del Progetto R.

TABELLA 6: DATI DELLA SCHEDULA ORIGINALE DEL PROGETTO R

Schedula originale – Progetto R	***Data d'inizio***	***Data di fine***	***Giorni (di calendario)***
Design di dettaglio dell'impianto pilota – Pianificazione delle operazioni	19-Feb-15	15-Apr-15	56
Costruzione dell'impianto pilota	16-Apr-15	19-Nov-15	219
Trasferimento dell'impianto pilota	20-Nov-15	30-Gen-16	73
Messa a punto dell'impianto pilota	01-Feb-16	25-Mar-16	53
Prima campagna sperimentale	26-Mar-16	02-Dic-16	251
Analisi dei risultati della prima campagna sperimentale	03-Dic-16	01-Feb-17	62
Seconda campagna sperimentale	02-Feb-17	27-Nov-17	300
TOTALE			**1014 giorni** **34 mesi**

TABELLA 7: DATI DELLA SCEHDULA EFFETTIVA DEL PROGETTO R

Schedula effettiva – Progetto R	***Data d'inizio***	***Data di fine***	***Giorni (di calendario)***
Design di dettaglio dell'impianto pilota – Pianificazione delle operazioni	19-Feb-15	15-Apr-15	56
Costruzione dell'impianto pilota	16-Apr-15	06-Mar-16	329
Trasferimento dell'impianto pilota	7-Mar-16	18-Mag-16	73
Messa a punto dell'impianto pilota	19-Mag-16	23-Set-16	130
Prima campagna sperimentale	24-Set-16	31-Mag-17	251
Analisi dei risultati della prima campagna sperimentale	01-Giu-17	31-Lug-17	62
Modifiche all'impianto pilota (revamping)	1-Ago-17	28-Nov-17	121
Seconda campagna sperimentale	29-Nov-17	30-Ott-18	337
TOTALE			**1359 giorni** **45 mesi**

Per quanto riguarda il Progetto W, la schedula originale è stata costruita facendo riferimento principalmente alle durate attività del Progetto R:

- è stato assegnato un giorno alla fase di prioritizzazione (che include l'analisi di rischio qualitativa e la riorganizzazione delle precedenze). Questa durata è stata assegnata dopo aver consultato degli esperti in merito. È assunto che la baseline è riorganizzata in accordo con le nuove precedenze: la nuova schedulazione non comporta tempi addizionali in quanto la prioritizzazione prevede semplicemente l'introduzione di buffer – per testare ed iterare le milestone ad altro rischio – e il cambiamento dell'ordine di esecuzione delle suddette milestone;
- si pianifica che la costruzione del pilota duri 3 mesi; ciò è giustificato dal fatto che il fornitore del pilota ha dimostrato, nel corso del progetto reale, di essere in grado di quantificare accuratamente il ritardo che avrebbe comportato l'esecuzione di alcuni test (effettivamente realizzati) sulle unità dell'impianto;
- una volta conclusa la costruzione, nel Progetto W si effettua una nuova pianificazione e una nuova analisi di rischio: in questo caso, è l'impianto stesso ad essere testato e portato a convergenza prima dell'inizio della campagna sperimentale. È assegnato un giorno per lo svolgimento di queste attività;
- la campagna sperimentale è unica perché la messa a punto dell'impianto è considerata la fase di verifica della funzionalità dell'impianto. Solo dopo che l'impianto è dichiarato operativo e stabile gli esperimenti possono iniziare;
- in aggiunta al tempo dedicato all'esecuzione degli esperimenti, sono aggiunti quattro mesi per via della risoluzione dei problemi relativi ad una pompa. Da un'analisi di rischio preliminare non possono emergere sempre con chiarezza quali sono i problemi che potrebbero influenzare il successo del progetto, e pertanto possono essere fatte solo delle considerazioni generali: in questo caso, la pompa di processo era già stata identificata come una potenziale criticità per il progetto e quindi – per essere conservativi – alle attività ordinarie viene aggiunto un buffer valutato sull'ipotesi di un malfunzionamento totale della pompa. Lo stesso buffer è quantificato sulla base del giudizio di fornitori qualificati: le pompe che hanno una maggiore probabilità di risultate adeguate al processo sono costruite in tre o quattro mesi. Siccome il successo di una pompa nuova non può essere assicurato, si sceglie

di optare per un buffer di quattro mesi: in questo modo, si tiene in considerazione la possibilità di poter iterare fino ad eliminare l'instabilità dell'unità;

- per quanto riguarda gli esperimenti, la durata della singola campagna è stata considerata pari alla seconda campagna sperimentale del Progetto R – svolta una volta che il funzionamento dell'impianto si è dimostrato stabile.

La schedula effettiva del Progetto W è stata modellata sulle considerazioni fatte per la sua schedula originale e considerando i tempi effettivi di realizzazione del Progetto R. Nel progetto W, i giorni destinati alla messa a punto dell'impianto si trovano in numero maggiore perché, per garantire l'efficienza del pilota raggiunta nella seconda campagna sperimentale del Progetto R, è stato incluso un revamping (121 giorni addizionali).

Infine, essendo gli esperimenti del Progetto W pari al numero di esperimenti della seconda campagna sperimentale del Progetto R, si assume che la fase sperimentale abbia una durata uguale alla seconda campagna sperimentale del Progetto R.

Le Tabelle 8 e 9 riportano rispettivamente le schedule originali ed effettive relative alla seconda fase del Progetto W.

TABELLA 8: DATI DELLA SCHEDULA ORIGINALE DEL PROGETTO W

Schedula originale – Progetto W	***Data d'inizio***	***Data di fine***	***Giorni (di calendario)***
Design di dettaglio dell'impianto pilota – Pianificazione delle operazioni	19-Feb-15	16-Apr-15	57
Costruzione dell'impianto pilota	17-Apr-15	21-Feb-16	312
Trasferimento dell'impianto pilota	22-Feb-16	05-Mag-16	74
Messa a punto dell'impianto pilota	06-Mag-16	28-Ott-16	177
Campagna sperimentale	29-Ott-16	23-Ago-17	300
Analisi dei risultati della campagna sperimentale	24-Ago-17	23-Ott-17	62
TOTALE			**982 giorni** **32 mesi**

TABELLA 9: DATI DELLA SCHEDULA EFFETTIVA DEL PROGETTO W

Schedula originale – Progetto W	***Data d'inizio***	***Data di fine***	***Giorni (di calendario)***
Design di dettaglio dell'impianto pilota – Pianificazione delle operazioni	19-Feb-15	16-Apr-15	57
Costruzione dell'impianto pilota	17-Apr-15	07-Mar-16	329
Trasferimento dell'impianto pilota	08-Mar-16	20-Mag-16	74
Messa a punto dell'impianto pilota	21-Mag-16	13-Mar-17	298
Campagna sperimentale	14-Mar-17	12-Feb-18	337
Analisi dei risultati della campagna sperimentale	13-Feb-18	15-Apr-18	62
TOTALE			**1157 giorni** **38 mesi**

5.3 Risultati ed analisi dei contenuti

Per quanto riguarda la valutazione dell'accuratezza, l'aspettativa iniziale era quella per cui il computo del MAPE dimostrasse che il progetto What-if fosse più accurato del Progetto R; infatti, la schedula del Progetto W è stata ampliata con l'introduzione di alcuni test per verificare il funzionamento di alcune unità del pilota e i tempi dedicati al troubleshooting sono stati allungati: una maggiore durata del progetto approssima meglio la realtà del progetto effettivamente svolto.

Le date d'inizio e di termine sono incluse nel calcolo delle fasi temporali. Dal momento che si considerano le estensioni temporali, si considerano anche i giorni non lavorativi.

Per la campagna sperimentale del Progetto R, la prima e la seconda sono state sommate per poter rappresentare il numero effettivo di giorni necessari per la validazione della tecnologia.

La sezione delle modifiche all'impianto include i giorni destinati alla messa a punto dell'impianto e al revamping.

La Tab. 5 riporta i valori del MAPE.

TABELLA 10: RISULTATI PER IL CALCOLO DEL MAPE

Fase	R: $\hat{y}_t$	R: y_t	$MAPE_R$	W: $\hat{y}_t$	W: y_t	$MAPE_W$
Design di dettaglio dell'impianto pilota – Pianificazione delle operazioni	56	56	0	57	57	0
Costruzione dell'impianto pilota	219	329	33,43	312	329	5,17
Trasferimento dell'impianto pilota	73	73	0	74	74	0
Modifiche all'impianto pilota	53	251	78,88	177	298	40,60
Campagne sperimentali	551	588	6,29	300	337	10,98

Le previsioni del nuovo processo di controllo sono, nella maggior parte dei casi, maggiormente o tutt'al più ugualmente accurate rispetto a quelle del Progetto R. Colin (1982) [tt] permette l'interpretazione dei risultati ottenuti; per un MAPE<10, la previsione è altamente accurata. Questo risultato è stato ottenuto in tutte le fasi di progetto relative alla pianificazione: di fatto, è meno probabile che la semplice pianificazione possa incorrere in ritardi perché non c'è la possibilità fisica di verificare se le soluzioni tecniche teorizzate possano essere efficaci una volta implementate.

Nel Progetto R, la costruzione, le modifiche all'impianto e la campagna sperimentale si sono caratterizzate da deviazioni che hanno complicato la misura dell'avanzamento. Un miglioramento sensibile si può osservare per la fase di costruzione perché si assume che il fornitore dell'impianto pilota sia esperto e possa prevedere la quantità di tempo da destinare allo svolgimento di test specifici sulle unità; questa assunzione corrisponde alla realtà.

Per ciò che concerne la messa a punto dell'impianto, è davvero complesso conoscere in anticipo quali potrebbero essere i problemi specifici che possono influenzare la sua affidabilità: solo l'esatta comprensione delle anomalie tecniche permette al project manager di considerare delle azioni correttive mirate e la loro quantificazione temporale.

Il risultato della campagna sperimentale del Progetto R è in controtendenza: infatti sembrerebbe che le previsioni del progetto reale siano più accurate di quelle del Progetto W. Questo risultato può essere interpretato considerando che, in questa analisi, i giorni relativi ad entrambe le campagne sperimentali sono stati sommati. Come già evidenziato, la possibilità di svolgere la seconda campagna sperimentale nel Progetto R era stata presa in considerazione nel planning iniziale, ma ha rappresentato un'estensione dello scopo originale del progetto. La seconda campagna sperimentale del Progetto R può essere considerata come una sorta di iterazione della prima campagna e, per questa ragione, il valore assunto dal MAPE è migliorato. Se la seconda campagna sperimentale non fosse stata considerata nel computo, l'indice MAPE risulterebbe pari a 53,31, un valore molto più alto rispetto a quello ottenuto per il Progetto W.

Ciononostante, sebbene il Progetto R riporti un risultato migliore per le campagne sperimentali, questo non è in grado di compensare i risultati ottenuti per le altre fasi studiate. Queste considerazioni dimostrano che l'iterazione, sia per la pianificazione che per lo svolgimento delle attività, dovrebbe essere incentivata – concetto fortemente supportato nel nuovo processo di controllo.

Sulla base di questi risultati, è possibile affermare che l'accuratezza delle previsioni e, conseguentemente, il processo di controllo sono migliorati.

6 Conclusioni

Nelle sezioni precedenti, sono stati analizzati tre progetti R&D; le loro caratteristiche sono ciò che rendeno il loro processo di controllo particolare. Sebbene negli ultimi anni del XX secolo [o], [s] l'introduzione dei metodi e dei processi flessibili ha fortemente modificato le modalità di gestione per nuove tipologie di progetto, principalmente quelli relativi all'ambito dei software ([j], [t], [u]–[bb], [cc], [dd]), questi non possono essere applicati tal quali a progetti che contemplano nel loro scopo la costruzione di un impianto pilota e il successivo svolgimento di campagne sperimentali.

In questo lavoro, è stato assunto che le difficoltà relative al controllo dei progetti R&D giacciono, essenzialmente, nella fase di pianificazione, che è resa più complessa dalle incertezze di progetto. Sebbene la letteratura offra un buon numero di esempi e tentativi di modellare tale incertezza attraverso dei metodi stocastici [q], [w], [dd], [fff], [ggg], questi non possono fornire risultati accurati se le simulazioni sono svolte a partire da dati inaccurati. Il processo di controllo qui proposto si presenta come una soluzione pratica per le società che gestiscono progetti R&D: l'introduzione, l'identificazione e la classificazione dei rischi permette la loro prioritizzazione nella schedula, e l'introduzione dei buffer è destinata alle prove di verifica dell'efficacia delle soluzioni tecniche apportate. In aggiunta, il nuovo processo di controllo tutela il progetto. Come spiegato nell'articolo, l'anticipazione dei test – che hanno una forte influenza sulla schedula – svolti per verificare la funzionalità dei componenti, permette di minimizzare l'impatto delle azioni correttive da intraprendere.

È stato selezionato un progetto R&D sviluppato in Tecnimont per testare l'accuratezza del processo di controllo proposto; la sua schedula è stata confrontata con una seconda costruita adottando il nuovo processo di controllo (per mezzo di una What-if analisi). Da un punto di vista quantitativo, il nuovo processo si dimostra essere più efficiente. Anche se l'analisi dell'indice MAPE è stata applicata ad un singolo progetto, la sua efficienza è stata riconosciuta da tre project manager. Questo garantisce l'estensione del risultato a progetti R&D diversi dal caso specifico analizzato.

Il caso studio selezionato è stato analizzato in dettaglio: sebbene nella pianificazione originale non si contemplassero i test meccanici sopra menzionati, tuttavia questi sono stati svolti in tempo, evitando l'insorgenza di deviazioni che avrebbero provocato grandi perturbazioni nella schedula.

Inoltre, deve essere evidenziato il ruolo fondamentale svolto dal fornitore esperto e qualificato che ha suggerito di svolgere i test sopra citati.

Il nuovo processo di controllo mostra comunque delle limitazioni. Se i buffer per la verifica e l'iterazione sono quantificati attraverso un approccio conservativo, questo non esclude che il tempo allocato per lo svolgimento di un'attività specifica possa essere maggiore rispetto a quello che potrebbe essere effettivamente impiegato: in questo caso, il vantaggio temporale andrebbe perso. Anche se una ripianificazione può essere svolta, tuttavia, per alcune attività di progetto caratterizzate da scarsa flessibilità, i suoi benefici sarebbero trascurabili.

Per via di questa limitazione, potrebbe essere svolto uno studio più approfondito sui metodi per la stima della durata delle iterazioni. Una possibilità è rappresentata dall'impiego delle logiche fuzzy: questa soluzione potrebbe compromettere l'applicazione immediata del processo di controllo, ma migliorerebbe verosimilmente la qualità dell'estensione temporale del buffer.

Un altro aspetto di un'ulteriore investigazione è la scelta della metrica di controllo. In questo articolo è stato assunto che i problemi maggiori fossero le deviazioni della baseline dalla realtà progettuale: nonostante questo, non può essere escluso a priori che alcune metriche possano fornire informazioni più dettagliate e accurate relative all'avanzamento del progetto.

In aggiunta, un altro aspetto da considerare è la valutazione di un nuovo sistema per il calcolo del fondo di rischio (contingency). Per i progetti non-R&D, le contingency sono tipicamente molto accurate e sono calcolate come un valore percentuale dell'intero budget destinato al progetto; per via delle limitazioni descritte nell'Introduzione, per i progetti R&D è più difficile garantire la stessa confidenza statistica.

Infine, considerando gli attuali avvenimenti che si stanno verificando a livello mondiale, è lecito pensare che l'impatto di questi mutamenti possano essere osservati anche a livello progettuale: le circostanze ed i vincoli ambientali potrebbero indurre nuove necessità e, per questa ragione, non può essere escluso che la proposta di controllo descritta nella presente discussione possa essere testata anche su progetto non R&D.

Introduction

The following thesis work was internally carried out in Tecnimont S.p.A., an Italian international leader in industrial Engineering, Procurement and Construction. The Company provides a wide and integrated range of services, ranging from conceptual studies, technology selection, process engineering, and detailed design. Tecnimont S.p.A. is able to perform different functions as main contractor for entire complexes on an EPC basis, providing the complete chain of services up to supervision of erection, construction and commissioning, proceeding with assistance to start-up, operation & maintenance, revamping, preservation & relocation.

The Company belongs to Maire Tecnimont Group, a technology-driven multinational Group working for the transformation of natural resources into innovative products at the crossroad between the energy and the manufacturing industries.

In detail, Tecnimont R&D department (RIES – Ricerca Innovazione e Sviluppo) fulfils the Company's need to valorise its internal development potential by focusing on innovation, either by studying and developing new technologies or by innovating engineering tools and methodologies.
In accordance with its mission, RIES develops and executes research projects aiming at validating proprietary innovative technologies with reference, in particular, to laboratory-scale pilot plants.
Besides the technological aspects, R&D projects are managed with the most advanced project management techniques that are also applied to EPC projects: the objective of the present thesis work is evaluating if the present project control strategies are optimal considering R&D projects characteristics and – if not – providing a suitable control process.

The thesis is organized into six chapters.
In the first one, an overview of project management is provided: its historical development is briefly presented as well as project management themes and project control.
In the second chapter, Tecnimont management tools are described. It follows the presentation of control processes used for FEED and EPC projects.
In the third chapter, R&D projects are defined: their characteristics and the state of art about current R&D management methods and frameworks are highlighted. In the last paragraph, it is presented to control process proposed to manage Tecnimont S.p.A. R&D projects.

Chapter four is devoted to the theoretical validation of the control process described before: its validity is tested by collecting R&D projects experts' opinions about the salient features of the innovative process. The interviewed experts belong to RIES, NextChem and KT - Kinetics Technology S.p.A., some Maire Tecnimont Group's companies.
In detail, NextChem operates in the field of green chemistry and technologies for the energy transition. The Company is managing a portfolio of projects aimed to mitigate the environmental effects of the technologies used for the transformation of oil and natural gas, limiting or eliminating CO_2 and other greenhouse gas emissions released from existing plants. NextChem's aim is reducing plastic waste and waste-to-chemicals technologies – to produce renewable gas, hydrogen or any traditional chemical from the gasification of waste – and producing intermediates, fuels and plastics from renewable sources.
KT is committed to developing the Maire Tecnimont Group's distinctive process engineering know-how in the Oil & Gas sector, particularly in the Refining and Gas Processing. The Company is also committed to maximizing its EPC delivery capabilities in Hydrogen & Syngas, Gas Treatment, Sulphur Recovery, and Fired Heaters. Nowadays KT is also heavily involved in creating new industry standards that minimize environmental impact.
After the theoretical validation, the goal of chapter 5 is providing evidence about the appropriateness of the Control process: this is done by carrying out a "what-if analysis" on a past R&D project managed by RIES.
Finally, in the conclusive section, the results obtained, as well as suggestions about future researches, are discussed.

For further developments, Appendix A is present: overall R&D experts' interviews are reported.

1 The Project and the Project Management

In the first chapter Project and Project Management definitions are provided; it is also presented a brief historical overview outlining the phases that lead to the modern model for managing projects. A particular focus is dedicated to Project Control, considering planning and cost assessment.

1.1 The definition of Project

To talk about project management it is firstly necessary to deepen the meaning of the word "*project*". According to the definition suggested by the Project Management Institute [1], a project is defined as "a temporary endeavor undertaken to create a unique product, service, or result". Moreover, the project accomplishment has to satisfy defined timed and budget [1].

Temporariness, uniqueness and multidisciplinarity are the characterizing elements of a project.
A project is temporary as it is imposed a clear starting date and deadline. The conclusion of a project is reached when all the set objectives are satisfied or when there are factors that do not allow – partially or completely – the fulfilment of established objectives [1].
Temporariness should not be interpreted as an indication about the project time-extension, far less about the project products: since goods and/or services can last many years, there is no relation between the project, the goods or services duration and the service life.
A project is always one of a kind, although it belongs to a category that includes similar projects: for example, despite different plants for the production a specific product exist and are in function – propylene plant, for example – every plant is different from their similar because of technical characteristics (such as production capacity, employed raw materials, by-products, location, environmental conditions, etc.). The repetitiveness of some elements does not affect the project's uniqueness as the objective fulfilment depends on constraints (legal, cultural, ethical, etc.) which are from time to time different.
The project multidisciplinarity originates from the need for integrating specialized knowledge in order to reach the predetermined goals. A project is a complex entity characterized – more and more in the last years – by an increment in the technological content [2].

Nowadays the concept of “project” is applied extensively also to industrial realities. Projects belong to diversified areas: for this discussion, only projects aimed at the construction of industrial plants will be considered.
The plant project is characterized by a logical-time sequence which articulates in five principal phases [2]:

1. Basic Engineering;
2. Detail Engineering;
3. Procurement;
4. Construction;
5. Start-up.

In the Basic Engineering all the fundamental technical characteristics are defined and successively developed in the Detail Engineering. The Procurement phase concerns the goods and services acquisition from vendors at the best economic conditions; during the Construction phase, all the physical elements that are part of the plant (tubes, mechanical components, etc.) are constructed and installed in the physical site where the plant will rise up. In the Start-up phase, the plant is tested before being delivered to the owner.

1.2 Project management

Project management is the application of knowledge, skills, tools, and techniques to project activities to meet the project requirements [1].
Project management is a set of several areas of expertise that interact producing a model made up of five big processes: initiation, planning, execution, monitoring and controlling and closure. The set of processes from the starting phase until the closing phase is called *project lifecycle*. Although these five processes could be presented as discrete elements – whose boundaries are well defined – in practice, they are overlapping and are interdependent. The representation of typical processes interactions is given in Fig. 1-1.

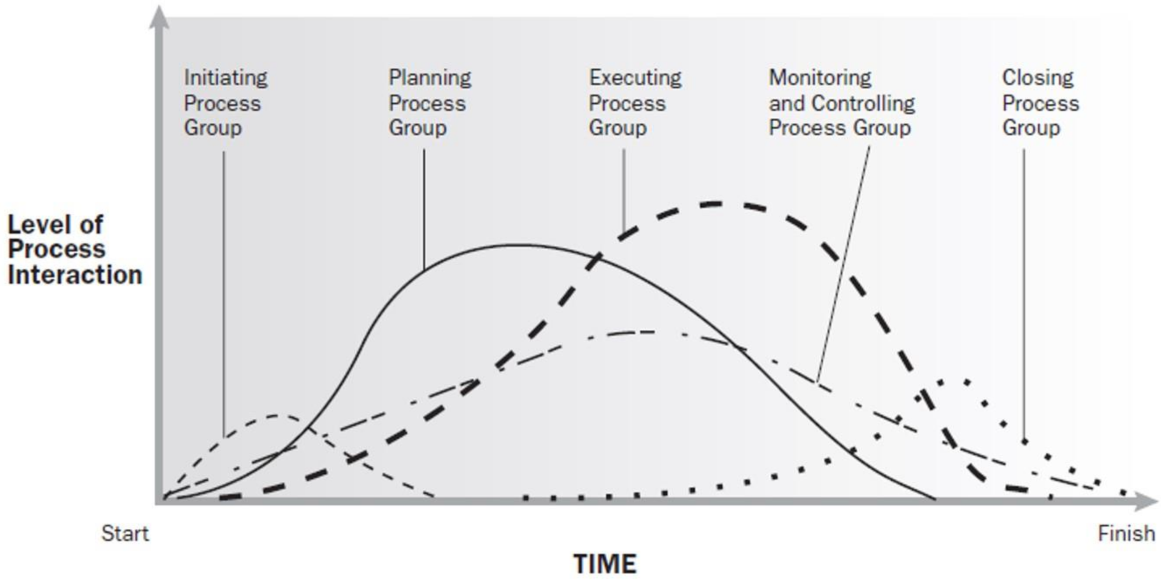

Figure 1-1: Process groups interaction in a project

1.2.1 Historical overview

The birth of project management dates to the beginning of 1900, but the need for managing the evolution of a project finds its roots in ancient times. Before the 20th century, there had been different projects completed successfully (let's think of the Egyptian Pyramids or the Chinese Great Wall construction). Although sources are suggesting the presence of a first kind of organizational form – in the case of Pyramids, it was found a construction plan that, if not respected, would have condemned the Chief Architects to the Nile crocodiles [2] – it is not possible to talk about project management: hence, a lot of freedom was still given to the single worker, stimulating their improvisation [3].

During the Middle Ages, operators started being assigned more qualifying tasks in which they had matured certain experience. Always in those years, the separation between the future end-user of the result of the project (owner) and the person in charge of its execution (contractor) began to be more evident [3].

Starting from 1900, the industrial and technological impulse changed substantially the approach to projects. Cars diffusion and the growth of telecommunications allowed to shorten the spaces and times [4] causing a consistent contraction of activities programs (*schedules*) of the project. Moreover, if in the previous centuries the major goal was realizing the endeavour at any cost, since '900 the concept of efficiency started spreading [3]; in fact, the first project management tools date to those years.

Frederick Taylor proposed the application of the scientific method to the industrial reality demonstrating that operations, which were largely manual and aimed at the realization of a product, could be studied and made more efficient. In 1910, Henry Gantt proposed a graphical method that facilitated the visualization of times associated with the different project activities: this was possible through a bar chart (still known as Gantt chart) which shows also how activities are related. Another contribution was made by Henry Fayol (1916) who proposed a managerial process that comprehended planning, organizational, command, direction and controlling phases [5].

In the years between 1958 and 1979, further progress concerned both the managerial and technological fields. In those years, Du Pont Corporation developed the Critical Path Method (CPM) for the management and maintenance of its plants [6]; at the same time, U.S. Navy's Special Projects Office used the Program Evaluation and Review Technique (PERT) tool for its missile project Polaris. In 1975, Bill Gates and Paul Allen founded Microsoft and, following, a lot of software companies developed management software based on CPM and PERT. The Work Breakdown Structure (WBS) – an approach which is defined as the backbone of planning and control [5] – was introduced in 1960.

The foundation in 1965 and in 1969 of the International Project Management Association (IPMA) [7] and of the Project Management Institute (PMI) [8] are worthy of mention. If the institution of management associations officially marked the consolidation of project management practices, on the other side, these tools were not performing for some typologies of projects. The *waterfall method* (see chap. 3, par. 3.3) – i.e. the approach by which the project is divided linearly into sequential phases – resulted in being too rigid and inefficient for fields in which innovation is a key feature. A solution to this problem was the introduction of *Flexible methods* and *frameworks* which spread since the 80s in response to the need for tools that were able to manage a continuous innovation in an extremely competitive environment such as the one of software [9]. Many flexible methods have been proposed but, with their variations, all of them share some peculiar characteristics. The most typical traits of these methods are reported in the *Manifesto for Agile Software Development* (2001) [10] and will be presented in chapter 3.

1.2.2 Project Management themes

As already mentioned, the project and project management are characterized by the interdisciplinarity of different knowledge areas. PMBOK and APM suggest different classifications of project management themes. The Project Management Institute offers higher specificity and completeness in the subdivision than the other Guideline; for this reason, in the present discussion, it will be adopted the PMBOK approach. The phases for integration, scope, time, cost, quality, human resource, communications, risk, procurement and stakeholder management are described in the following.

Project Integration Management represents a preliminary phase of a project. Once the product and activities requirements are clear – as well as their constraints –, all project management knowledge areas are integrated to produce a preliminary execution plan which will be better defined during the project. The construction of this plan is iterative because, above all at the early stages, there are many uncertainties related to activities. Integration Management is basically a planning phase where all operative, managerial and organizational processes must converge.

The identification of the processes that build the project is strictly related to the determination of the scope. *Project Scope Management* is the management of the work content related to the project. The scope is specified primarily employing the Work Breakdown Structure (WBS), a tool that, through a tree structure, lists the activities that must be completed to reach the project accomplishment. Splitting the work into activities not only allows the association of times and costs but also helps to understand how activities are logically linked. The structure and the rules for the production of a WBS are deepened in chapter 2 (par.2.1.1).

Project Time Management is the area of management devoted to the association of time durations to activities. The planning logic is governed by deadlines that are usually imposed by contractual constraints. The accuracy thanks to which lead times are estimated is related to the level of detail reserved for planning [2]. Once time estimates are done, these are used to assemble the schedule, a time reference that is used in the project to visualize the logical sequence of activities. The schedule can be consulted graphically through the Gantt charts, bar diagrams that represent the distribution of activities during the project lifecycle. Gantt charts can also be used to visualize real-time progress.

Project Cost Management is the management area that quantifies the costs that will be incurred during the project. The vagueness that – with a decrescent trend characterizes the project lifecycle – becomes explicit when it comes to foresee the costs in the initial phase of the project [2]. Costs can be classified in direct, specific and ordinary costs. *Direct costs* are related to the physical progress of the project. *Specific costs*, which can be attributed only to the single projects [2], are in their turn divided into apportioned costs, level of effort costs and period costs. The *apportioned costs* have a proportionality with the resources employed in the project phases; the *level of effort costs* reflect the work intensification whenever it was necessary to face a delay, unexpected events, etc.; *period costs* are fixed and related only to the project duration (instrumentation maintenance, etc) [2]. Finally, *ordinary costs* are the costs referred to the maintenance of the corporate structure.

Project Quality Management includes the processes and the activities that determine the quality policies, objectives and responsibilities in order to guarantee that the project satisfies the need for which it was undertaken [1]. Differently to what happens in the manufacturing industry, the project uniqueness does not allow to have an incremental improvement process for quality; by the way, it is possible, to improve progressively the corporate quality system through a lesson learned system which is formalized in the finishing phases of the project [2]. In general, all the lessons learned are applied – when possible – to future projects.

Project Human Resource Management includes the processes that organize, manage and guide the project team [1]. The team is composed of different people to whom are assigned specified tasks and responsibilities. Team flexibility produces added value and strengthens the project components effort [1].

Project Communication Management embraces all the processes that are needed to guarantee the appropriateness of the phases of planning, collection, creation, distribution, storage, retrieval, management, control, monitoring, and the ultimate disposition of project information [1]. Communication can be both internal or external the organization and has a big impact on the project execution and outcome.

Project Risk Management is the process that allows the understanding of the single or the overall project risk. In this way, it is possible to manage risk proactively, trying to take advantage of opportunities that show up, maximizing the success probability and minimizing the effect of adverse events that could threaten the fulfilment of objectives [11]. Standard

Guides [1], [12]–[14] provide different definitions for the word “risk”. According to the one more spread and accepted, the risk is the possibility that an event – once it becomes concrete – could affect in some way the project. The definition does not distinguish if the effect on the project is in its favour or not. Risk is an intrinsic characteristic of the project and can cause a deviation between the effective progress and the planned one [2]. In Companies that work for projects, risks are classified in several categories, which are the subject of qualitative and quantitative analyses. For example, Tecnimont S.p.A. categorizes risk as “Political”, “Financial”, “Contractual”, related to HSE, etc.

Historical data (related to unexpected events that occurred in the past) can help in the risk identification process; the implicit assumption is that history will repeat in the same manners in the future [13], which is reasonable but not necessarily true.

The variance between the set of data that is needed to reach the project success and what is known in reality is defined as *knowledge gap* [15], [16] which is unlikely filled [17]. For the project purposes, dealing with the knowledge gap means estimating for all the uncertain events the occurrence probability and the magnitude of consequences – expressed in terms of extra costs or delays. The *contingency reserve* is defined as the increase in resources or time that is added to the initial estimate. It is necessary to reduce the risk below a determined threshold in order to avoid facing extra costs or delays.

Additionally to contingencies, which are allocated to mitigate the possible effects of uncertain events, *allowances* are assigned for certain activities that cannot be defined completely in terms of scope.

Project Procurement Management includes the processes needed for the acquisition and purchase of products, services or results; the Company can be both the buyer or the vendor of these products, services, results of a project [1].

Project Stakeholder Management consists of the systematic identification, analysis and planning of actions to communicate with, negotiate with and influence stakeholders [11]. *Stakeholders* are the organizations or people who have an interest or role in the project or are impacted by the project [11].

1.3 Project control

Project control is the set of activities and tools used to verify if the project proceeds according to the time and costs trends forecasted. The importance of control lies in the possibility of detecting possible creeps with respect to a reference plan called *baseline*. The baseline is built by planning activities times to which costs are associated: the reference must be compliant with the contractual constraints imposed.

The knowledge of the project progress allows to understand how resources have been employed and to make forecasts about how they should be invested in the future.

In presence of creeps, it is the Project Manager and the team duty to apply corrective measures that reduce the impact of the aforementioned creeps.

Planning usually refers to WBS since, thanks to the tree structure, single activities are already pointed out, characterized and deepened to a level of detail that is defined for each type of project.

Time assignment for activities can be done through different approaches; they are more or less recommended according to the project typology and according to how fast estimates should be produced. In addition, an expert or a group of experts' experience can guide the choice.

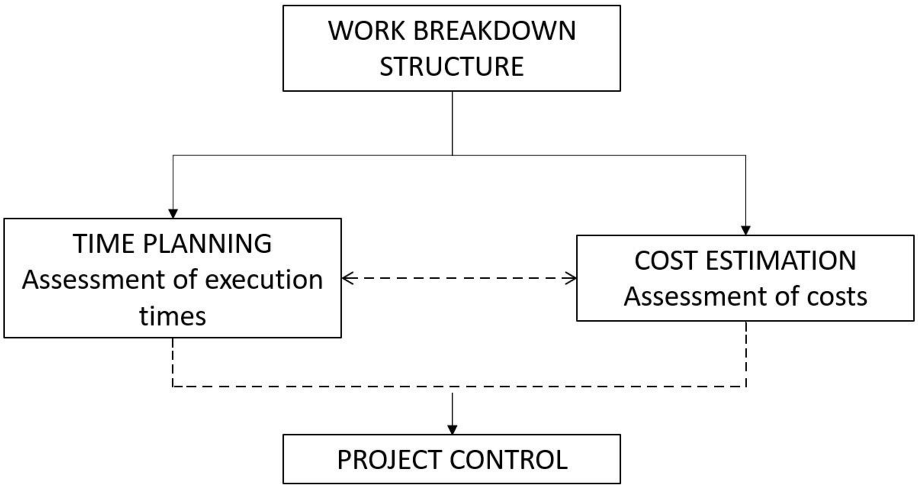

Figure 1-2: Control relationship with time and costs assessment (adapted from Piras and Patrone, 2007)

Similar considerations can be done for cost estimation: the sum of all forecasted expenses is defined as *budget*.

Accurate time and costs planning allows the understanding of how to distribute optimally the resources in the project lifecycle. If planning is not meticulous, then there is a higher probability of incurring in deviations from the reference.

Project control is performed comparing real time and costs progress with respect to the planned times and costs. For a better comparison, it is necessary to use a metric that allows to provide a measure for the progress as well as to establish – through objective and measurable targets – the deviations entity.
Metric, to be effective, should be limited to important factors for the project: the collection and the study of non-relevant data would bring to an overcontrol that, in its turn, would cause an increase in documental production and the loss of the real project focus [18].
Maylor, describing the inefficiency of the control process, proposes an analogy with a tank which is provided with a flow controller: the installation and maintenance of the controller represents a cost; moreover, its presence can perturbate the flow entering the tank. Similarly, the resources that are allocated to project control activities are a cost; if control is inefficient and not organized, this leads to time losses and to complications in the flow of information.
Maylor expands the tank analogy also to the type of control: it can be feedback, when the output of a variable is compared to a set value; it can be feedforward if it is able to forecast the trend of the analyzed variables. This last control approach requires a deep knowledge of the controlled processes.
The choice for the metric, together with the possibility of stating objectively the project progress (or its deviations), is not always easy to make. Patrone and Piras [19] observe that, often, delays and cost increases are the consequences for the inadequacy of the control tools adopted. This problem results more evident in Research and Development projects that, for their nature, are characterized by highly uncertain elements.

Starting from this consideration, the current thesis work is meant to develop an adequate control tool that can be applied to R&D projects that are carried out in Tecnimont.

2 Project planning and control in Tecnimont

In the following chapter, control and planning methodologies adopted in Tecnimont are analysed. Two classes of projects are here described: the so-called Service Projects, that include Feasibility Studies, BASIC Studies, Front End Engineering Design Studies, and EPC Projects: their characteristics and complexity will be described in detail in par. 2.2 and 2.3.

2.1 Basic tools for planning and control

Tecnimont manages different projects that can be very diversified according to their scope, complexity and – consequently – management tools. Nevertheless, some project control techniques are extensively adopted because they are the cornerstones of project management. In par. 2.2 and 2.3, the application of the mentioned tools will be better explained according to FEED and EPC peculiarities and requirements.

2.1.1 Work Breakdown Structure

The *Work Breakdown Structure* (WBS) is an approach for which all the activities needed to fulfil the project objectives are ordered hierarchically. WBS's purpose is linking and integrating all the project information, organizing and defining the project scope. WBS is developed through an iterative process that considers technical requirements, project objectives and functionality. A first WBS is proposed in the early conceptual stage of the project; lately, thanks to a more detailed definition of specification, it will be possible to refine the tree structure. A simplified example is provided in Fig. 2-1.

As already mentioned, the WBS has the advantage of highlighting how activities are linked and of providing, known these connections and the overall project scope, estimates that are more accurate in terms of time and costs. The standard approach to build the WBS – which is adopted also in Tecnimont – is the top-down approach: starting from the project macro activities, these are decomposed in activities whose scope is better defined and limited. Each activity is studied and decomposed in its turn in sub-activities and/or *deliverables* – which are works that produce tangible and verifiable results [1]. Each WBS element must represent a single item of tangible work. Deliverables must be unique and different from their peers; the level of detail reached during the decomposition must be the same for all the tree structure branches. The high level of detail that can be reached using the

WBS allows gathering the activities with the same objectives in the so-called *work packages*. Deliverables must be limited in their dimensions and definition so that it is possible to apply an efficient control and, at the same time, they should not include activities which require a too short time to be accomplished: this to avoid an overcontrol that would imply excessive and unnecessary expenses. Similarly, deliverables dimensions should not make the risk for the activities unmanageable or inacceptable. Once the project scope is identified and assigned the value of 100% – which represents its completeness – every work package and activity represents a percent value of the entire scope: summing all the activities and sub-activities, the value of 100% must be reached.
WBS is not only used for the management of activities, but also for the company organization (Organizational Breakdown Structure), the plant areas division (Plant Breakdown Structure) and project risks (Risk breakdown Structure).

The *Organizational Breakdown Structure* provides an overview of how the corporate structure is organized. It associates project responsibilities to the personnel.

The *Plant Breakdown Structure* is produced to geographically segregate the scope of work for a plant that is forecasted to be built. Portioning is done accordingly to the complexity and topology of the plant.
When the project areas are individuated, they are univocally coded and assigned to project teams. An example of area portioning can be observed in Fig. 2-2.

The *Risk Breakdown Structure* is the tree structure that is used to organize logically project risks.

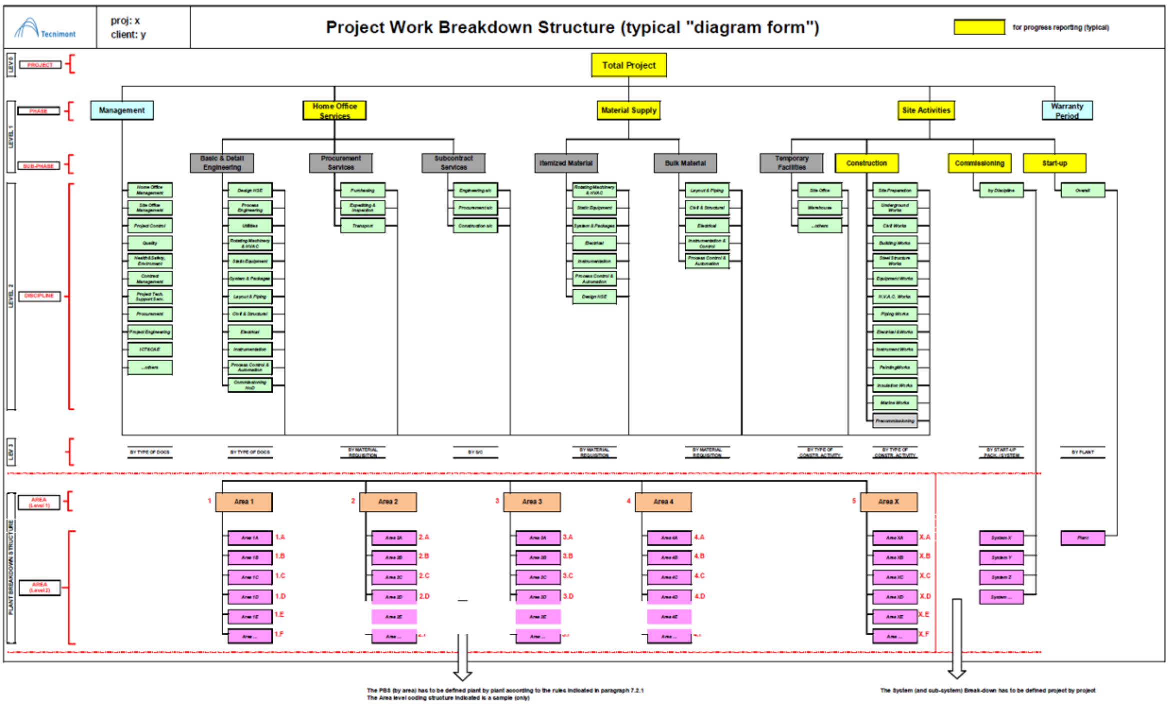

Figure 2-1: Example of Work Breakdown Structure

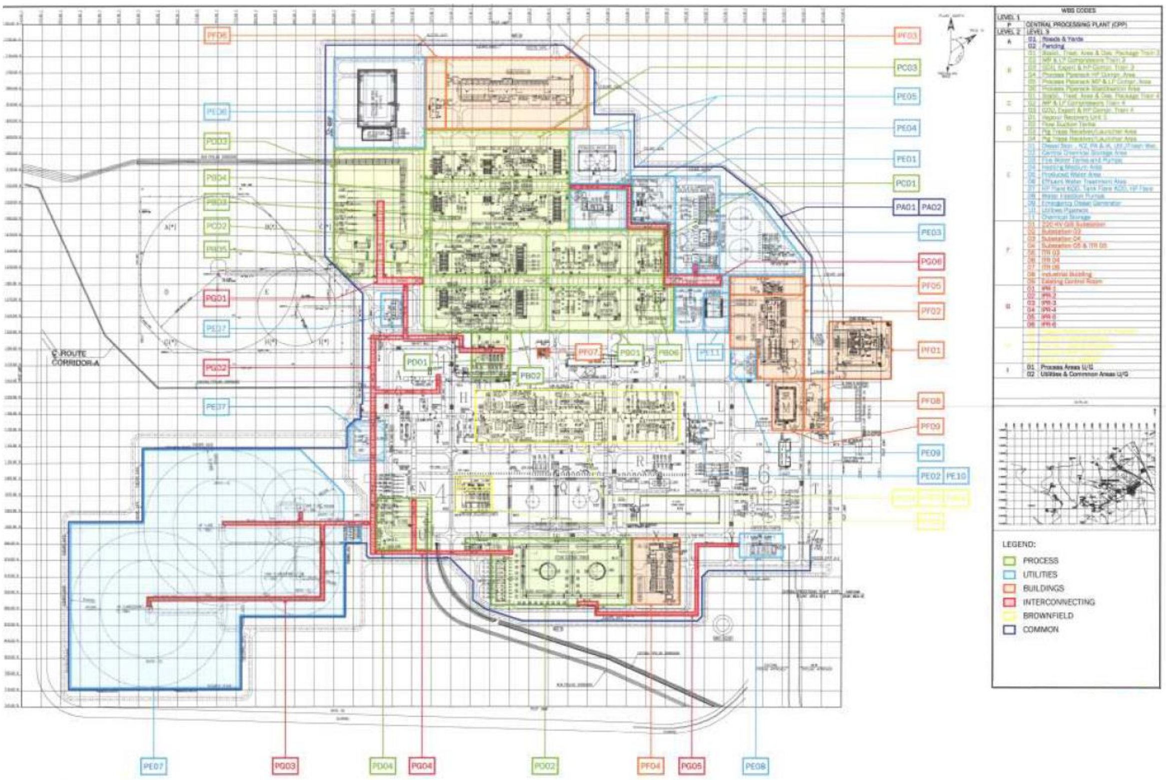

Figure 2-2: Example of Risk Breakdown Structure

2.1.2 Time and costs estimation

Estimating means assigning time durations to activities that are present in the WBS. Estimates are the reference value used to plan, monitoring and evaluating the project work. Making estimations about activities not only means providing their durations but also proposing an approximation for the resources that will be used to complete the activities.

People who are in charge of making estimates consider multiple causes for variance, including risk: on the basis of their experience, they provide a value for the activity variance. Historical data are recorded, updated and used to speed up the estimation process. Since the project scope is never identical (it should be remembered that projects are unique), productivity coefficients are used to make the estimate more realistic. Adopting this approach for time estimates has some limits: productivity, in fact, in a non-constant parameter and there is no linear relation between the number of forecasted steps to complete an activity and the overall work duration. Duration and costs are closely dependent on the resource chosen to perform the activity.

Tecnimont adopts the analogy, parametric, bottom-up estimations and Monte Carlo analysis to estimate the average activities duration.
Estimates by analogy make references to similar past projects to get time and costs estimates for the current one. *Parametric estimates* use historical data and other variables (such as the square meters of concrete poured in situ) and, exploiting regression models, it is possible to obtain a formula that describes the activity performance. In particular, this kind of estimate is used for the computation of costs through the following algorithm:

$$\frac{\mathrm{Cost}_1}{\mathrm{Cost}_2} = \left(\frac{\mathrm{Size}_1}{\mathrm{Size}_2}\right)^{\mathrm{N}}$$

Equation 2-1: Parametric estimate

Where the exponent N changes according to the field of application of the algorithm. The algorithm provides the expected value; for the variance computation, independent evaluations are needed.

Bottom-up estimate is done by summing all the costs associated with the milestones, starting from the most specific activities to most generic ones. The WBS represents an important reference for the application of this technique because it organizes all the activities in work packages.

All the estimates obtained with the previous techniques are used in the *Monte Carlo simulation* which computes iteratively all the values that the studied model can assume; input values, that can be modified as well as the range they belong to, are selected randomly in every iteration. A probability function is assigned to each variable. According to this method, paths can become critic varying the durations assigned to activities; the identification process of possible critical paths is called *"path convergence"*.

2.1.3 Baseline construction

After time durations have been assigned to activities, they are linked in order to build the baseline. Tecnimont classifies connections as compulsory, when activities have mandatory technical of physical connections that cannot be changed (for example, concrete cannot be poured before formworks installation), or discretional, when it is possible to apply a preferential logic (for example, shifting the sequence of two activities can be feasible but more expensive).

Dependencies are represented with the *Activity-on-Node (A-o-N) diagrams*, where the kind of sequence related to activities are specified. These can be:

1. finish to start: B cannot start before A finishes;
2. start to start: B can start simultaneously with A or after A starts;
3. finish to finish: B can only finish after A finishes, or simultaneously;
4. start to finish: B cannot finish before A has started.

A-o-N diagrams are a fundamental element for the *Critical Path Method* (CPM) application.

The application of CPM allows identifying the *critical path*, i.e. the sequence of activities whose delay causes the entire project delay. Before tracing the critical path, it is necessary to link each activity to its duration. In addition to this information, each activity is given a specific name, an *Early Start Time* (EST) – the date when the activity would start if all previous operations were not subjected to delays – and a *Late Start Time* (LST) – the date when the activity would start if all previous operations were subjected to the maximum delay. EST and LST are respectively associated with the *Early Finish Time* (EFT) and the *Late*

Finish Time (LFT), which are similarly defined. Schedule flexibility is measured by the amount of time that a schedule activity can be delayed or extended from its early start date without delaying the project finish date or violating a schedule constraint, and is termed "total float" [1].

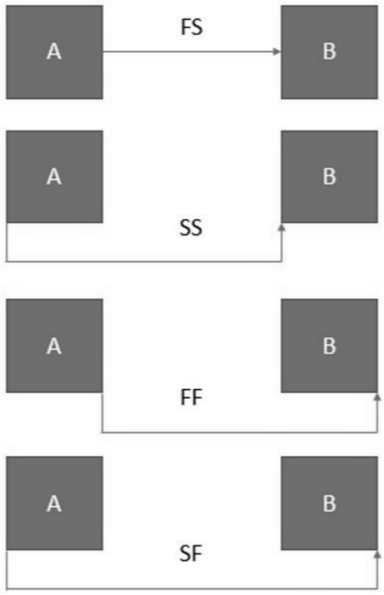

Figure 2-3: A-o-N dependences

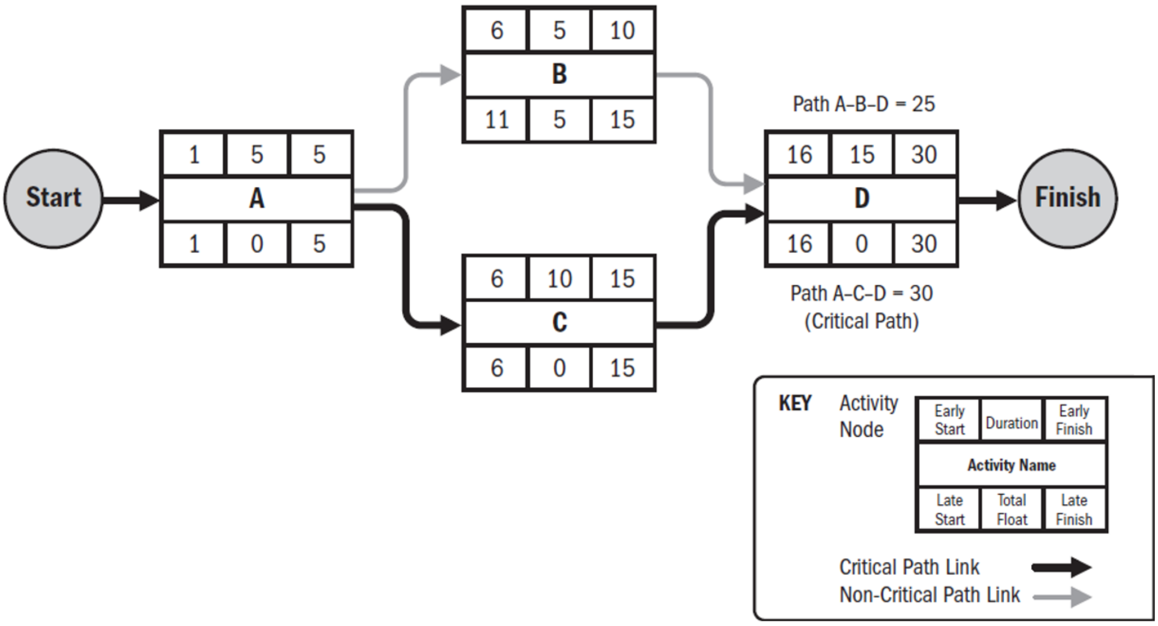

Figure 2-4: Example of application of Critical Path Method

The critical path is the sequence of activities that has a total float equal to zero. Projects, according to their complexity can show more than a single critical path. Logical constraints applied during the planning phase should be minimized as much as possible because they reduce the schedule flexibility: so, they should be introduced only when necessary and have to be justified in the schedule documentation. In detail, the “not earlier than” constraint affects the project progress imposing some activities to be completed before starting the new ones, the “not later than” constraint causes an acceleration of the project as some activities must be started before others, the “must” or “mandatory” constraint imposes the activities to respect the imposed dates. These constraints are represented with the Gantt charts which are bar diagrams whose extension is proportional to activities durations. Gantt charts are often used to represent graphically the project progress (also in real-time): since they are very intuitive, they are used for the CPM to better highlight the critical/s path/s (Fig. 2-5).

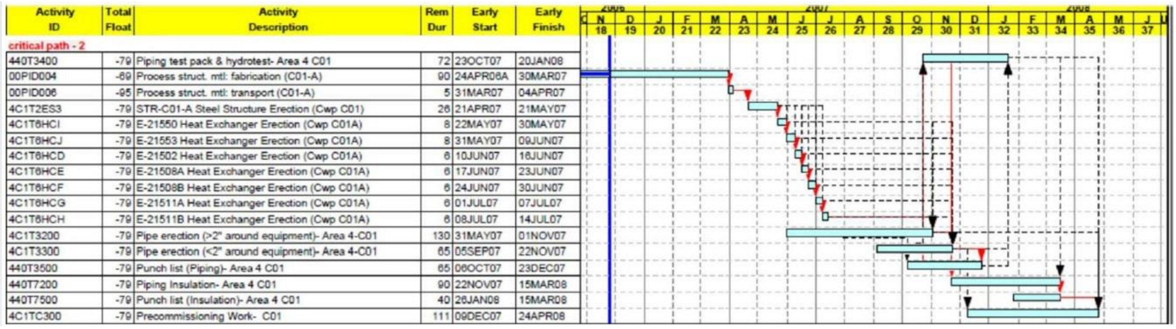

Figure 2-5: Critical Path, example

The CPM described above is used by the Planning and Control department and implemented in project management software used in the Company.

CPM is combined with other tools such as progress curves and manpower histograms. *Progress curves*, better known as *S curves*, enable the project manager to have a global vision on time and costs progress [2]. According to the forecasted activities, every day or month is assigned a percent progress value that, through a cumulation process, produces the typical S shape of the curve. Tecnimont traces two curves for each project discipline: the early curve, that represents the most optimistic project trend (all the activities start at their EST and are completed with the lowest expense), and the late curve, that represents the most pessimistic project trend (all the activities start at their LST and are completed with the highest expense).

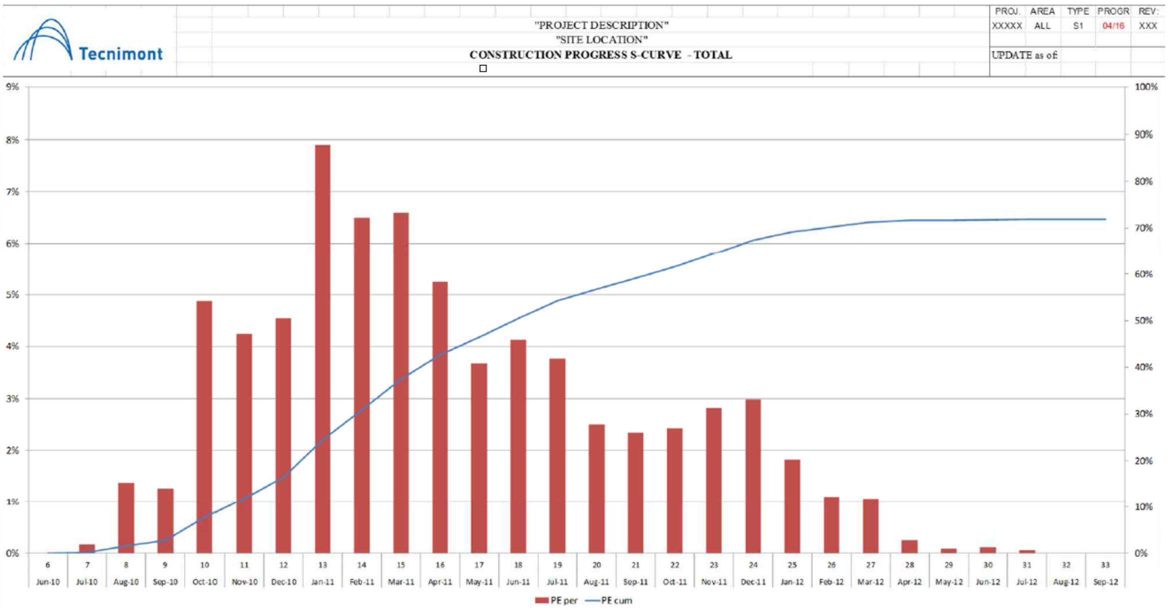

Figure 2-6: Progress S curve, example

Manpower histograms represent graphically the resources distribution that are planned for the project.

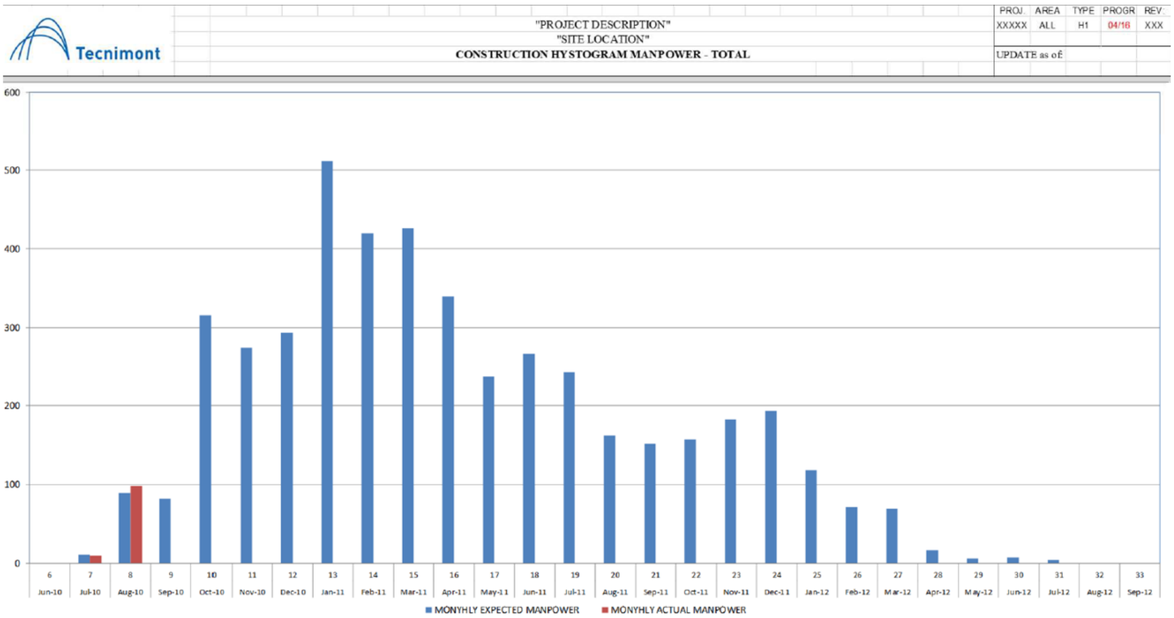

Figure 2-7: Manpower histogram, example

2.1.4 Control tools

Tecnimont controls times and costs; in both cases, the planned progress and the effective one are compared. Cost trends are closely linked to time considerations. For the sake of completeness, it is specified that costs can be subjected to modifications that do not depend on the schedule time deviations: for the purposes of the present discussion, independent cost variations will not be considered.

Tecnimont uses the Earned Value Method, progress curves and resources histograms as control tools.

Earned Value Management (EVM) was introduced in 1962 by the USA Defense Department to standardize cost and planning systems for their commissions [19], [20]. By this means, not only the project progress can be computed, but also performance analyses can be done: according to their results, it is possible to make forecasts of the project completion date and costs. This method has been proven to be one of the most effective performance measurement and feedback tool for managing projects [21]. According to the type of work to be controlled, it is possible to adopt some metrics that enable progress identification. The Company differentiates the work for its duration and its tangibility in:

- *discrete effort*, if work is directly related to a product realization or a tangible service;
- *apportioned effort*, if the work for the project is not easily separated in discrete efforts but can be expressed proportionally to the work related to discrete efforts;
- *level of effort*, if work cannot be divided into discrete elements (such as project support and project control [22]).

Measured the progress, some indicators are computed. They are based on three fundamental parameters [1] that are defined in the following:

- *Planned Value* (PV): is the planned value for times and costs. PV is also known as *Budgeted Cost for Work Scheduled* (BCWS);
- *Earned Value* (EV): it is the value that represents the progress at a specified time i.e. the work actually performed. EV is also known as *Budgeted Cost for Work Performed* (BCWP);
- *Actual Cost* (AC): it represents the quantity of resources that have been employed in a certain timespan to complete activities. AC is also known as *Actual Cost for Work Performed* (ACWP).

Progress indicators and forecasts can be computed as:

- $cost\ variance = BCWP - ACWP$;
- $schedule\ variance = BCWP - BCWS$;
- $cost\ performance\ index\ CPI = BCWP/ACWP$;
- $schedule\ performance\ index\ SPI = BCWP/BCWS$;
- $EAC\ (Estimate\ At\ Completion) = BAC/CPI$ (if variances occurred and it is likely that they will continue occurring in the same way) where BAC is *Budget At Completion*;
- $ETC(Estimate\ To\ Complete) = EAC - ACWP;$
- $TCPI(To\ Complete\ Performance\ Index) = (BAC - BCWP)/(BAC - ACWP)$.

For what concerns progress curves, the ones related to the effective progress are traced thanks to the constant monitoring of activities. If the effective progress curve is below the early curve and above the late curve, the project is proceeding with a planned variance. When the effective progress curve is not included in the range defined by the planned curves – and it is closer to the late curve – there is the presence of a creep.

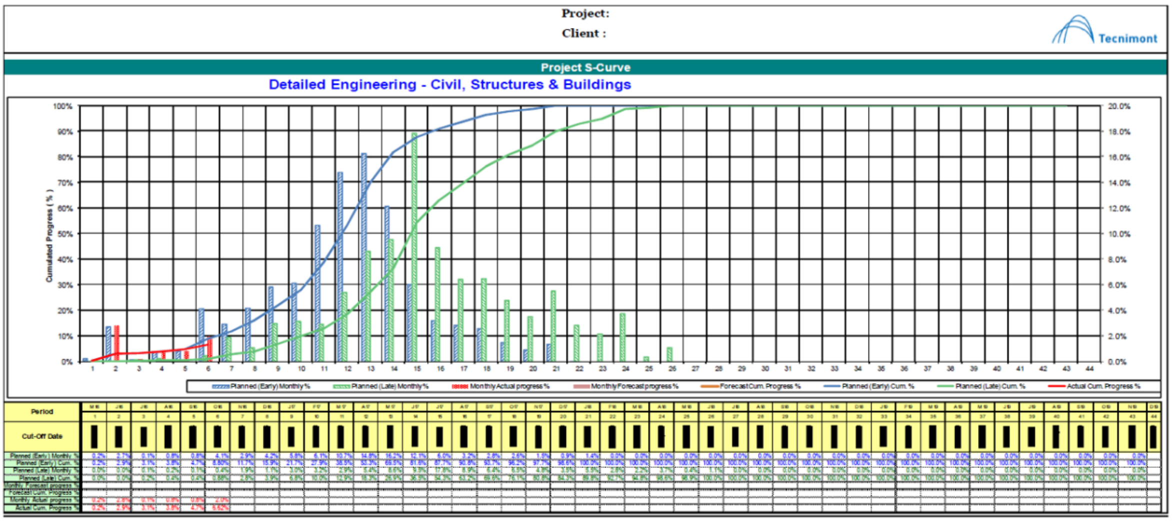

Figure 2-8: Physical project progress curve, example

Resources histograms are traced based on the hours spent by resources to complete activities. If resources that were employed overcome the planned ones, there is the presence of a creep.

2.2 FEED projects

Front-End-Engineering Design studies (FEED) belong to the category of service projects that are, mainly, projects limited to engineering documental production. They are aimed at defining plants' characteristics in a more or less detailed manner according to the type of study done: through the Front-End-Engineering Design, the project assumes its first complete technical-quantitative configuration. In this phase, all the plant systems and materials are individuated and characterized functionally and numerically [2]. The execution of the Front-End can proceed in parallel with detailed engineering that elaborates information that is useful for a (possible) successive procurement phase. In addition to the FEEDs, which are the studies that reach the highest level of detail, the Company manages two other kinds of projects: feasibility studies and BASIC studies.

A *feasibility study* is the first analytical approach to a project for which some business opportunities are detected. In the initial phase, limits, constraints and implications about the project construction are endorsed and it is decided if the study of the project should be deepened furtherly [2].

BASIC studies include the definition of functional characteristics related to all the systems that will be present in the plant [2].

The complexity of Feasibility and BASIC studies does not worth the implementation of a highly structured planning and control system: for this reason, these studies will not be analysed. Conversely, FEED control must be accurate: indeed, the choices made in this phase have a maximum impact on the plant budget and time duration.

The control process for FEED studies is based on the constant comparison of the work effectively performed with respect to the objectives defined in the contractual phase. The identification of potential deviations is managed by implementing corrective and mitigation measures. The activity plan is represented by a deliverables list to which costs (they are expressed in terms of man-hours) and a set of dates are associated. A database collects the information that is necessary to temporally and economically quantify the level of effort, the apportioned effort and any other secondary cost (travels, services, etc.).

Project management depends on the project typology and on the client's requirements. FEED projects are classified for their low, medium or high complexity. The deliverable list for low complexity projects associates a milestone to each document to be prepared. In medium complexity projects, it is adopted the same strategy but deliverables dates are defined with the support of a scheduling system (MS Project or Primavera). In high complexity projects, all the planning and control tools mentioned in the corporate procedures are used. The procedure includes the baseline definition (Start-up Planning), the actualization and the standard progress control.

The *Start-up Planning* can be rectified in case of scope modification. The baseline is built using the tools described in par. 2.1.3. Optionally, although suggested, project forecasts can be uploaded every thirty days (whatever the project complexity is). Standard progress is assessed every month; every fifteen days physical progress is updated and forecasts are made for the future six weeks. Every six months the Corporate Budget Progress, an assessment about the progress related to the project costs, is computed: on the basis of its value, it is possible to confirm or modify the financial and economic project objectives.
"Maintenance" is planned during the control phase: this has the goal of keeping the project objectives coherent and consistent with the constraints that possibly show up over time. The above-mentioned maintenance must be guaranteed but has not to impede the fulfillment of project objectives.

Tecnimont uses two types of indicators: some of them measure the project performance, other highlight critical aspects and potential process areas that can be improved.
For what concerns performance indicators, the Company adopts the ones proposed in the Earned Value methodology (SPI and CPI).

2.3 EPC projects

EPC projects include the Engineering, Procurement and Construction phases. Each of these phases will be described in par. 2.3.1,2.3.2, 2.3.3 respectively.

Tecnimont defines for EPC projects a set of planning levels that, in ascending order, have the highest level of detail. As it is possible to observe from Fig. 2-9, four levels are defined:

- Level 1: Project Summary Schedule;
- Level 2: Project Master Schedule;
- Level 3: Project Control Schedule;
- Level 4: Detailed Schedules.

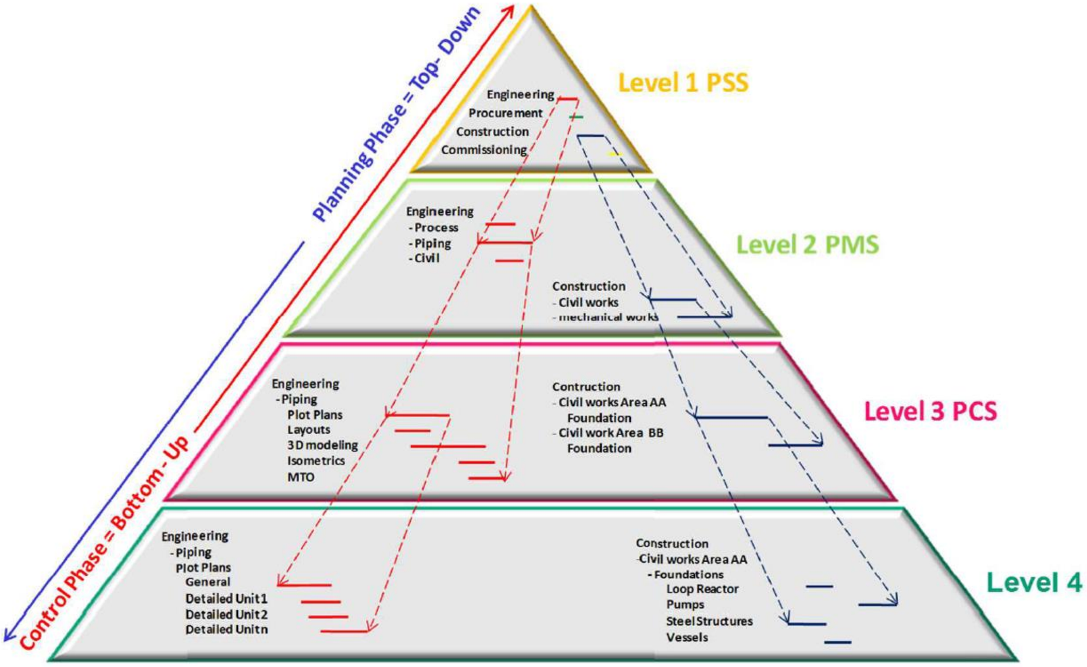

Figure 2-9: Tecnimont scheduling levels

The first level illustrates how to generically organize the project work in order to fulfil contractual obligations. The second level is the expansion of the first: it specifies the level of detail that is needed to identify the main project objectives (milestones) and to implement effective strategies to target the project goals. It also identifies the first constraints that the planning and control phases will be subjected to.

The first and the second levels are, so, preliminary steps for the actual planning and control that are included in the third level.

Level 3 is the first level where the critical path can be traced in detail and completely. Precedence network is drawn through CPM-based software and the output is the graphical representation of activities in bar charts and precedence diagrams. The third level output is officially reported in the *Project Control Schedule* (PCS) that is the reference document with respect to which all the control system is developed. The baseline is contained in the PCS and is combined with man-hours/manpower histograms and S Curves. The baseline cannot be modified unless the work scope changes.

In case it was necessary to better identify the main critical paths related to the schedule, the PCS is furthermore detailed: this is what is done in Level 4. This last level contains work schedules that can be prepared without the help of CPM-based software: corporate spreadsheets, databases and in-house tools are used. Level 4 schedules are updated every ninety days unless particular project needs or requests.

For EPC projects, control is essential because the knowledge about the project progress can have a strong effect on contractual conditions between Tecnimont, the client, vendors and subcontractors. Progress can be measured if it is tangible (there is physical progress), earned (the activity is performed completely), and factual (the activity completion cannot be subjected to any interpretation). Progress evaluation depends on the explored area: progress is measured differently for Engineering, Procurement or Construction phase.
The measuring system for the progress is based on the Earned Value methodology: once defined the milestones, a percent weight is assigned to them.

Tecnimont uses some tools and software for the planning and control phases:

- Planning and Scheduling: Primavera (P6);
- Progress Measurements: Spreadsheets (for example, Excel) and the Tecnimont Progress Measurement System (TPMS), an in-house software prepared by the Control Department that contains a detailed program for every engineering discipline.

2.3.1 Engineering

Engineering in EPC projects represents the phase when engineering planning takes place. Planning is more detailed and complex than the service projects. Engineering deliverables are documental production related to the plant. The documentation contains specifications, construction criteria and provides a detailed unit modelling that resembles the definitive one.

Engineering planning follows Level 4 indications. Deliverables are organized in a list and in milestones. The TPMS is used to build the schedule for Level 4 which is the reference for monitoring and controlling the Engineering progress. Level 4 control is more detailed than the one that could be performed considering only Level 3; nonetheless, Level 4 outputs must be coherent with Level 3 milestones. Direct effort, apportioned effort and level of effort are the inputs for the construction of the schedule.

Direct effort progress, associated – for example – to draws and document production, is computed as work actually done, not as man-hours spent to reach the objective.

Apportioned effort progress is measured as the number of activities that belong to the apportioned effort group with respect to the activities that are still to perform. Usually, some activities that are part of this category are:

1. 3D Modelling (Piping, Civil, Electrical & Instrument);
2. Stress Analysis, Isometric Issuance, P&IDs marked-up;
3. Vendor Documents follow-up.

For modelling activities, a detailed control sheet is implemented from the early stages of the project. The progress for 3D models is computed as the ratio between the number of units or item modelled over the total number of units of item to be modelled. For the activities reported in the second point, criteria for the progress measure are defined at the beginning of the project and, accordingly, S curves are traced. For activities that engage vendors, there is a document in which all deadlines are reported: this document represents the reference.

For the level of effort, the value assigned to the man-hours devoted to the coordination of project operations regarding specific disciplines is limited (typically between 5 and 10%) by the total man-hours that are considered as discrete effort for the same discipline. If the contract does not include level of effort activities, then the hours that would have been devoted to level of effort are distributed and attributed to direct effort.

The weight for the activities of direct, apportioned and level of effort is based on the man-hours assigned for each discipline. Man-hours are considered as they were resources in order to trace progress curves. Earned man-hours are collected inside PCS activities and are recorded monthly (or weekly, if necessary) to compare the planned curves with the ones representing the actual situation.

L	CLUSTERS & REMOTE WELLS															
11.0	CIVIL/STRUCTURAL/ARCHITECTURAL															
TPMS Element	Drawing / Document Title	Drawing / Document Number	Est. Man Hours	Relative Weight		Started	Draft Completed	Issue for Approva (IFA)	Incorporated Company Comments - Reissue fo	Final Issue Approved						Actual Earned Manhours
						5	50	80	90	100	0	0	0	0	0	
3844-AA-CS-2LB06	CONCRETE DESIGN CALCULATION REPORT–FOR CLUSTER 8H	3844-AA-CS-LB06001	5.50	.01	ACT	AACS2LB06020	AACS2LB06020	AACS2LB06020	AACS2LB06040	AACS2LB06090						2.750
					P	10/12/2015	06/01/2016	06/01/2016	17/02/2016	15/04/2016						
					F			22/04/2016	03/06/2016	12/08/2016						
					A	15/01/2016	29/01/2016									
3844-AA-CS-2LB06	CONCRETE DESIGN CALCULATION REPORT–FOR CLUSTER 8H	3844-AA-CS-LB06002	5.50	.01	ACT	AACS2LB06020	AACS2LB06020	AACS2LB06020	AACS2LB06040	AACS2LB06090						2.750
					P	10/12/2015	06/01/2016	06/01/2016	17/02/2016	15/04/2016						
					F			22/04/2016	03/06/2016	12/08/2016						
					A	15/01/2016	29/01/2016									
3844-AA-CS-2LB07	CONCRETE DESIGN CALCULATION REPORT–FOR CLUSTER 9J	3844-AA-CS-LB07001	5.50	.01	ACT	AACS2LB07020	AACS2LB07020	AACS2LB07020	AACS2LB07040	AACS2LB07090						2.750
					P	19/10/2015	13/11/2015	13/11/2015	25/12/2015	01/02/2016						
					F			19/04/2016	31/05/2016	26/07/2016						
					A	11/12/2015	14/01/2016									
3844-AA-CS-2LB07	CONCRETE DESIGN CALCULATION REPORT–FOR CLUSTER 9J	3844-AA-CS-LB07002	5.50	.01	ACT	AACS2LB07020	AACS2LB07020	AACS2LB07020	AACS2LB07040	AACS2LB07090						2.750
					P	19/10/2015	13/11/2015	13/11/2015	25/12/2015	01/02/2016						
					F			19/04/2016	31/05/2016	26/07/2016						
					A	11/12/2015	14/01/2016									
3844-AA-CS-2LB08	CONCRETE DESIGN CALCULATION REPORT–FOR CLUSTER 10K	3844-AA-CS-LB08001	5.50	.01	ACT	AACS2LB08020	AACS2LB08020	AACS2LB08020	AACS2LB08040	AACS2LB08090						2.750
					P	09/11/2015	04/12/2015	04/12/2015	15/01/2016	12/02/2016						
					F			19/04/2016	31/05/2016	26/07/2016						
					A	11/12/2015	14/01/2016									
3844-AA-CS-2LB08	CONCRETE DESIGN CALCULATION REPORT–FOR CLUSTER 10K	3844-AA-CS-LB08002	5.50	.01	ACT	AACS2LB08020	AACS2LB08020	AACS2LB08020	AACS2LB08040	AACS2LB08090						2.750
					P	09/11/2015	04/12/2015	04/12/2015	15/01/2016	12/02/2016						
					F			19/04/2016	31/05/2016	26/07/2016						
					A	11/12/2015	14/01/2016									

Figure 2-10: Engineering document deliverable register

2.3.2 Procurement

In the *Procurement* phase, vendors are identified, orders are done and unit/material logistics, as well as transportation, are planned. Plant item specifications and quantities are defined in the previous Engineering phase. Procurement deliverables are the documental production and organization of information, which are useful for plant materials/items acquisition, and transportation. The procurement phase lays the foundations for the Construction phase by getting all the plant units and items.

The procurement planning phase follows Level 4 indications. Deliverables are divided into three sub-levels – which will be detailed later – and define the milestone list. The schedules obtained by the application of Level 4 methodology are the reference for monitoring and controlling the Procurement progress.

Procurement is characterized by three detailed schedules: one for Procurements Services, one for Subcontract Services and one for Manufacturing and Delivery.
Procurement Services schedule is the tool used to monitor and control the project deliverables acquisition. An example, but not limited, of Procurement Services deliverables can be observed in Fig. 2-11.

Sr. No.	Item Description	Relative Weight	P F A	RFQ	BID RCPT	TBE	PO	KOM	FIN. INSPECT.	AT SITE	Weighted Progress		Remarks / Status
				10%	10%	20%	10%	8%	32%	10%	Plan	Act	
1.1	KK MR 020 FIRE & GAS SYSTEM (for field/building devices)	20.00%	Act ID	PSBD70050Q	PSBD70050Q	PSBD70050Q	PSBD70050Q	PSBD70050Q	PSBD70050Q	PSBD70050Q			
			P	05-Oct-09	04-Nov-09	19-Dec-09	03-Jan-10	23-Jan-10	30-Sep-10	29-Nov-10	4.00%		
			F										
			A	05-Oct-09	04-Nov-09							4.00%	
2.1	KK MR 062 CORROSION MONITORING SYSTEM	20.00%	Act ID	PSBD70060Q	PSBD70060Q	PSBD70060Q	PSBD70060Q	PSBD70060Q	PSBD70060Q	PSBD70060Q			
			P	22-Aug-09	21-Sep-09	05-Nov-09	20-Nov-09	10-Dec-09	17-Aug-10	16-Oct-10	10.00%		
			F										
			A	22-Aug-09	21-Sep-09	05-Nov-09	20-Nov-09					10.00%	
3.1	KK MR 455 TELECOMMUNICATION SYSTEM	20.00%	Act ID	PSBD73020Q	PSBD73020Q	PSBD73020Q	PSBD73020Q	PSBD73020Q	PSBD73020Q	PSBD73020Q			
			P	23-Sep-09	23-Oct-09	07-Dec-09	22-Dec-09	11-Jan-10	18-Sep-10	17-Nov-10	4.00%		
			F										
			A	23-Sep-09	23-Oct-09							4.00%	
4.1	JK MR 010 INTEGRATED CONTROL SYSTEM - YOKOGAWA ENGINEERING ASIA PTE.	20.00%	Act ID	PSBD71020Q	PSBD71020Q	PSBD71020Q	PSBD71020Q	PSBD71020Q	PSBD71020Q	PSBD71020Q			
			P	12-Aug-09	11-Sep-09	26-Oct-09	10-Nov-09	30-Nov-09	07-Aug-10	06-Oct-10	10.00%		
			F										
			A	12-Aug-09	11-Sep-09	26-Oct-09						8.00%	
5.1	JK MR 040 MACHINE MONITORING SYSTEM	20.00%	Act ID	PSBD70040Q	PSBD70040Q	PSBD70040Q	PSBD70040Q	PSBD70040Q	PSBD70040Q	PSBD70040Q			
			P	20-Oct-09	19-Nov-09	03-Jan-10	18-Jan-10	07-Feb-10	15-Oct-10	14-Dec-10	4.00%		
			F										
			A	20-Oct-09	19-Nov-09							4.00%	
	Total (INSTRUMENTATION & CONTROL)	**100.00%**									**32.00%**	**30.00%**	

Act ID — Activity ID from PCS (ID:step -> 1:1 or 1:n)
P — PLAN date as for baseline PCS
F — FORECAST as for current PCS
A — ACTUAL date as for actual reporting

Relative Weight — based on HOME OFFICE man-hours

Figure 2-11: Procurement service register

Subcontract Services schedule is the tool used to monitor and control subcontractors' project deliverables. An example, but not limited, of Subcontractors Services deliverables can be observed in Fig. 2-12.

Sr. No.	Item Description	Relative Weight	P F A	RFQ	BID RCPT	TBE	PO	KOM	FIN. INSPECT.	AT SITE	Weighted Progress		Remarks / Status
				10%	10%	20%	10%	8%	32%	10%	Plan	Act	
1.1	CIVIL WORK	30.00%	Act ID	CCBD70050Q	CCBD70050Q	CCBD70050Q	CCBD70050Q	CCBD70050Q	CCBD70050Q	CCBD70050Q			
			P	05-Oct-09	04-Nov-09	19-Dec-09	03-Jan-10	23-Jan-10	30-Sep-10	29-Nov-10	6.00%		
			F										
			A	05-Oct-09	04-Nov-09							6.00%	
2.1	PILING WORK	10.00%	Act ID	CCBD70060Q	CCBD70060Q	CCBD70060Q	CCBD70060Q	CCBD70060Q	CCBD70060Q	CCBD70060Q			
			P	22-Aug-09	21-Sep-09	05-Nov-09	20-Nov-09	10-Dec-09	17-Aug-10	16-Oct-10	5.00%		
			F										
			A	22-Aug-09	21-Sep-09	05-Nov-09	20-Nov-09					5.00%	
3.1	MECHANICAL WORK (equipment, piping, insulation)	30.00%	Act ID	CCBD73020Q	CCBD73020Q	CCBD73020Q	CCBD73020Q	CCBD73020Q	CCBD73020Q	CCBD73020Q			
			P	23-Sep-09	23-Oct-09	07-Dec-09	22-Dec-09	11-Jan-10	18-Sep-10	17-Nov-10	6.00%		
			F										
			A	23-Sep-09	23-Oct-09							6.00%	
4.1	ELECTRICAL & INSTRUMENT WORK	20.00%	Act ID	CCBD71020Q	CCBD71020Q	CCBD71020Q	CCBD71020Q	CCBD71020Q	CCBD71020Q	CCBD71020Q			
			P	12-Aug-09	11-Sep-09	26-Oct-09	10-Nov-09	30-Nov-09	07-Aug-10	06-Oct-10	10.00%		
			F										
			A	12-Aug-09	11-Sep-09	26-Oct-09						8.00%	
5.1	HEAVY LIFTING	10.00%	Act ID	CCBD70040Q	CCBD70040Q	CCBD70040Q	CCBD70040Q	CCBD70040Q	CCBD70040Q	CCBD70040Q			
			P	20-Oct-09	19-Nov-09	03-Jan-10	18-Jan-10	07-Feb-10	15-Oct-10	14-Dec-10	2.00%		
			F										
			A	20-Oct-09	19-Nov-09							2.00%	
	Total (CONSTRUCTION)	**100.00%**									**29.00%**	**27.00%**	

Act ID — Activity ID from PCS (ID:step -> 1:1 or 1:n)
P — PLAN date as for baseline PCS
F — FORECAST as for current PCS
A — ACTUAL date as for actual reporting

Relative Weight — based on HOME OFFICE man-hours

Figure 2-12: Subcontracting service register

Manufacturing & Delivery schedule is the tool used to monitor and control the project deliverables related to materials supply. An example, but not limited, of Manufacturing & Delivery deliverables can be observed in Fig. 2-13.

Sr. No.	Item Description	Relative Weight	P F A	PO	KEY VENDOR DOC. RECEIPT	MAIN SUB-ORDER MAT. ISSUE	MAIN SUB-ORDER MAT. ARRIVAL	TEST	EX-WORK	AT SITE	Weighted Progress		Remarks / Status
				10%	5%	20%	20%	35%	5%	5%	Plan	Act	
1.1	KK MR 020 FIRE & GAS SYSTEM (for field/building devices)	11.55%	Act ID	TCBD70050Q	TCBD70050Q	TC0R70050Z	TC0R70050Z	TC0R70050Z	TC0R70050Z	TC0R70050Z			
			P	05-Oct-10	27-Dec-10	03-Jan-11	26-Jan-11	25-Feb-11	27-Mar-11	06-Jun-11	10.97%		
			F										
			A	05-Oct-10	27-Dec-10	03-Jan-11						4.04%	
2.1	KK MR 062 CORROSION MONITORING SYSTEM	1.23%	Act ID	TCBD70060Q	TCBD70060Q	TC0R70060Z	TC0R70060Z	TC0R70060Z	TC0R70060Z	TC0R70060Z			
			P	22-Nov-10	11-Feb-11	18-Feb-11	13-Mar-11	12-Apr-11	12-May-11	22-Jul-11	1.17%		
			F										
			A	22-Nov-10	11-Feb-11	18-Feb-11						0.43%	
3.1	KK MR 455 TELECOMMUNICATION SYSTEM	16.61%	Act ID	TCBD73020Q	TCBD73020Q	TC0R73060Z	TC0R73060Z	TC0R73060Z	TC0R73060Z	TC0R73060Z			
			P	23-Aug-10	17-Sep-10	24-Sep-10	17-Oct-10	16-Nov-10	16-Dec-10	19-Aug-11	15.78%		
			F										
			A	23-Aug-10	17-Sep-10	24-Sep-10						5.81%	
4.1	JK MR 010 INTEGRATED CONTROL SYSTEM - YOKOGAWA ENGINEERING ASIA PTE.	48.82%	Act ID	TCBD71020Q	TCBD71020Q	TC0R71010Z	TC0R71010Z	TC0R71010Z	TC0R71010Z	TC0R71010Z			
			P	24-Mar-10	07-Sep-10	14-Sep-10	07-Oct-10	06-Nov-10	06-Dec-10	13-Jul-11	46.38%		
			F										
			A	24-Mar-10	07-Sep-10							7.32%	
5.1	JK MR 040 MACHINE MONITORING SYSTEM	21.79%	Act ID	TCBD70040Q	TCBD70040Q	TC0R70040Z	TC0R70040Z	TC0R70040Z	TC0R70040Z	TC0R70040Z			
			P	12-Nov-10	13-Jan-11	20-Jan-11	12-Feb-11	14-Mar-11	13-Apr-11	27-Oct-11	20.70%		
			F										
			A	12-Nov-10	13-Jan-11							3.27%	
	Total (INSTRUMENTATION & CONTROL)	**100.00%**									**95.00%**	**20.88%**	

Act ID — Activity ID from PCS (ID:step -> 1:1 or 1:n)
P — PLAN date as for baseline PCS
F — FORECAST as for current PCS
A — ACTUAL date as for actual reporting

Relative Weight — based on BUDGET cost

Figure 2-13: Manufacturing & Delivery register

For all schedules, the “day” is the planning unit. The same unit is used to compute the progress got. Milestones are assigned a percent weight on the basis of the activities that characterize every phases: for Procurement Services and Subcontracts Services, the weight is proportional to the standard-man-hours quantity, for Manufacturing & Delivery, weight is associated to material cost. Partial endings or percentages are not allowed except in Manufacturing & Delivery where there is the possibility of managing big milestones in terms of expense or whose ex-works are remarkable. The weight is kept constant for all the project duration unless there is a modification in the work scope or an internal adjustment. Earned material requisitions are collected inside the PCS activities and are reported monthly (or weekly, if necessary) in order to compare the planned curves with the ones representing the actual situation. Even if control is applied to Level 4 schedules, the results for Level 4 control must be coherent with Level 3 milestones.

2.3.3 Construction

Construction phase in EPC projects is characterized by the management of the plant's physical erection. Construction is strongly influenced and bonded to Engineering and Procurement results and studies. Deliverables are unit installations and their connections through a pipeline network.

The geographical site where the plant is planned to be built is divided into areas (each covering 10% of the overall construction work). Every area has its Construction plan and, in its turn, it is divided into sub-areas to which a specific schedule is assigned.

Planning refers to Level 3 but follows Level 4 indications. The schedule is organized considering the work devoted to each plant item: this level of fragmentation allows, in the control phase, to have a view on all components and to guarantee accurate management of Construction critical paths. The Construction planning unit is the day, except for some particular activities: in this case, the hour unit is used.

To control the Construction phase, three forms, C1, C2 and C3 – differentiated for their level of detail – are used.

C1 is the form for the physical progress computation; it has the lowest level of detail. This form takes into consideration the percent of progress got for every discipline. C2 form considers the progress obtained by single planning groups dedicated to construction areas; it has an intermediate level of detail. C3 form has the highest level of detail and considers all the passages that bring to the single item/unit erection.

The approved progress control curves are the work baselines that cannot be subjected to any modification. All modifications must be overlapped on original curves to highlight any possible approved revision or change. During design development, in case Engineering quantities were subjected to considerable changes compared to the ones defined in the baseline, also the progress measurement system should be revised and updated in terms of relative weight (%): this is done using the same methodologies adopted for the computation of Construction standard-man-hours.

Here below, the concepts for the definition of progress measurement are described:

- each Construction planning group has its relative weight based on standard-man-hours, a percentage value given by the ratio between the estimated standard man-hours for completion of activities and the estimated standard-man-hours for the completion of the discipline to which it belongs;
- within any Construction planning group, each item has a relative weight, given by the ratio between the physical quantity attributed to it and the total physical quantity estimated for completion of the related Construction planning groups activity;
- progress of work steps is basically 0% – 100% based on the whole completion of work. For those work activities that follow a “linear progress step”, intermediate progress from 0% to 99% is applicable based on the amount of work completed versus total;
- the earned man-hours for each Construction planning group shall be aggregated to calculate the percentage of completion;
- standard direct-man-hours are evaluated in terms of costs according to Tecnimont standards;
- “earned man-hours” for each construction planning group are computed multiplying the initially planned man-hours with the progress percentage reached.

Even if control is applied to Level 4 schedules, the results for Level 4 control must be coherent with Level 3 milestones.

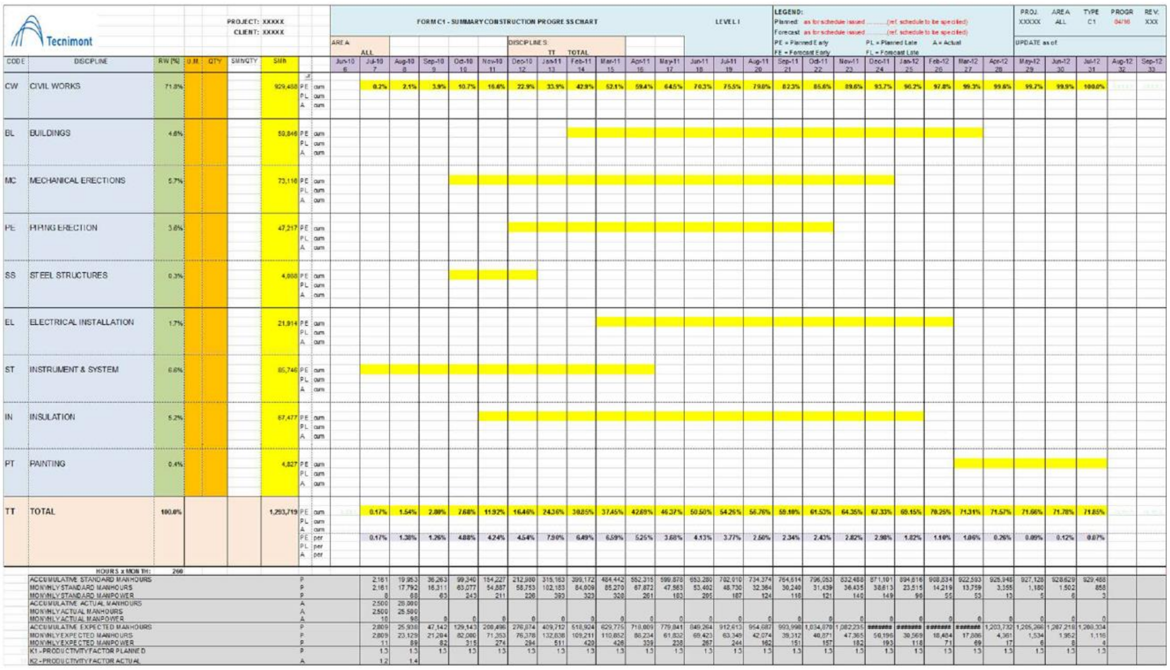

Figure 2-14: Construction progress chart – form "C1" by discipline

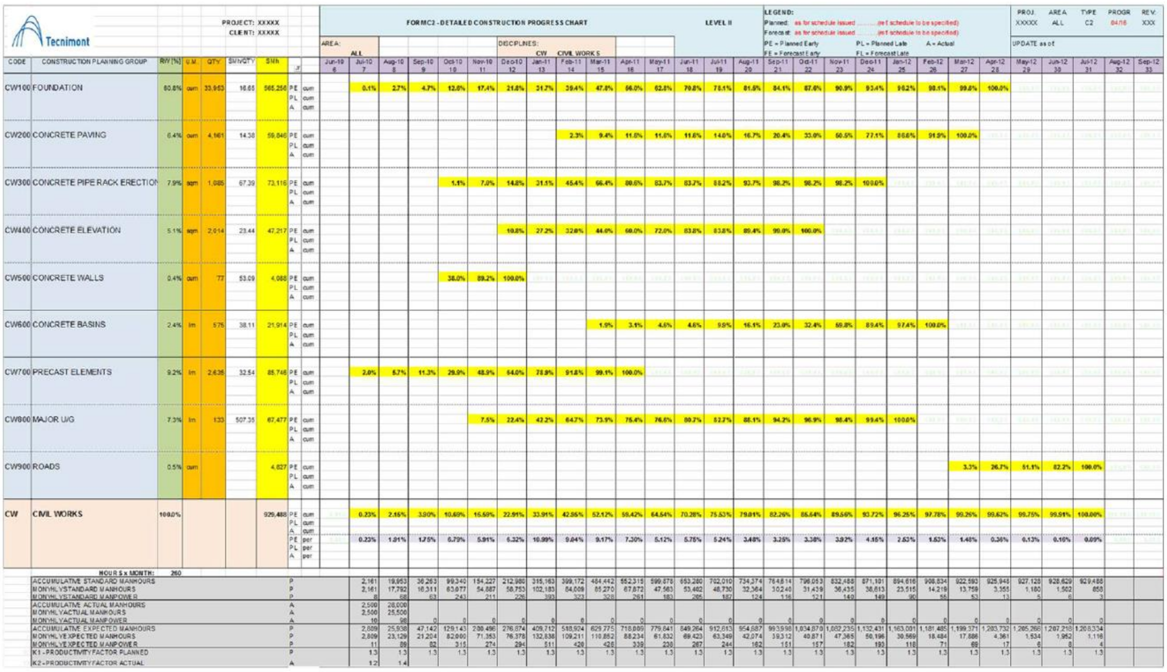

Figure 2-15: Construction progress chart – form "C2" by planning group

CONSTRUCTION PLANNING GROUP - C3 ITEM VIEW

Tecnimont
PROCO

DISC: BB - CIVIL WORK
PG: BB02 - EQUIPMENT CONCRETE FOUNDATIONS

05 Anchor Bolts / Plates
04 Formwork
03 Reinforcement
02 Lean Concrete
01 Excavation
06 Concrete Pouring
07 Formworks Stripping, Conc. Prot. & Backf

PROJECT : C3 SAMPLE PROJECT
RESPONSIBLE : TCM
Previous Cut Off : 23-Dec-13
Current Cut Off : 30-Dec-13

C3 Refer.	C3 Item ID (Tag)	P6 Activ ID	C3 Item Description	UM	Orig Estim	Best Estim	Equiv. Install	5	5	25	20	10	20	15	5			Weighting Factors	Weight %	Progress % Previous	Period	Current	Actual Dates Start	Finish	C3 Item Codes DWGS	S/C_ID	AREA	UNIT
1000	FDN-GT1000	BB-6150000	Gas Turbine Unit 1 - Main Foundation	CM	350	350	350	100	100	100	100	100	100	100	100			598,648	9.40	95.24	4.76	100.00	3-Sep-11	25-Nov-11	DWG-10	S/C1	A-10	UNIT1
1010	FDN-GT2000	BB-6150000	Gas Turbine Unit 1 - Auxiliaries Foundations	CM	150	150	150	100	100	100	100	100	100	100	100			256,564	4.03	95.24	4.76	100.00	15-Sep-11	25-Nov-11	DWG-10	S/C1	A-10	UNIT1
1020	FDN-GT3000	BB-6150010	Gas Turbine Unit 2 - Main Foundation	CM	350	350	350	100	100	100	100	100	100	100	100			598,648	9.40	95.24	4.76	100.00	29-Sep-11	7-Dec-11	DWG-10	S/C1	A-10	UNIT2
1030	FDN-GT4000	BB-6150010	Gas Turbine Unit 2 - Auxiliaries Foundations	CM	150	150	150	100	100	100	100	100	100	100	100			256,564	4.03	95.24	4.76	100.00	15-Oct-11	7-Dec-11	DWG-10	S/C1	A-10	UNIT2
1040	FND-HR30	BB-6400000	HRSG Unit 1 - Fondation	CM	350	600	600	100	100	100	100	100	100	100	100			1,140,812	17.92	95.24	4.76	100.00	3-Aug-11	14-Oct-11	DWG-10	S/C1	A-10	UNIT1
1050	FDN-HR40	BB-6400010	HRSG Unit 2 - Fondation	CM	500	600	600	100	100	100	100	100	100	100	100			1,140,812	17.92	95.24	4.76	100.00	19-Aug-11	15-Nov-11	DWG-10	S/C1	A-10	UNIT2
1060	FDN-TR1000	BB-6500000	TR01 - Transformer - Foundations	CM	400	400	381	100	100	100	100	100	100	100				665,210	10.45	78.74	16.49	95.24	2-Nov-11		DWG-20	S/C1	A-10	COMMON
1070	FDN-TR2000	BB-6500000	TR02 - Transformer - Foundations	CM	400	400	38	100	100									665,210	10.45	7.87	1.65	9.52	15-Nov-11		DWG-20	S/C1	A-10	COMMON
1080	FDN-P101	BB-6550000	F101 - Fuel Oil Forwarding Pump Foundation	CM	75	75	75	100	100	100	100	100	100	100	100			142,403	2.24	95.24	4.76	100.00	2-Nov-11	21-Dec-11	DWG-20	S/C1	A-20	COMMON
1090	FDN-P102	BB-6550000	F102 - Fuel Oil Forwarding Pump Foundation	CM	75	75	75	100	100	100	100	100	100	100	100			142,403	2.24	95.24	4.76	100.00	15-Nov-11	21-Dec-11	DWG-20	S/C1	A-20	COMMON
1100	FDN-P1000	BB-6600000	P1000 - CW Pumps Unit 1 Foundations	CM	120	120	62	100	100	100	90	10						190,003	2.98	45.11	6.32	51.43	2-Dec-11		DWG-20	S/C2	A-20	UNIT1
1110	FDN-P2000	BB-6600000	P2000 - CW Pumps Unit 1 Foundations	CM	120	120	6	100										190,003	2.98	4.01	0.75	4.76	10-Dec-11		DWG-20	S/C2	A-20	UNIT1
1120	FDN-P3000	BB-6600010	P3000 - CW Pumps Unit 2 Foundations	CM	120	120	10	100	70									190,003	2.98	6.01	2.08	8.10	22-Dec-11		DWG-20	S/C2	A-20	UNIT2
1130	FDN-P4000	BB-6600010	P4000 - CW Pumps Unit 2 Foundations	CM	120	120	6	100										190,003	2.98	2.51	2.26	4.76	23-Dec-11		DWG-20	S/C2	A-20	UNIT2
			TOTAL		3,280	3,630	2,852	100	93	81	80	78	78	78	67	0	0	6,367,286	100.00	74.74	5.43	80.17	Total % Progress					

- >> DATA TO BE FILLED IN BY SUBCONTRACTOR << -

CONSTRUCTION PLANNING GROUP - ACTIVITY VIEW

P6 Activ ID	P6 Activity Description	UM	Orig Estim	Best Estim	Equiv. Install	Progress by P6 Activity Work Step										Total Weighting Factors	Weight %	P6 Progress % Previous	Period	Current	P6 Actual Dates Start	Finish	P6 Activity Codes DWGS	S/C_ID	AREA	UNIT
BB-6150000	Gas Turbine Unit 1 - Foundation Construction	CM	500	500	500	100	100	100	100	100	100	100	100	0	0	855,212	13.43	95.24	4.76	100.00	3-Sep-11	25-Nov-11		S/C1	A-10	UNIT1
BB-6150010	Gas Turbine Unit 2 - Foundation Construction	CM	500	500	500	100	100	100	100	100	100	100	100	0	0	855,212	13.43	95.24	4.76	100.00	29-Sep-11	7-Dec-11		S/C1	A-10	UNIT2
BB-6400000	HRSG Unit 1 - Foundation Construction	CM	350	600	600	100	100	100	100	100	100	100	100	0	0	1,140,812	17.92	95.24	4.76	100.00	3-Aug-11	14-Oct-11		S/C1	A-10	UNIT1
BB-6400010	HRSG Unit 2 Foundation Construction	CM	500	600	600	100	100	100	100	100	100	100	100	0	0	1,140,812	17.92	95.24	4.76	100.00	19-Aug-11	15-Nov-11		S/C1	A-10	UNIT2
BB-6500000	Transformers Foundations	CM	800	800	419	100	100	50	50	50	50	50	0	0	0	1,330,420	20.89	43.31	9.07	52.38	2-Nov-11			S/C1	A-10	COMMON
BB-6550000	Fuel Oil Forwarding Pumps Foundations	CM	150	150	150	100	100	100	100	100	100	100	100	0	0	284,806	4.47	95.24	4.76	100.00	2-Nov-11			S/C1	A-20	COMMON
BB-6600000	CW Pumps Unit 1 Foundation Construction	CM	240	240	67	100	50	50	45	5	0	0	0	0	0	380,006	5.97	24.56	3.53	28.10	2-Dec-11			S/C2	A-20	UNIT1
BB-6600010	CW Pumps Unit 2 Foundation Construction	CM	240	240	15	100	35	0	0	0	0	0	0	0	0	380,006	5.97	4.26	2.17	6.43	22-Dec-11			S/C2	A-20	UNIT2
	CONSTRUCTION PLANNING GROUP TOTAL BY P6 ACTIVITY	CM	3,280	3,630	2,852	100	93	81	80	78	78	78	67	0	0	6,367,286	100.00	74.74	5.43	80.17	Total % Progress					

- > EQUAL TO TCM SMh

CONSTRUCTION PLANNING GROUP - DRAWING VIEW

Dwg ID	Drawing Description	UM	Orig Estim	Best Estim	Equiv. Install	Progress by P6 Activity Work Step	Total Weighting Factors	Weight %	P6 Progress % Previous	Period	Current	P6 Actual Dates Start	Finish	P6 Activity Codes DWGS	SUB_ID	AREA	UNIT
DWG-10		CM	1,850	2,200	2,200		3,992,048	62.70	95.24	4.76	100.00	3-Aug-11	7-Dec-11	DWG-10			
DWG-20		CM	1,430	1,430	652		2,375,238	37.30	40.29	6.56	46.85	2-Nov-11		DWG-20			
	TOTAL	CM	3,280	3,630	2,852		6,367,286	100.00	74.74	5.43	80.17						

CONSTRUCTION PLANNING GROUP - S/C VIEW

S/C ID	Drawing Description	UM	Orig Estim	Best Estim	Equiv. Install	Progress by P6 Activity Work Step	Total Weighting Factors	Weight %	P6 Progress % Previous	Period	Current	P6 Actual Dates Start	Finish	P6 Activity Codes DWGS	SUB_ID	AREA	UNIT
S/C1		CM	2,800	3,150	2,769		5,607,274	88.06	82.92	5.78	88.70	3-Aug-11			S/C1		
S/C2		CM	480	480	83		760,012	11.94	14.41	2.85	17.26	2-Dec-11			S/C2		
	TOTAL	CM	3,280	3,630	2,852		6,367,286	100.00	74.74	5.43	80.17						

CONSTRUCTION PLANNING GROUP - AREA VIEW

S/C ID	Drawing Description	UM	Orig Estim	Best Estim	Equiv. Install	Progress by P6 Activity Work Step	Total Weighting Factors	Weight %	P6 Progress % Previous	Period	Current	P6 Actual Dates Start	Finish	P6 Activity Codes DWGS	SUB_ID	AREA	UNIT
A-10		CM	2,650	3,000	2,619		5,322,468	83.59	82.26	5.84	88.10	3-Aug-11				A-10	
A-20		CM	630	630	233		1,044,818	16.41	36.44	3.37	39.82	2-Nov-11				A-20	
	TOTAL	CM	3,280	3,630	2,852		6,367,286	100.00	74.74	5.43	80.17						

Figure 2-16: Construction control sheet– form "C3" by items and multiple views

3 R&D projects: definition, state of the art and control process proposal

Chapter 3 is devoted to R&D projects; their definition, which is functional to the present discussion purposes, is provided and their characteristics are described. Successively, it is given an overview of current R&D management methods and frameworks: their description is aimed at providing some elements that will be used in the formulation of the new control process.

3.1 A definition for Tecnimont R&D projects

Research and Development projects are coherent with the definition of a project (namely, they are unique, temporary and multidisciplinary) that produces a result that is not obsolete. This kind of project can be extended to any field (chemical, fashion, medical industry, etc.), so it is complex to provide a univocal definition. Moreover: whenever it was possible to provide a definition for a peculiar thematic area, R&D projects could not be qualified precisely. Let's think about the chemical sector: an R&D project can be a laboratory research for the kinematic characterization of a reaction, the study of a new competitive process or an optimization analysis of a product or process.

In order to propose an adequate process to control the R&D projects carried out in Tecnimont, it is necessary to limit the numerous interpretations that can be provided. Without any pretension of generality, from now on (unless otherwise specified) R&D projects will be meant as the ones aiming at validating a new process and verifying its applicability on an industrial scale. Such validation, in the lack of previous successful examples and applications, can require the construction of a laboratory-scale pilot plant and the execution of experimental campaigns.

3.2 R&D project characteristics

R&D projects are consistent with all projects' characteristics listed in par. 1.1 but their uncertainties and risks are magnified. This is due to the fact that there are no previous technological references for plant construction as well as some scientific and/or technological information could be missing. In this case, project management systematization should not be intended as an antithesis: the fact that R&D projects are carried out with a certain “creativity”, making some non-conventional choices, does not mean that they cannot be coordinated or, more generally, managed: citing Wingate [9], an R&D project is like a piece of art whose creative passages cannot be defined a priori but, if the canvas is not stretched and primed, this has a considerable effect on the probability of completing successfully the artwork. By the way, some constraints or problems can be observed and faced only during the project itself.

R&D projects are profoundly different with respect to FEED and EPC’s: they have different objectives and are not comparable process and plant sides. The purpose of R&D project is research; EPCs are aimed at production.

As already mentioned, the possible lack of historical data and solid technical background, as well as the potential lack of proven technical solutions, increases the project managerial complexity [9]. Other factors to be considered are the difficulties in estimating the duration of activities and that the project could, potentially, not reaching its objectives: if the experimental apparatus does not work properly, tests could provide ambiguous results that cannot be used to validate the technology.

In addition to all these problems, the choice of constructing a pilot plant introduces other issues.

In general, the features of a pilot plant are different from those of an industrial plant. Technical solutions implemented are different from those adopted on the industrial scale: this is the direct consequence of the different scale between a pilot and an industrial plant [23]. Moreover, chemical and physical phenomena can vary according to the characteristic dimensions of the item analyzed. The pilot should be also designed to be flexible: in this way it can work at different operative conditions and the entire experimental domain can be explored by modifying the plant equipment. The project success is represented by the possibility of stating, with no residual doubts, that the technology is replicable on an industrial scale.

Although the pilot construction introduces additional problems with respect to an industrial plant construction, it is a necessary step for technology validation and it is preparatory for a successive transfer of the technology – once validated – on a larger (industrial) scale. A small-scale pilot plant turns into relatively small capital investment, in principle lower than the one required for the industrial scale. This limits the possible economic losses occurring in case the technology cannot be validated.

3.3 Management of R&D projects: state of the art review

Historical developments of the last years of 1900 (see par 1.2.1) showed the need to develop methods and frameworks that could better adapt to new projects' characteristics. Up to that moment, the waterfall method was adopted: each requirement was defined at the beginning of the project and activities were performed through a sequential project plan.

The flexibility of the waterfall method was so low that it resulted in not being adequate for fields where innovation and R&D projects were – and still are – very common. Due to these reasons, *flexible methods* and *framework* – originally born for the management of software – started spreading. The concept behind these new tools is that the traditional management approach does not suite the level of ambiguity, risk and experience related to these innovative projects.

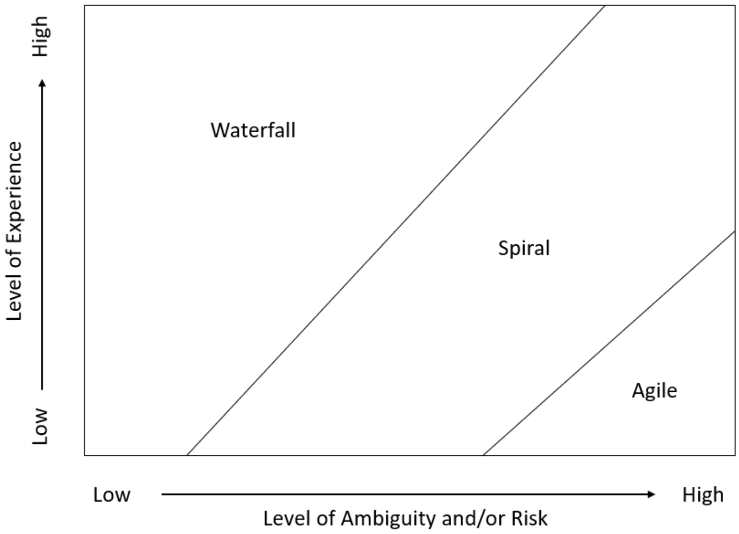

Figure 3-1: Method to use according to level of experience, ambiguity and risk (adapted from Wingate, 2004)

Fig. 3-1 shows that the waterfall method is the best approach when it is dealt with projects whose requirements are well expressed and in which experience is gained. If the level of ambiguity and risk increases – while experience decreases – the adoption of flexible methods and frameworks appears more appropriate [9].

According to the literature [10], [20], [21]–[28], [29], [30], nowadays, flexible methods are still used for software mainly.

3.3.1 Flexible Methods

Flexible methods suggest a systematic approach to the management of R&D projects. Although there are many flexible methods, the ones that are best known in the software area are the Spiral Development and the Agile Method. The aforementioned methods represent the starting point for the flexible frameworks that will be described in par. 3.3.2.

Spiral Development

The *Spiral Development* is a cyclic approach in which each iteration is meant to add value to the previous version of the product. It is an approach that provides many opportunities to add requirements along the way [9]. The method is divided into four phases: a preliminary analysis, a risk evaluation, the development and the planning of the successive iteration. Each iteration is called *spiral*.

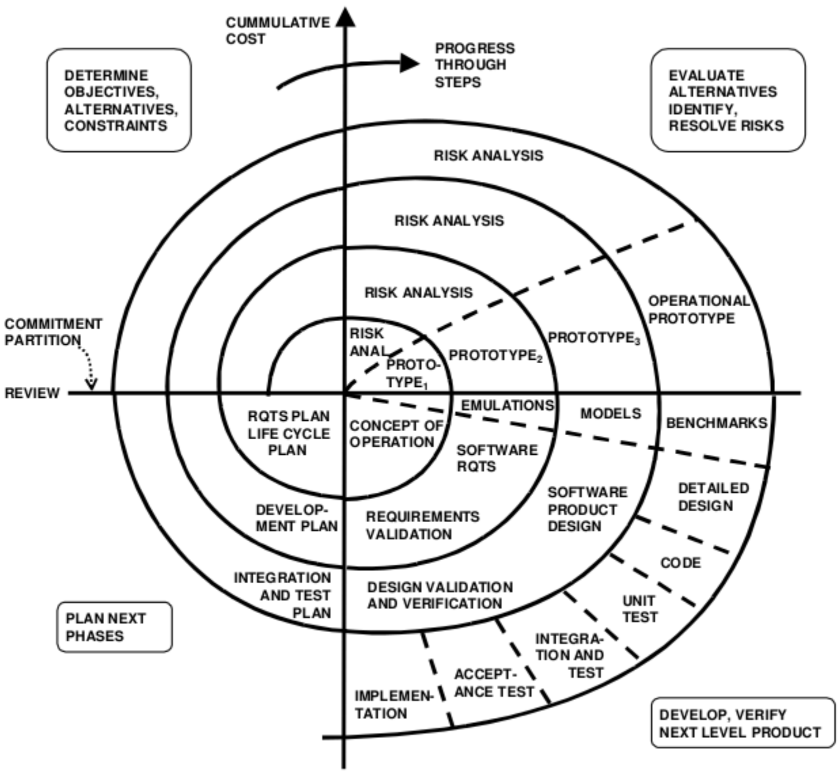

Figure 3-2: Graphical representation of Spiral Development Method [35]

In the analysis phase, project objectives and constraints are identified. The risk evaluation is done in the second phase: risk is assessed and corrective actions are planned. Once the second phase is concluded, it is decided how to execute the project activities; this means that it has to be decided which project management tools better suits the project. This phase includes also the product testing phase. Finally, the fourth phase includes the revision of previous passages: the presence of problems and anomalies will be managed in the next iteration. This method allows to have better control of risk in the project; additionally, thanks to iteration, it allows the incremental product design based on requirements or constraints that can be more evident only by going on with the project. Other methods derive from Spiral and have similar characteristics. Some examples are the Rapid Application Development, the Adaptive Software Development, the Evolutionary Project Management and the Feature-Driven Development [9]. Deriving from Spiral Development, they have similar features and, for this reason, they will not be dealt with here.

Agile Method

The *Agile Method* refers to a method of structuring work in a way that achieves outcomes quickly and approaches the resolution of the most difficult challenges early in the development process [9]. The method adds value as soon as possible: rather than treating complex systems by providing lengthy-time slots to solve them, the problems that are expected to be most complex are analyzed first. In this way, more challenging requirements are prioritized. Wingate observes that this property is what makes this method appealing for R&D projects. The method appears similar to the Spiral Development, but there are few differences: the planning phase is done in advance in order to understand which activities are to perform first and every iteration (called *sprint*) is related to different activities.

Estimates of time and – consequently – costs, are done considering how the accuracy of an estimate is related to the effort sustained to produce that estimate. The relation between the accuracy and effort is represented in Fig. 3-3 [24].

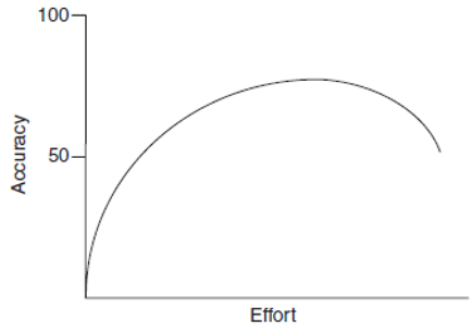

Figure 3-3: Additional estimation effort yields vs added value

Applying 10% of the effort 50% of the potential accuracy is got. Finally, it is noticed that eventually, the accuracy of the estimate declines. Estimates are made by teams adopting, mainly, three types of techniques, namely expert opinion, analogy and disaggregation of the activity into more easily quantifiable ones.

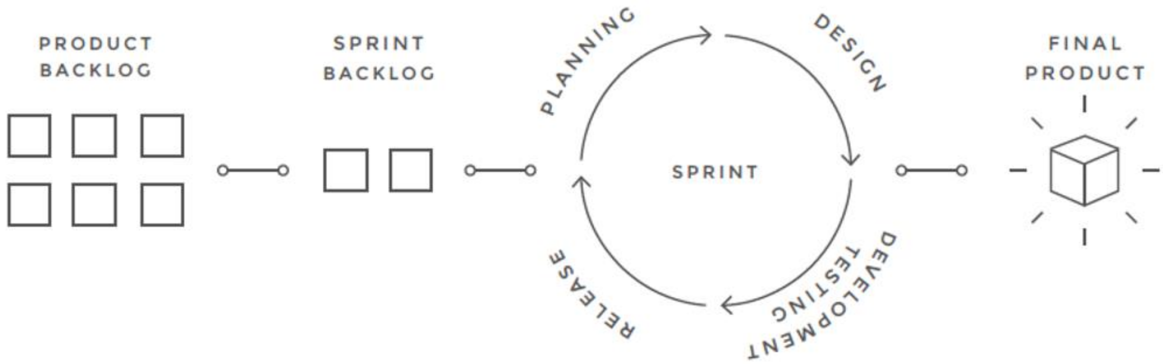

Figure 3-4: Graphical representation of Agile Method [36]

Once the phases of overall planning and estimate are concluded and product backlogs are individuated, sprints are performed. In each sprint it is present a planning and a design phase in which the activity is deeply characterized. Then it follows the developing and testing phase and the release of the first version of the product.

Other methods deriving from Agile (Extreme Programming, The Crystal Family) are based on twelve principles that are listed in the Agile Manifesto [10]:

1. The highest priority is to satisfy the customer through early and continuous delivery of valuable software;

2. Requirement changes are welcomed, even late in development. Agile processes harness change for the customer's competitive advantage;
3. Software are delivered frequently, from a couple of weeks to a couple of months, with a preference to the shorter timescale;
4. Business people and developers must work together daily throughout the project;
5. Project must be built around motivated individuals. They should be given the environment and support they need, and be trusted to get the job done;
6. The most efficient and effective method of conveying information to and within a development team is face-to-face conversation;
7. Working software is the primary measure of progress;
8. Agile processes promote sustainable development. The sponsors, developers, and users should be able to maintain a constant pace indefinitely;
9. Continuous attention to technical excellence and good design enhances agility;
10. Simplicity is essential;
11. The best architectures, requirements, and designs emerge from self-organizing teams;
12. At regular intervals, the team reflects on how to become more effective, then tunes and adjusts its behavior accordingly.

3.3.2 Flexible Framework

Flexible management frameworks are guidelines for project management [9]; for this reason, they are not prescriptive (differently from the PMBOK and from flexible methods before described [27]) and have to be adapted on the type of project that is carried out. Many frameworks refer to flexible methods: here only the ones that consistently influenced project management techniques [9] in the last two decades – and that do not belong to the manufacturing field – will be discussed. Among these flexible frameworks, Scrum, Unified Process and Dynamic System Development Method are the most important and representative. The main characteristics shared by all the flexible frameworks are iteration for control and planning, product features testing and fast changes implementation.

Scrum

Scrum is one of the most adopted flexible framework [28] and it is inspired by a Hirotaka Takeuchi and Ikujiro Nonaka's article published in 1968 [25], [28]. Its name is not an acronym but recalls the world of rugby where the word "scrum" identifies the movement of a team that, aggregating, arranges itself in a circle to catch the ball [29]. The sportive metaphor well represents the concepts of the framework: the components of the project team – to which is assigned a lot of importance – work together to reach the project objectives.

Scrum system includes, firstly, a planning phase that embraces a timespan that is extended until the forecasted project completion date. Although this approach does not guarantee a high level of detail for the planning of all project phases (because some requirements and constraints are learnt during the project itself), it allows to have a general overview: this eases the fragmentation of activities work units called sprints. WBS, due to its intrinsic nature (par. 2.1.1), is also used in Scrum [26], [27].

Sprints are inserted in a product backlog (i.e. the list of activities to be completed) and prioritized. Every project team deals with a single sprint at a time to which it is devoted a timespan between one and four weeks [25]. Daily meetings are programmed among the team members – they typically last fifteen minutes [26] – and the daily agenda is defined: during meetings, it is possible to discuss potential problems that occurred the day before. When the sprint iterative cycle is concluded, revisions and tests are performed to learn about some problems and/or deviations concerning the forecasted plan; if there is the need to implement some modifications, they will be included in the scope of the successive sprint.

The Scrum framework does not use Gantt charts but the Burndown (Fig. 3-7). *Burndown charts* are diagrams that compare the planned progress trends with the actual ones. The progress is tracked by ascertaining that the sprint activities are concluded. Burndown charts can be traced with the aid of software such as Microsoft Project [25] and Primavera [26].

Time and costs estimates, which represent the project reference, are produced in the same way as in Agile methodology (par. 3.3.1). Using Scrum, it is also possible to make forecasts: after the completion of a sprint, the speed through which the team performed their tasks can be measured. Speed records are the parameters that are used to compute the progress extent [26].

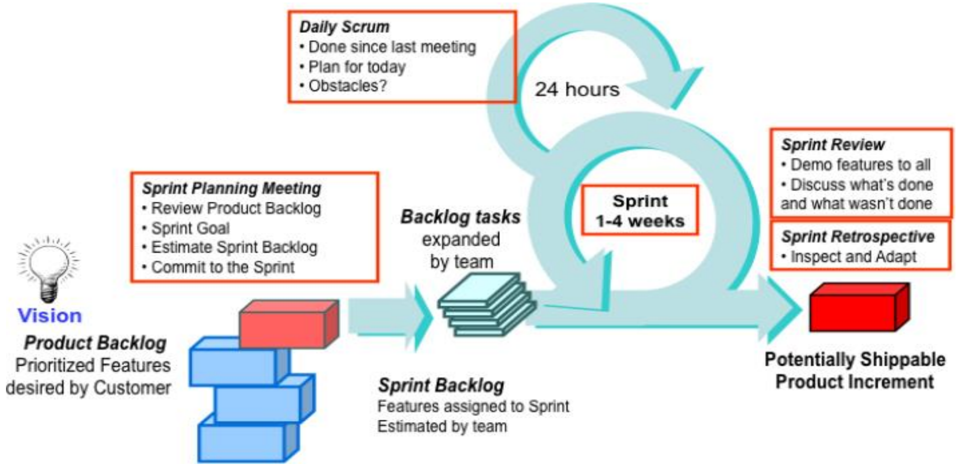

Figure 3-5: Graphical representation of Scrum framework [25]

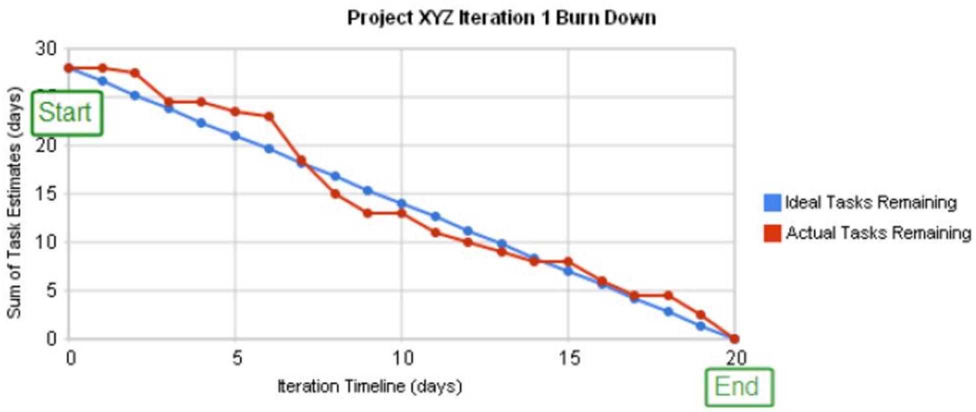

Figure 3-6: Example of Burndown chart [25]

Although Scrum proposes the study of the team velocity, the adoption of this metric is not necessarily exclusive. There is, indeed, no limitation related to other metrics application. For example, the Earned Value Method can be used: Faris and Abdelshafi [26] confirm this by asserting that the contamination of flexible frameworks with traditional project management techniques is the way to follow.

Rational Unified Process

Rational Unified Process (RUP®) is a framework born for software production. RUP® is based on the following hypotheses [31]:

- project requirements become clearer only during the project;

- risks should be detected as soon as possible in order to manage them in the project early stages;
- product quality must be verified with some tests;
- processes iteration favours risks mitigation and the refinement of project requirements.

RUP® is made of four main phases – inception, elaboration, construction, transition – and each of them has its iteration.

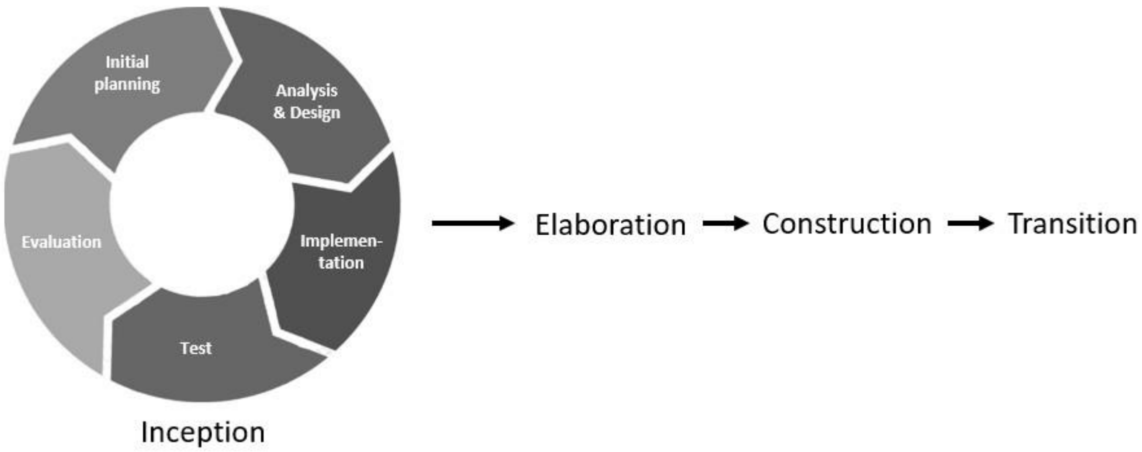

Figure 3-7: Graphical representation of RUP®

In the Inception phase, a first planning is done. Project objectives are highlighted as well as risks and acceptance criteria; these evaluations are also made considering stakeholders' demands. RUP® employs a rolling wave approach to project planning [31].
Elaboration is the moment of the project when the product architecture is designed. The outputs of this phase are the identification of all the people taking part in the project and the completion of prototypes that are preparatory to the Construction phase. Risks, after the Elaboration phase, are more detailed.
In the Construction phase, all the remaining components and project characteristics are developed, integrated and tested [30]. Since also this phase is characterized by iteration, risks can be more easily mitigated and possible defects can be corrected to reach the quality standards set [31].

Finally, during Transition, the product has reached a level of maturity for which it can be distributed among the user: there is, so, a commercial passage where marketing and manufacturing activities are performed [31].

Dynamic System Development Method

Dynamic System Development Method (DSDM) is a framework that spread during the 80s [9], [28]. The fundamental idea that underlies the framework is modelling product characteristics according to resources and times already established [28].
Applying the DSDM, the project phases reported are the following [9], [28], [30]:

- Feasibility study: it has the objective of verifying if the project can be carried out which are the associated risks. In addition, it is also evaluated the DSDM applicability; this usually takes a few weeks [28];
- Business study: it is a study used to identify who could be the potential user of the project product and to understand if the product market could be profitable. These considerations are usually done in workshop sessions among experts [30]. These sessions allow to understand which are the business priorities;
- Functional model iteration: in this first phase, prototypes are built in order to satisfy business priorities. Prototypes construction is iterative and in continuous evolution. Construction can be represented as a cycle that includes a first product identification (in accordance with modalities and times associated), a second phase for the product production and finally a revision and control of the product. The product incrementally acquires its functionality: priorities satisfaction is obtained by iteration;
- Design and build iteration: in this phase, the theoretical model is realized physically and tested;
- Implementation: the transition from the development environment to the production one occurs.

The feasibility study and the business study are sequential passages; the remaining phases are iterative and incremental.

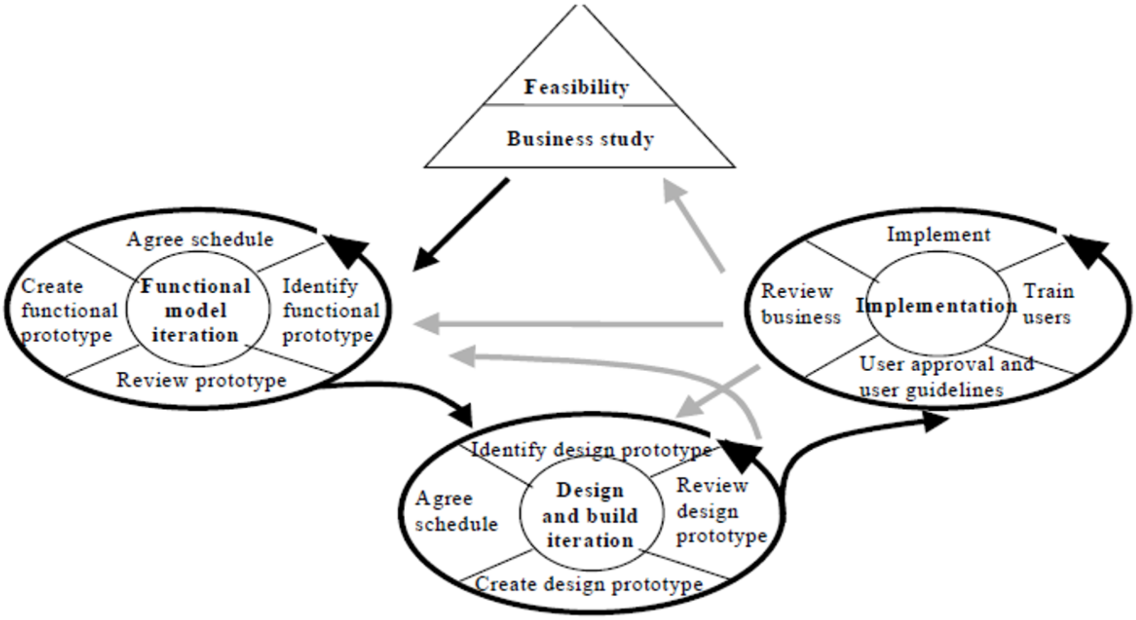

Figure 3-8: Graphical representation of DSDM [37]

3.4 Control process proposal for R&D projects

Getting back to the definitions and concepts already discussed in par. 1.2.3, project control is carried out by the comparison of the real-time and costs trends with respect to the planned one. The objective of control is detecting possible creeps and applying, if needed, corrective actions to minimize any negative impact that deviations would produce.

Since R&D projects are characterized by a high uncertainty (for what concerns technical feasibility, activities planning and the project results), the control process should provide information that doesn't add ambiguity and that can be functional for the project decisional phases. As described in chapter 2, Tecnimont adopts the Earned Value metrics. In the case of R&D projects, if control is carried out as simple comparison of economic parameters such as BCWS, BCWP and ACWP, this would result in being quite fruitless: it would bring to the straightforward observation of the presumed progress without giving any other useful element for the implementation of corrective measures.

In the present paragraph, it is presented a possible solution for the problem of controlling R&D projects; it does not imply the adoption of new metrics but the use of a process that includes a new planning strategy combining risk analysis. Modifying how the baseline is

built enables reference values to be more “eloquent” and more expendable: in fact, reference values to which comparing the progress are used in any metric.
Studying the control techniques that are adopted by Company, no evidence suggests avoiding the application of EVM also to R&D projects. It is believed, though, that the main problem for R&D projects control has not to be found in the metric chosen but in the baseline construction, whose planned times and costs can be a valid reference for project control purposes.

In Tecnimont the baseline is built up using CPM (chap. 2): the problem of CPM approach is that the critical path is traced on the basis of the most accurate estimate of times and costs related to activities. For R&D projects, even if it is known which activity will have to be performed, it is not possible to remove the uncertainty related to activities time and cost estimates: this is due because of the lack of previous references. For this reason, in the process proposal presented in this chapter, the CPM is combined with some considerations about activities precedences and priority. The order according to which activities should start finds its theoretical roots in the *Critical Chain Method* (CCM) and in the study of the so-called flexible methods and frameworks (par. 3.3.1 and 3.3.2).

CCM is based on Goldratt’s Theory of Constraints that puts the focus on how fundamental is managing project constraints. According to this theory, the constraint must be first identified, exploited, everything must be referred to it and then it has to be elevated [18]. Exploiting the constraint means eliminating it also in face of incurring in additional costs: this expenditure can be interpreted as the price for getting more certainty. Subordinating everything to the constraint means creating the conditions for the problematic activity to be performed in the best way. Finally, elevating the constraint means eliminating it increasing the work capacity of the means employed in performing the task.
In this case, constraints are interpreted as the milestones that are characterized by a high level of uncertainty and risk. Once detected these milestones, they must be prioritized: to do that, it is proposed the adoption of a qualitative risk analysis (par. 3.4.1) – carried out in the planning phase – where the magnitude and the probability related to adverse events belonging to milestones is expressed in economic terms. According to the results obtained, the milestone execution is ordered by the worst economic damage. Risk analysis formalization not only is an objective criterion for the choice of the activities execution, but

also helps the Project Manager and their team to identify, preventively, possible solutions and alternatives for the adverse events predicted in the risk analysis.

Fig. 3-9 displays the control process proposal for R&D projects.

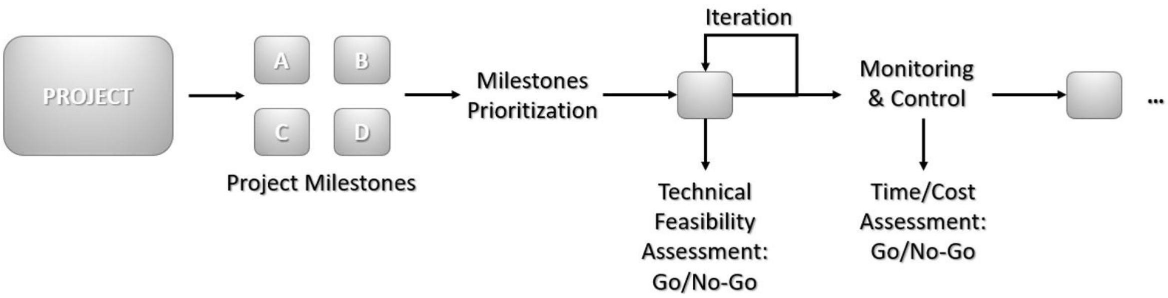

Figure 3-9: New control process proposal

Iterations, a typical trait of flexible methods and frameworks [34], are planned for each milestone. Iteration does not have to be considered as a buffer that mitigates delays related to activities completion: it is a very part of the process and can itself be subjected to delays. Iteration allows the application modifications and improvements in face of new knowledge elements acquired during the project. In this phase some tests can be done in order to verify the stability and the suitability of the installed units: the rapid problem detection allows to avoid – at the end of the project – extra costs incurred for understanding where the plant problem is and how the technical anomaly displays. Moreover, omitting tests and the verification of the functionality of components can cause the error propagation in the sequent phases of the construction; hence, above all in a plant construction context, unit specifications and functioning strongly affects the design of linked equipment.

Times and costs estimates for milestones are produced by analogy – when possible – through the bottom-up approach and, in case of innovative elements, consulting experts who belong to the same technical field. Estimates follow a conservative approach. Times and costs for the iteration are considered equal to the times and costs possibly incurred in the most pessimistic scenario, i.e. the occurrence of the maximum Gross Risk Expected Value related to the milestone with the highest Gross Risk Expected Value (see par. 3.4.1).

Once the iteration phase is concluded, it is possible to asses the milestone technical feasibility. The Project Manager will be facing the first "Go/No-Go" gate: in case of failure in the activity completion, it will be possible to abandon the project; in case of technical feasibility – after monitoring and controlling– it is possible to compare time and costs trends. Known the results from control, the Project Manager will evaluate if continuing the project. This evaluation and its successive decisions are supported by the logic thanks to which the baseline was originally built: for example, if the first milestone completion considerably overcomes the costs and times forecasted and, following, there are other milestones characterized by high uncertainty, it could be reasonable to abandon the project. Furthermore, abandoning the project before its overall completion would occur with a higher probability in the project's early phases because it is planned that the most uncertain milestones are executed first. This approach prevents the dangerous uncertainties from dragging up to the final phases of the project and eliminates the possibility of incurring in avoidable costs before understanding that the project is not technically and/or economically feasible.

It is suggested to re-plan the schedule when a milestone is completed: the pieces of information that emerged during the activities execution can be useful. This approach is coherent with the adoption of the Rolling Wave Work Breakdown Structure, an iterative planning technique in which the work to be accomplished in the near term is planned in detail, while the future work is planned at a higher level [1].
The planning method just described is inserted in the control process as shown in Fig. 3-10.

As it is possible to observe from the diagrams reported below (Fig. 3-11, Fig. 3-12, Fig. 3-13, Fig. 3-14), the present control process proposal is different from the processes used in Tecnimont. Differences are found in the presence of prioritization by performing a risk analysis and in the presence of “Go/No-Go” gates. As EVM (chapter 2) is a valid method for controlling the project, there is no difference in what concerns metric choice.

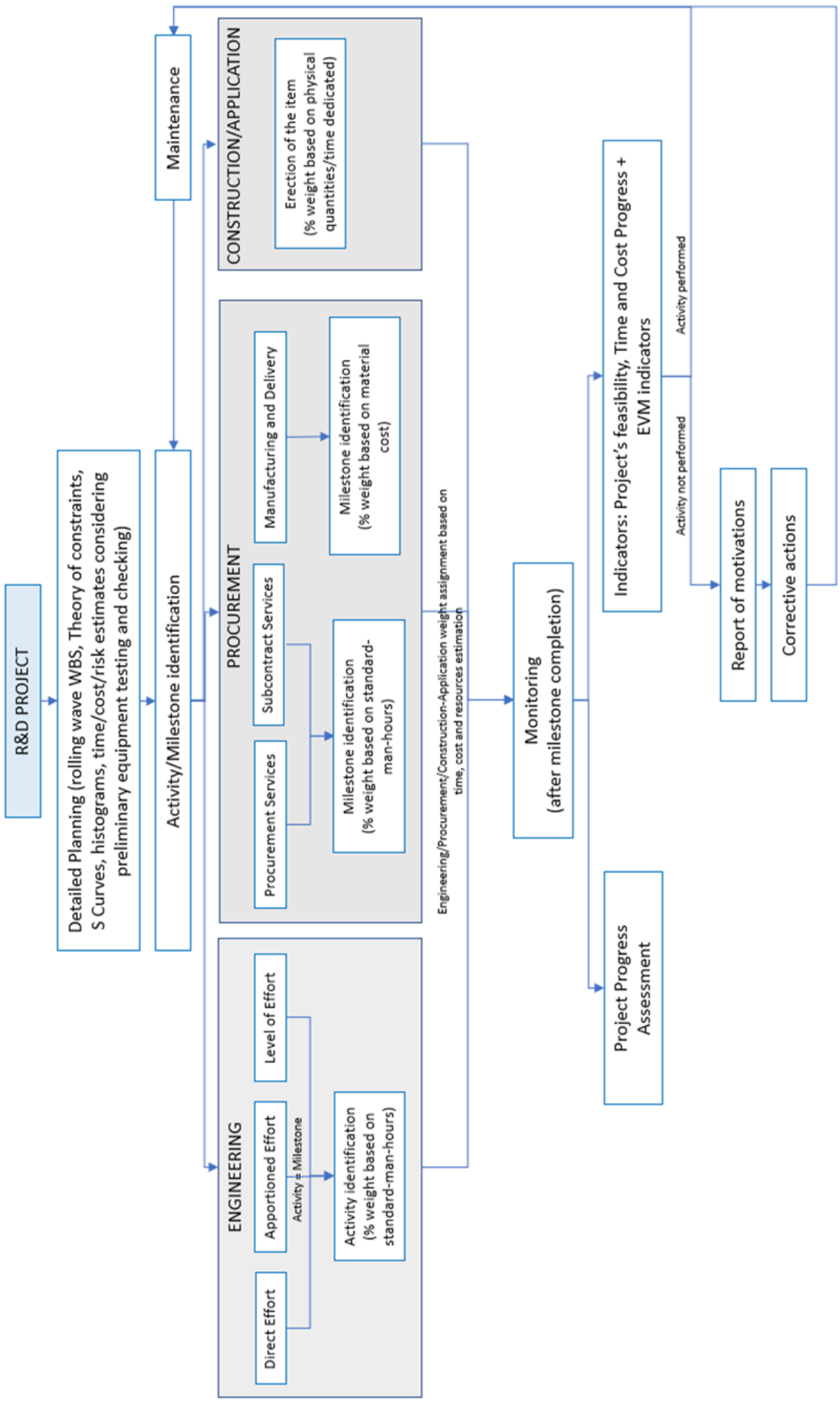

Figure 3-10: New control process diagram

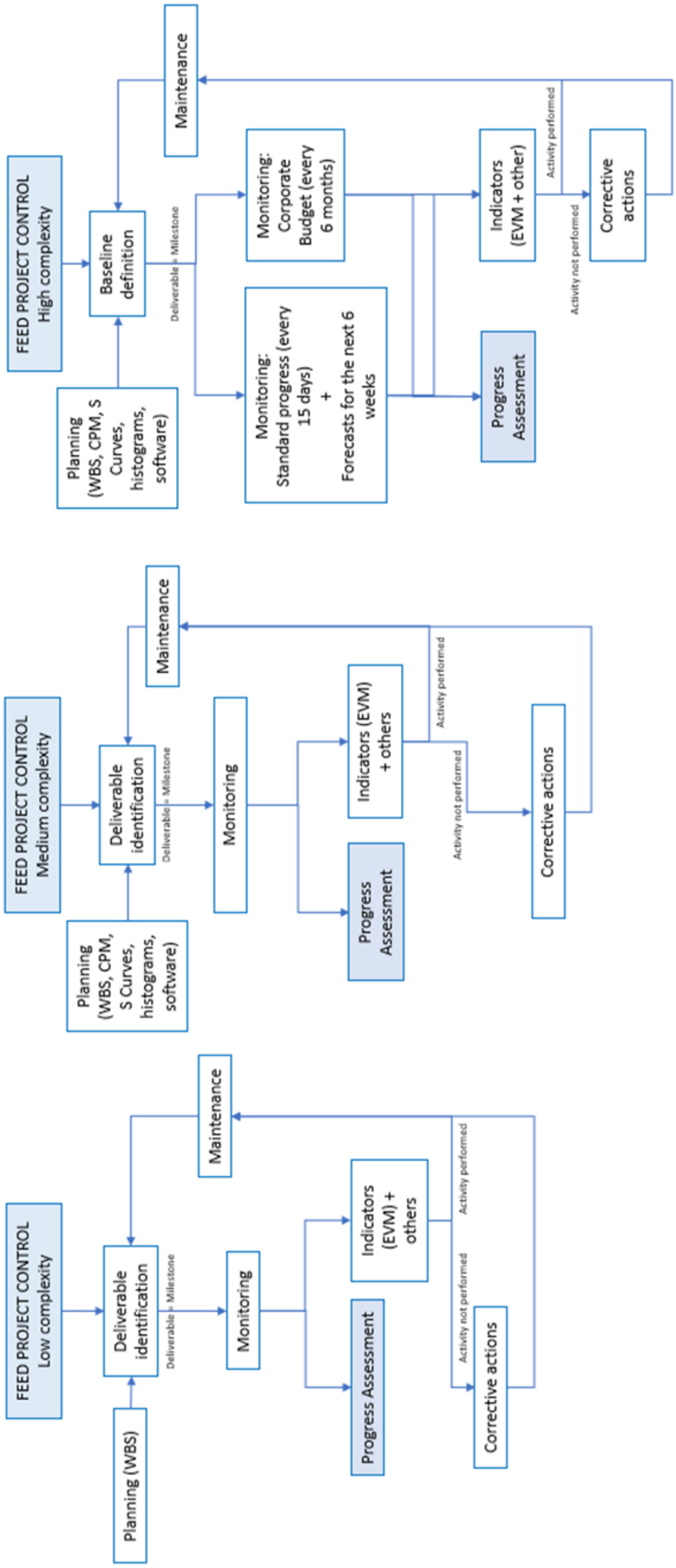

Figure 3-11: FEED control process diagrams

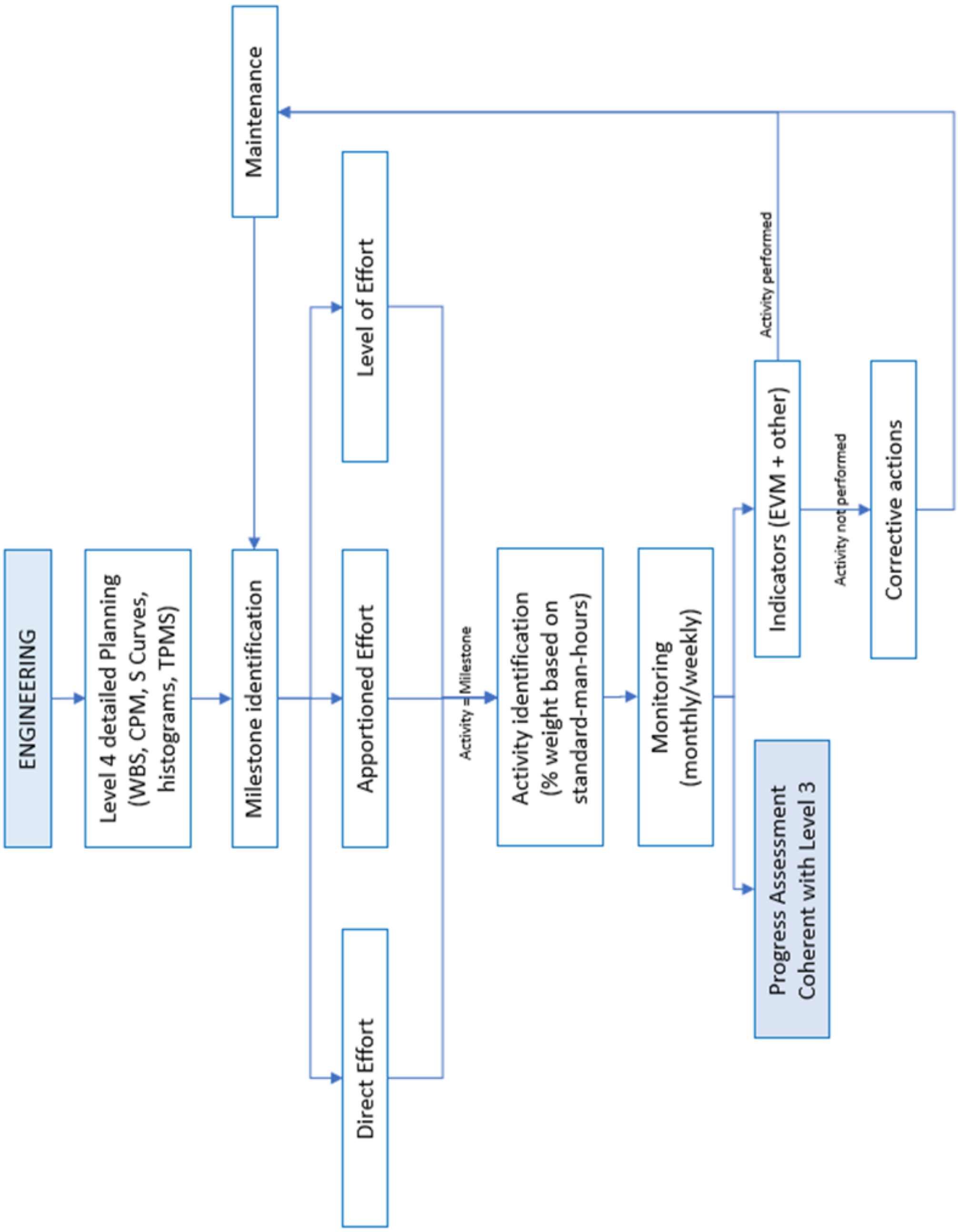

Figure 3-12: Engineering control process diagram

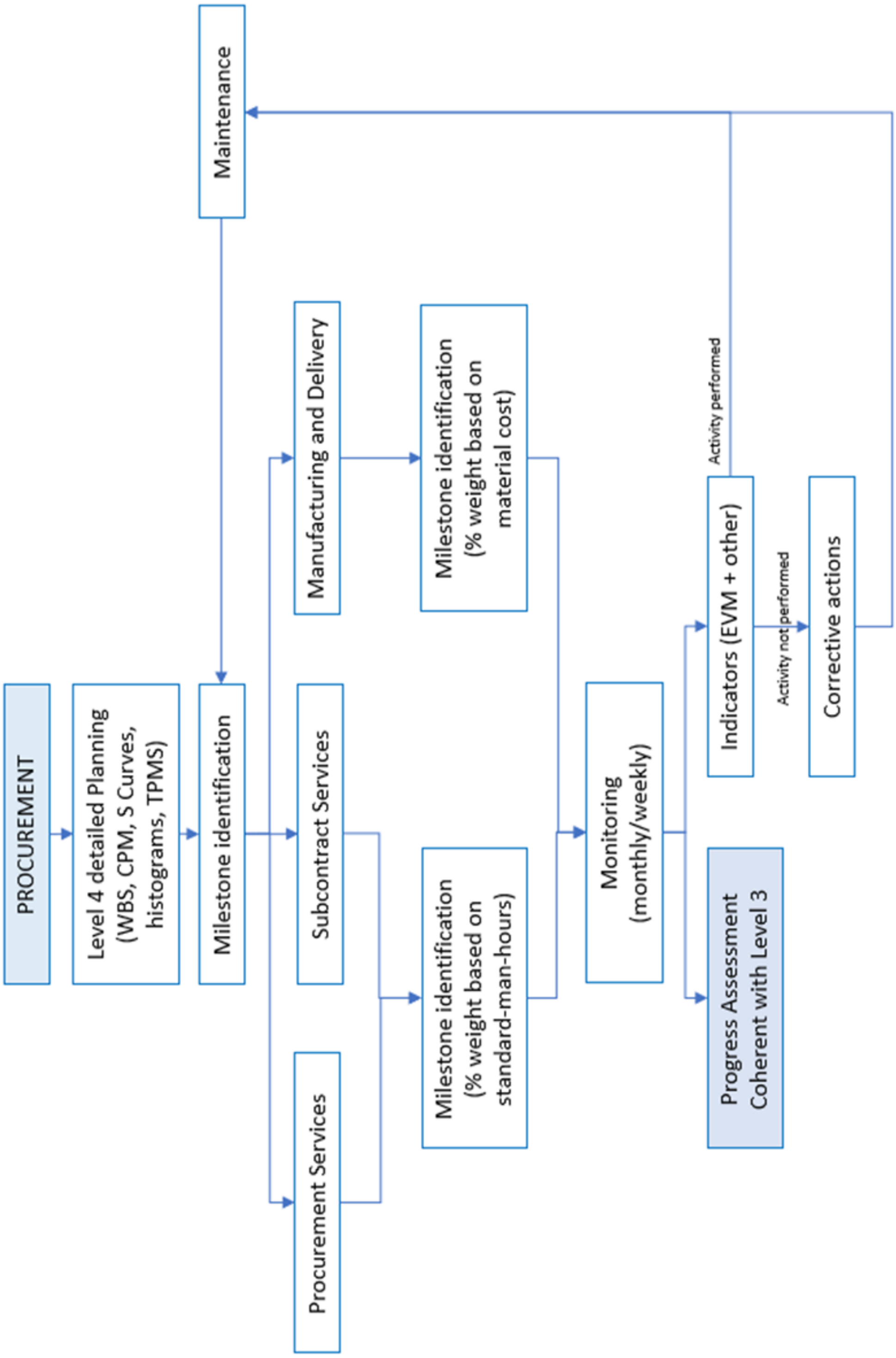

Figure 3-13: Procurement control process diagram

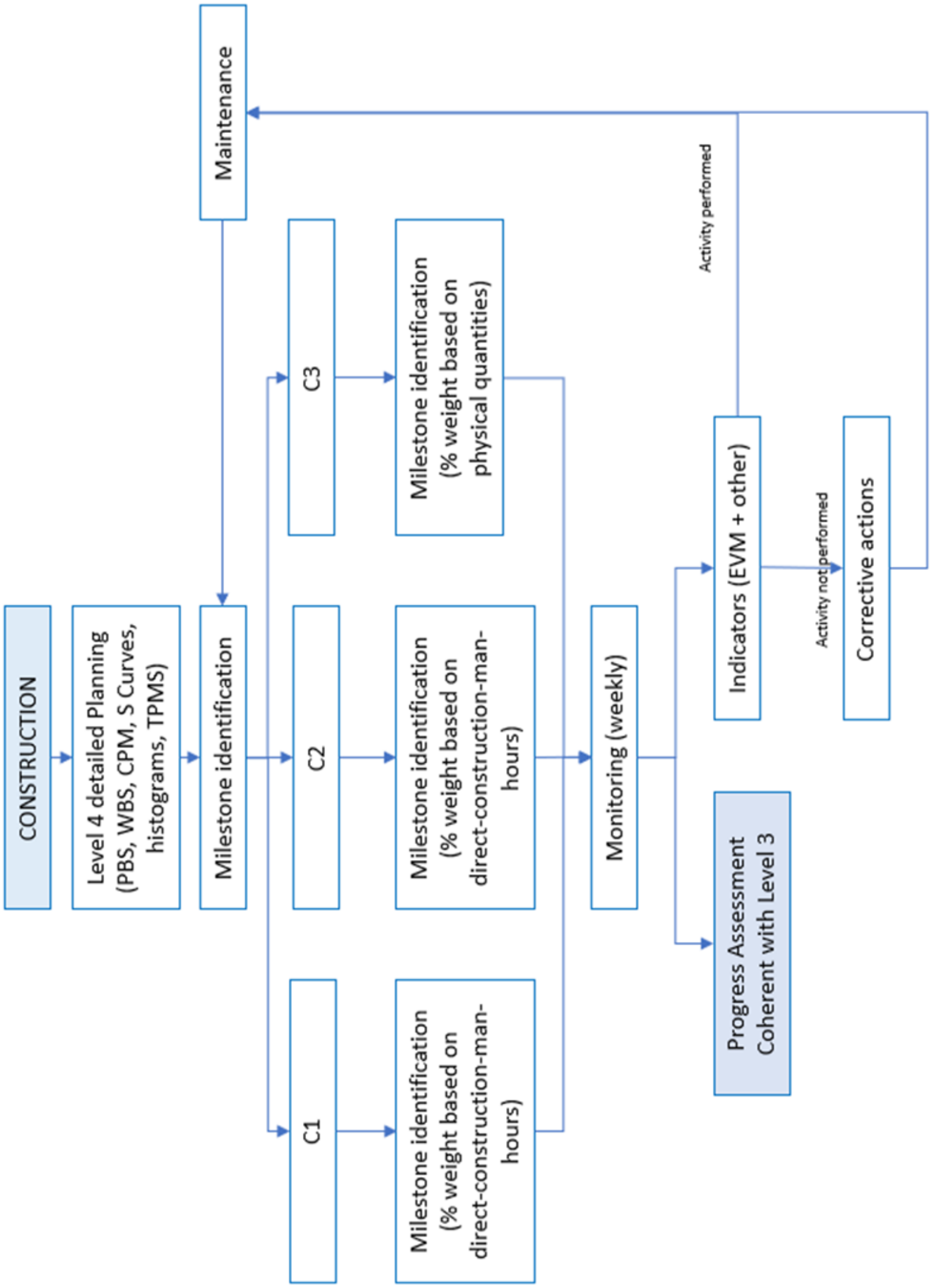

Figure 3-14: Construction control process diagram

3.4.1 Risk analysis: an original application to planning

Risk analysis is a tool that allows the quantification of risks and opportunities that have been individuated with the Risk Breakdown Structure. Thanks to this analysis, the Company verifies if the allocated contingencies cover the project risks.

The idea, already presented in par. 3.4, is to employ risk analysis as an objective tool to prioritize the milestones to be performed. To fulfil this objective, it is proposed to use Tecnimont risk analysis methodology, applying – whenever needed – modifications that better suit R&D projects' characteristics.

Risk analysis identifies in a detailed way risks and principal control strategies related to the project. Risk identification is mainly performed by the risk owner (in this case the project manager) on the basis of its expertise, experience and discipline, with the support of the risk manager. The comparison with historical data referred to similar projects, jointly to the risk owner's experience – who can benefit from the opinion of other experts –, are the methods that are employed for risk identification and measure. All these considerations are collected and organized in a checklist that is called Risk Breakdown Structure (RBS).

It is made a first risk analysis on the so-called Gross Risk, i.e. the intrinsic risk of the project that precedes any possible control and/or mitigation action. The Gross Risk is assessed considering the risk occurrence probability and its impact, which are factors computed through qualitative analysis. The analysis for risk determines a numerical value for the expected risk: this value can be obtained by the combination of the occurrence probability (which is estimated as high/medium/low assigning a percent value of 75/50/25% respectively) and the weighted average of the impacts. This analysis detects the risks that require higher attention. In the Company three types of risks (high/medium/low) are considered. They are differentiated according to the economic consequences related to the risk occurrence. In particular, three scenarios are identified: low impact, medium impact and high impact scenario. Moreover, Tecnimont studies which is the risk scenario more likely to occur and assigns to each scenario different percent probability weights.

Considering occurrence probability and the impact, Tecnimont defines the Average Gross Risk Value, the Gross Risk Impact and the Gross Risk Expected Value.
The Average Gross Risk Value is the weighted average of the three impacts multiplied for their relative percent weights on the basis of the most likely scenario.

The Gross Risk Impact is the score given in qualitative terms (high, medium or low) to the Average Gross Risk value, by evaluating its impact on the total project value. The Gross Risk Expected Value is the Average Gross Risk Value multiplied by the Probability of Occurrence.

In order to apply risk analysis to the control process described in par. 3.4, the Gross Risk Expected Value computation is needed for each milestone: this can be done by summing the Gross Risk Expected for each activity:

$$Gross\ Risk\ Expected\ Value_{milestone} = \sum_{i=1}^{n^{\circ}\ activities\ \in\ milestone} Gross\ Risk\ Expected\ Value_{i}$$

Equation 3-1: Computation of Gross Risk Expected Value

The Gross Risk Expected Value computed for the milestone is the parameter respect to which the prioritization is done: higher its value, higher the milestone level of attention.

4 Control process testing: theoretical validation

In the present chapter, the theoretical validation of the process for control proposed in chapter 3 is carried out. Robustness and completeness test was done by consulting three project managers belonging to Maire Tecnimont Group. The “interview” methodology was adopted: by this means, all project managers were able to discuss how they managed “Acid Gas Purification”, “DEMETO” and “H2S Cracking” R&D projects. According to their experience gained in the aforementioned projects, they were also asked their opinion about the peculiarities of the Control Process proposal: the themes analysed were risk and control metrics.

4.1 Methodology

In order to theoretically validate the proposal for the control process (described in par. 3.4) the interview methodology was adopted. This approach has already been used in other researches as a tool to verify the effectiveness of prototypes [38], to collect data from interviewees past experience [39]–[41], evaluate the effectiveness of a model [42], [43] and to ascertain and theorize prominent issues [44]. The validity of interviews is based on the assumption that interviewees are competent and […] truth tellers [41].

Interviewing is the most common format of data collection in qualitative research [40]; it consists of structured conversations [44], [45] aimed to collect information. In the present research, semi-structured interviews were employed. This kind of interview contains open and closed questions [45] – organized in thematic sections [41] – whose objective is guiding the interviewee through all topics of interest.

The data collection process started by identifying the target interviewees: three senior R&D Project Managers were selected. The reduced sample size is determined by the fact that – in Maire Tecnimont Group – there are only a few examples of R&D projects with the characteristics described in par. 3.1 and 3.2. Interviews were carried out between January 2020 and March 2020; they were conducted with face-to-face meetings (when possible), on the telephone and through virtual meetings. A questionnaire was also employed in order to ease distance communication: its use is justified when straightforward questions are asked [45]. All the interviewees were asked the same questions and encouraged to reply referring

to their case studies. The thematic sections discussed were the management of uncertainties, risk and the choice of control metrics.
Collecting information was an iterative process. All the interviewees' answers were firstly organized in notes, re-elaborated later in an organic text and finally submitted to interviewees to check the content consistency and correctness.

4.2 Results and content analysis

Here, the most significant questions and answers are reported and compared. To learn more about the project details and contextualization, Appendix A is available.

Theoretical validation passes through the analysis of the salient features of the new control process proposal: the employment of risk analysis to prioritize activities, the addition of Go/No-Go stages, the use of precedences not based uniquely on CPM, the use of Rolling Wave Work Breakdown Structure and the choice of the metric. The interviewed project managers were asked to express their opinions on these themes referring to the projects they managed. In Tab. 4-1 results of their interviews are summarized.

According to the replies transcribed, there is a wide convergence about the themes discussed. The two answers that are not completely shared between the three interviewees are the one about the project metric and the one related to the introduction of a timespan to test activities outcomes.
In general, all project managers are aware that changing the control metric is not a simple process when there are consolidated procedures or imposed rules. Anyway, the first divergence is not affecting the process validation: the new control process proposal is not going into the substance of selecting a more suitable metric, but is instead focusing on improving the accurateness of the baseline by considering some time to be devoted to iteration and testing.
For what concerns the introduction of a timespan to test activities, H_2S Cracking project manager asserts that testing should be even more anticipated to the Engineering phases: as much as it is possible, this conservative approach is not in conflict with the present control process proposal.

An interesting aspect that emerged from interviews is that in DEMETO and H_2S projects, a first qualitative risk analysis is considered an integral part of the project, confirming that integrating risk analysis in preliminary considerations about project feasibility can be done. Moreover, since the qualitative risk analysis is already a step for the project, in some cases, implementing this tool – used as an objective criterium to establish precedences – would not add substantial costs to the planning phases. Concerning this point, it was expected that the concept of usefulness of risk analysis was shared among all project managers. As it is possible to observe in literature, the attempt of integrating risk analysis into planning and project forecasts is always more frequent; this is done by different means, such as using stochastic methods: these attempts are the demonstration that project managers are aware of the importance of risks while planning and carrying out the project.

All project managers agree also on the fact that anticipating the execution – whenever possible – of the most critical items/phases could contribute to reduce project times and costs (this aspect will be discussed in chapter 5). All interviewees agree that this strategy is worth if problematic activities can be detected in advance. These feedbacks are coherent with the opinions expressed for the question related to risk management: in fact, risk diminishes acquiring knowledge about the processes and awareness can be obtained as soon as the issues reported in risk analysis are overcome.

According to the material and information collected with interviews, the new control process proposal can be considered theoretically validated.

Table 4-1: Results from interviews

QUESTIONS	C/D	Acid Gas Purification	DEMETO	H_2S Cracking
Is the PM able to establish a value for the risk related to undesired events (qualitative risk analysis)?		Yes. Qualitative risk analysis was implicitly performed	Yes. A risk map was formalized (see Appendix A)	Yes. Risk analysis is used also for the proposal of a robust project budget
Could a preliminary analysis of possible corrective actions be useful?		Yes, it could serve as a first Go/No-Go analysis	Yes, it is. A preliminary analysis of corrective actions was carried out starting from the risk map, resulting in Go gates for the project	Yes, it could serve as a first Go/No-Go analysis
Do you think that the Rolling Wave Work Breakdown Structure is a tool applicable and useful to have an updated baseline?		Yes, hence this tool was used	Yes, hence this tool was used	Yes, as all corporate management tools
With respect to the control metric used in your project, do you think that adopting a different one could have favoured the control process?		No because the problem is not the metric but the creep between what is planned to be performed and was is actually done. Anyway, changing the Company procedures in not simple	Maybe, but changing the established metric for the project is not easily feasible	No because the control process is favourited by deep knowledge of activities (resources, times, etc.)
Do you think that the introduction of a timespan for testing and iteration would allow a better control?		Yes	Yes	Only if these critical items are studied in the preliminary Engineering phase
Do you think that dealing with critical items/project phases first could diminish the impact on project times and costs?		Yes	Yes	Yes

Legend:
Convergence
Divergence

5 Control process application to "Acid Gas Purification" project

In this chapter, the new control process is applied retroactively to the Acid Gas Purification project. Through a What-if analysis, the new project schedule, produced accordingly to the new control process proposal (par 3.4), is challenged to be better performing than the control process actually applied. Processes performances are compared by studying forecast accuracy. Further implications are discussed successively.

5.1 Methodology

To tune the control process proposed in par. 3.4, "What-if analysis" tool was used.
What-if analysis is a simulation whose goal is to inspect the behavior of a complex system (i.e., the enterprise business or a part of it) under some given hypotheses [46]. It measures how changes, in a set of independent variables, impact on a set of dependent variables with reference to a given simulation model that is a simplified representation of the business [46]. This methodology has already been applied to evaluate beforehand the impact of a strategical or a tactical move [46]–[48] and for the validation of simulation models [46]. In the present case, the answer to be replied in the analysis is "is the new control process more efficient than the one actually applied to the Acid Gas Purification project?". To provide an answer to the previous question, a structured approach was adopted.

Time forecast accuracy was studied. The most representative phases for the real and the What-if schedule were detected and distinguished. Phases representing events that occurred in reality, but that would not occur applying the new control process, are not present.
As done by Chen et al. and Andrade et al. [49], [50], accuracy for each node was computed using the Mean Absolute Percentage Error (MAPE). MAPE is probably the most widely adopted unit-free measure and can be used when data have a meaningful zero (ratio-scaled data) [51]. It is defined as:

$$MAPE = \frac{100}{n} \sum_{n=1}^{n} \left| \frac{\hat{y_t} - y_t}{y_t} \right|$$

Equation 5-1: Mean Absolute Percentage Error where:

- y_t is the actual value for time t to perform an activity or a set of activities;
- $\widehat{y_t}$ is the predicted value for y_t to perform an activity or a set of activities;
- n is the number of phases to which the computation for accuracy is related.

5.2 Acid Gas Purification project

The "Acid Gas Purification" project has been carried out in Tecnimont.
The project objective was the demonstration of the technical feasibility of a new technology for natural gas sweetening, based on an innovative cryogenic distillation process, and its applicability on an industrial scale. The project scope included also the design and construction of a small-size (laboratory-scale) pilot plant and the execution of experimental campaigns in order to validate the innovative process tested. Therefore, the project success was defined as follows: 'through the construction of an original pilot plant (prototype) and the execution of a certain number of experiments for which no precedents exist, to state without ambiguity whether the proposed distillation process works or not'.

The principle on which the idea is based on (cryogenic distillation on two pressure levels) allows to obtain a clean gas – avoiding the carbon dioxide to solidify in the column – and the direct use of distillation by-products (re-injection, Enhanced Oil Recovery). Tecnimont, given the increasing interest worldwide in the exploitation of very acid gas fields (i.e. gases containing a high level of CO_2 and H_2S), decided to investigate this innovative technology, that, combining low costs and a simple plant configuration, is in principle economically competitive with respect to the technologies for gas sweetening (e.g.: amine washing, membrane separation, etc.) that are currently in use.

With respect to projects aimed to plant design, construction and operation, this project showed some peculiar critical issues. In particular, the process had never been tested before: this means that there were no similar experimental apparatuses or pilot plants that could have been used as a good reference for its design. In addition, to reduce financial risks, building up a small-scale plant turned into the need of making use of technical solutions that are very far from those that will be implemented on an industrial scale. Finally, the very peculiar process conditions to be achieved, combined with the small size of the plant, turned into the difficulty to find on the market items and pieces of equipment that were fit for purpose; this required an ad hoc fabrication of brand new items or the customization of items available on the market but designed for other purposes.

The project started in 2013 and ended in 2018, concluding the second experimental campaign. The whole project was divided into two different phases.

More in detail, the objectives of the first phase of the project, lasting one year (2013-2014), were the verification of technical feasibility of a new plant based on a new technology, the preliminary assessment of the economic competitivity of the new process and the demonstration of the feasibility of a small size pilot plant. These three activities were successfully performed in accordance with the planned schedule and allocated budget.

The objectives of the second project phase (lasted from 2014 to 2016) were the detailed design, the pilot plant construction and the execution of a first experimental campaign for the technology validation: this is the phase that is subjected to accuracy and adherence analysis. In case the results of the first experimental campaign would not have been sufficient to validate or confute the new process, the possibility to perform a second experimental campaign was taken into account. For these activities vendors with expertise in pilot plants detailed design, construction and operation were identified. All the activities aimed at the plant construction were performed in the forecasted times and respecting the assigned budget: this was possible thanks to the revision of the construction schedule after the verification of the malfunctioning of the cooling system. At the beginning of the experimental campaign (summer 2016), the technical failure of some components – in particular, malfunction of a process pump – and the time required for remedial actions turned into the cancellation and/or postponing of the tests that were originally planned: consequently, the original schedule of the experimental campaign and the budget had to be revised. Once the main technical problems had been fixed, the tests were executed and the experimental campaign was completed in May 2017. All experimental activities were performed in accordance with the schedule which was revised after the main pieces of equipment were fixed. The Campaign was planned to include 80 tests diluted in a period in which workshop activities were forecasted.

In the light of the results obtained during the first experimental campaign – which did not allow to fully validate the technology – the pilot plant was modified (autumn 2017) and a new experimental campaign was planned. This new campaign, started in November 2017, was concluded definitely in 2018 in accordance with the planned schedule. The number of experiments for the Second Campaign was reduced to 60 since the plant was proved to be more stable.

5.2.1 Reference data

In order to reconstruct the project baselines, reports, documents and internal communications were studied. The initial project duration was planned to be lasting 34 months. The project started officially on 19th February 2015. The full Acid Gas project history is described in Tab. 5-1. For non-specified dates (generic references to months in the documents collected), the 15th day of the month is assumed.

Table 5-1: Reference data

2015	
19th February – 15th April	Pilot Plant Detailed Design – Planning of operations
16th April – 14th June	Construction up to the Vendor's proposal to make some tests to the cooling system
15th June – 25th June	Buffer time before Tecnimont approves tests on the cooling system
26th June – 17th July	Buffer time
20th July – 27th August	Cooling system tests
15th July – 15th November	Planning for the Experimental Campaign
28th August – 8th September	Tecnimont approves the modification of the cooling system
9th September – 15th October	Buffer time
16th October – 2nd November	Tests on the new cooling system
3rd November – 8th November	Buffer time
9th November – 6th March 2016	Fabrication of new pieces for the cooling system and end of pilot plant construction
2016	
7th March – 4th April	HSE and inspection tests up to definitive handover to Tecnimont
4th April – 19th May	Pilot Plant planned functionality tests
19th May – 9th July	Pilot Plant further tuning
9th July – 23rd September	Interruption due to pump unsuitability and evaluation of possible solutions

24th September – 31st May 2017	First Experimental Campaign: experiments (80 days) and minor troubleshooting (50 days)
2017	
1st June – 31st July	First Experimental Campaign results analysis
1st August – 28th November	Pilot Plant revamping
29th November – 30th October 2018	Second Experimental Campaign: experiments (60 days) and minor troubleshooting (10 days)

It has to be noticed that the dates reported in Tab. 5-1 are the ones representing the actual development of the project. Since the aim of the following analysis is evaluating forecast accuracy, also data referred to original planning have been collected. The original planning for the actual Acid Gas Purification project (in the following, Project R) and the one related to the project that would have been carried out adopting the new control process (in the following, Project W) are reported in Tab. 5-2 and Tab. 5-4 respectively.

For the present work, the list of activities and the schedules are simplified: micro activities are not reported as they are likely to be the same in both projects: the activities reported are the ones that trace the logical sequence and highlight the major differences between the two processes.

For what concerns Project W, the original schedule was assembled mainly referring to Project R activities durations:

- one day is assigned to the prioritization phase (which includes a qualitative risk analysis and the reorganization of activities precedences). This amount of time was established in accordance with the experts' opinions. More correctly, it is thought that half-day is the right amount of time to be reserved for a qualitative risk analysis. It is assumed that the baseline is defined according to new precedences: no extra time for scheduling is considered since prioritization only involves the insertion of times – related to test and iterate the considered phase – and some activity order change;
- construction is planned to be three months longer: in the real project development, the vendor's expertise allowed the accurate estimation of the delay that the test of cooling system would have caused; for this reason, it is assumed that this delay could be forecasted also before the occurrence of the cooling system problems. Moreover, no deadtimes are assumed because the control process itself requires the cooling

system to be tested without any approval: in Project R, it was not originally planned to test the cooling system so, after this proposal was suggested, some dead time passed;

- once construction is concluded, a new planning ad risk analysis session are done in Project W: here the plant is assumed to be the element to be tested and iterated before the experimental campaign starts. One day is assigned to this planning session;
- the experimental campaign is unique because troubleshooting is meant as the testing phase for the plant functionality. Only after the plant is declared to be operative and stable experiments can start;
- times for troubleshooting duration have been estimated as suggested in par. 3.4: in addition to the time used for tests, four months are added for the pump troubleshooting. Since at the early stage of risk evaluation it is not always clear which could have been the specific problem affecting the project success, general considerations are done: the process pump had already been detected as a potential criticality for the project so – in order to be conservative – the complete failure of the pump was considered to compute the amount of time to be added to ordinal activities. According to qualified pump constructors, pumps that were likely to suit the project purposes are built in three or four months: as the success of a brand-new pump is not assured, four months are taken as timespan. In this way, it is accounted for any further iteration to solve the pump instability;
- for what concerns the experiments, the duration of the single campaign iss assumed to be equal to Project R second experimental campaign – which was performed once the plant was proved to be stable.

Project W actual schedule was modelled on the considerations made for its original schedule and considering the actual time for Project R. Days devoted to Project W actual Plant Tuning are increased because, in order to guarantee the plant efficiency obtained for Project R second experimental campaign, a revamping must be included (121 additional days). Since Project W number of experiments is equal to Project R second experimental campaign, the experimental phase has to last as Project R actual second experimental campaign. Finally, no modification was applied to activity precedences because they were already performed in accordance with the principles described in par. 3.4.

The two schedules for original planning (Tab. 5-2, Tab. 5-3) are coupled with their correspondent effective schedules, representing how Project R actually progressed and how Project W would have (Tab. 5-4, Tab. 5-5).

Table 5-2: Original planning for Project R

Original schedule – Project R	***Start date***	***End date***	***Days (calendar)***
Pilot plant detailed design – planning of operations	19-Feb-15	15-Apr-15	56
Pilot plant construction	16-Apr-15	19-Nov-15	219
Pilot plant handover	20-Nov-15	30-Jan-16	73
Pilot plant tuning	01-Feb-16	25-Mar-16	53
First experimental campaign tests	26-Mar-16	02-Dec-16	251
Analysis of 1st experimental campaign results	03-Dec-16	01-Feb-17	62
Second experimental campaign tests	02-Feb-17	27-Nov-17	300

Table 5-3: Original planning for Project W

Original schedule – Project W	***Start date***	***End date***	***Days (calendar)***
Pilot plant detailed design – planning of operations	19-Feb-15	16-Apr-15	57
Pilot plant construction	17-Apr-15	21-Feb-16	312
Pilot plant handover	22-Feb-16	05-May-16	74
Pilot plant tuning	06-Mar-16	28-OCt-16	177
Experimental campaign tests	29-Oct-16	23-Aug-17	300
Analysis of the experimental campaign results	24-Aug-17	23-Oct-17	62

Table 5-4: Actual development for Project R

Actual schedule – Project R	***Start date***	***End date***	***Days (calendar)***
Pilot plant detailed design – planning of operations	19-Feb-15	15-Apr-15	56
Pilot plant construction	16-Apr-15	06-Mar-16	329
Pilot plant handover	7-Mar-16	18-May-16	73
Pilot plant tuning	19-May-16	23-Sep-16	130
First experimental campaign tests	24-Sep-16	31-May-17	251
Analysis of 1st experimental campaign results	01-Jun-17	31-Jul-17	62
Pilot plant modification (revamping)	1-Aug-17	28-Nov-17	121
Second experimental campaign tests	29-Nov-17	30-Oct-18	337

Table 5-5: Actual development for Project W

Actual schedule – Project W	*Start date*	*End date*	*Days (calendar)*
Pilot plant detailed design – planning of operations	19-Feb-15	16-Apr-15	57
Pilot plant construction	17-Apr-15	07-Mar-16	329
Pilot plant handover	08-Mar-16	20-May-16	74
Pilot plant tuning	21-May-16	13-Mar-17	298
Experimental campaign tests	14-Mar-17	12-Feb-18	337
Analysis of 1st experimental campaign results	13-Feb-18	15-Apr-18	62

5.3 Forecasts accuracy

As mentioned in par. 5.1, forecast accuracy is studied using the MAPE index. Data related to original planning and effective project trends are used. The values for time used in computations refer to the completion of activities.

MAPE computation is expected to demonstrate that Project W forecasts are more accurate than Project R; in fact, Project W's original schedule is widened because of the introduction of tests on the cooling system and of the elongation of plant tuning times: a longer duration better resembles the actual project development.
"Start" and "end dates" are included in the computation of timespans. As it is dealt with time extensions, both working days and holidays are considered.

For Project R actual experimental campaign, the first and the second Campaign days are summed to represent the effective number of days needed for the technology validation. For the original planning of Project R, the second experimental campaign is not present because it wasn't part of the original Project R scope.
In Tab. 5-6, values for MAPE are reported.

The results reported in Tab. 5-6 can be interpreted with the support of Tab. 5-7 which represents typical MAPE values for industrial and business data [52].

Initial expectations related to Tab. 5-6 results are satisfied. As expected, some phases have the same MAPE which is equal to 0; this value is mainly associated with planning activities: seen that no complication occurred in Project R, it is assumed that Project W planning phases did not arise particular problems.

Table 5-6: Results for MAPE computation

Phase	R: $\hat{y}_t$	R: y_t	$MAPE_R$	W: $\hat{y}_t$	W: y_t	$MAPE_W$
Pilot plant detailed design – planning of operations	56	56	0	57	57	0
Pilot plant construction	219	329	33,43	312	329	5,17
Pilot plant handover	73	73	0	74	74	0
Pilot plant modifications	53	251	78,88	177	298	40,60
Experimental campaigns	551	588	6,29	300	337	10,98

Table 5-7: Interpretation of typical MAPE values (from Lewis, p.40, 1982)

MAPE	*Interpretation*
<10	Highly accurate forecasting
10-20	Good forecasting
20-50	Reasonable forecasting
>50	Inaccurate forecasting

Construction, plant modifications and experimental campaign phases were the most difficult to control. If the project baseline deviates a lot from the activities actually carried out, progress computation does not provide meaningful information; being the now control process based on this assumption, higher accuracy was expected – and confirmed. Introducing in Project W test and iteration phases is demonstrated to attenuate project creeps.

For pilot plant construction phase, MAPE < 10 (highly accurate forecasting): this is possible because the expert and qualified vendor was able to quantify the delay related to the introduction and execution of tests on the cooling system.

For plant tuning, it is very complex to hypothesize a priori which could be the problem that can cause the pilot plant malfunctioning: hence, only the exact knowledge about the technical anomaly enables the project manager to consider possible corrective actions and their temporal quantification. Differently from cooling system tests, for which it was known what was going to be verified, for instrumentation and the pump case it wouldn't have been possible to know in advance the entity of malfunctioning problems. The same consideration is done for Project W's actual plant tuning: only by testing the pilot plant it is possible to acquire data and understand if a revamping is needed.

For the experimental campaign, higher accuracy was not obtained by better defining the time devoted to experiments but by the reduction of the number of the experiments: planning for a longer plant tuning phase is assumed to assure that the plant is more reliable. If the plant operability is guaranteed, experiments can be completed with a higher success percentage and, consequently, also workshop activities between experiments can be reduced.

5.4 Further considerations

Besides the advantages on control, it is interesting to analyse qualitatively whether the new control process produces additional benefits on the project. To do that, Project R and Project W's schedules have been compared: it appears (Tab. 5-4, Tab. 5-5) that, although some activities were completed in different ways, Project W includes additional tasks compared to Project R.

Tab. 5-8 reports the list of activities that are studied in this analysis. Additional days/experiments with respect to Project R's schedule are denoted with "+". The analysis takes into account only working days.

Differences are mainly due to prioritization and scheduling activities, the test of the cooling system, the reduction of experiments and the decrease of the number of days devoted to troubleshooting.

Prioritization and scheduling require only one working day, so the impact on costs can be considered negligible.

Although Cooling System Testing and Iteration time difference amounts to 24 day – which would usually correspond to a considerable cost impact on the project – in Project R, these days were devoted to other activities (such as procurement, manufacturing of equipment): for this reason the elimination of deadtimes represent a negligible impact on the overall project budget.

The most important parameter that affects considerably the cost of the projects is the number of experiments carried out.

Project R included two experimental campaigns with an overall number of tests equal to 121. In the first experimental campaign, 61 experiments were carried out: only 13 of them were successful, i.e. the plant was stable and all the process information (mass balance, pressure, temperature, etc.) were collected over a time period sufficiently long to assess the outcome of the experiment.

The remaining 48 tests were unsuccessful for various reasons such as plant instability, components failure and/or partial recording of data due to instrument failures.

The percentage of successful tests was around 21% and did not enable the Project Team to collect sufficient data for the validation of the technology: for this reason, the plant was revamped in order to improve the overall reliability, and a second experimental campaign, including 60 experiments, was scheduled. This second experimental campaign demonstrated that the revamping was successful since the success rate increased to 85%.

For Project W, since the experiments are planned to be performed only after the revamping – when the plant is reliable –, a lower number of experiments is required to achieve the target (60 successful experiments).

Considering X the average cost for a single experiment (including manpower, operative costs and workshop activities carried out during the experiment and in the days between tests), the cost difference between Project R and Project W is equal to 13X, which corresponds approximately to 9% of the overall costs of both Project R experimental campaigns and the revamping. However, this analysis assumes – optimistically and for the sake of simplicity – that anticipating the revamping would have as a result the increase of reliability up to 85%: this implicitly means that very early, during first during the experimental campaign, the performance of few tests was sufficient to identify and address all the revamping activities that have been performed in Project R: this is not necessarily true.

All the data collected at the end of 1 Experimental Campaign – and in particular all the information about the failures that have occurred – have been studied in detail in order to identify and prioritize all the revamping activities. In detail, the revamping activities carried out were the following:

- complete review of the primary cooling system: the three original cooling loops were split into five independent cooling loops, with the addition of two independent circuits; in this way, the different sections of the plant could be cooled down more efficiently;
- replacement of the isopentane pumps: the three reciprocating plunger pumps, pneumatically driven, were replaced by five (one for each loop) electrically driven rotary pumps;

- replacement of the liquid nitrogen tank with a new tank liquid nitrogen tank, having an overall capacity of 5 m^3, thus allowing to prolong the test runs reducing the occurrence of an anticipated stop of tests due to lack of cooling medium;
- general check-up of the instrumentation: all the Coriolis flowmeters were inspected and recalibrated (a Coriolis flowmeter was replaced with a new one); the gas chromatograph was inspected and recalibrated at the site together with the manufacturer; a general check of all the instrumentation was also carried out.

It has to be highlighted that the corrective actions here above described and implemented were the result of the failure analysis after Project R's first experimental campaign; if the number of tests carried out prior the revamping had been lower, it is questionable whether the failure analysis would have allowed identifying the same technical solutions. It is the project manager's opinion that a failure analysis over a much lower number of tests would have not allowed reaching the performance of the previously described revamping. For example, part of the instrumentation would have not been recalibrated or replaced, the cooling system would not have been split into 5 loops (but only in three) and the nitrogen tank would have not been replaced.

The difference between the days spent for troubleshooting activities in Project R and in Project W is equal to 45 days.

Even if the time difference is very high, it cannot be easily associated with consistent money saving because – as already reported – a lower number of experiments could not provide complete technical information for a future revamping. For this reason, the expense saved in Project W troubleshooting phases can be considered balanced by the lower success rate expected for Project W experimental campaign. However, the cost of one working day spent in troubleshooting is significantly lower than the overall costs (manhours and consumable materials) spent for one day of experiment: the ratio is approximately 1/3. Then, the hypothetical saving of 45 days corresponds to 15 days of experiments, which is comparable with the considerations made for successful experiments.

Table 5-8: Results for times and costs analysis

Activities	Notes	Project R	Project W	Δ Time	Δ Cost
Prioritization and Scheduling	Not Performed in Project R	0 h	1 day	+ 1 day	negligible
Cooling System Testing and Iteration (plant construction)	Performed in both Projects	106 days	82 days	- 24 days	negligible
Successful Experiments	Performed in both Projects	50+13 experiments	50 experiments	- 13 experiments	13X
Troubleshooting	Performed in both Projects	63 days	18 days	- 45 days	15X

An alternative analysis, finalized to show the importance of testing and iteration carried out over the entire project, is studying how different management approaches could have influenced the project overall budget of the project.
Given that the second experimental campaign (whose successful tests were 48 out of 60) allowed validating the technology, one wonders how many tests would have been necessary to get the same number of successful experiments without considering any revamping, and assuming at the same time a success ratio equal to the real one (around 21%). This new scenario does not correspond nor to Project R either to Project W.

In this regard, two approaches for carrying out experimental campaigns have been considered: the scheduling of two experimental campaigns along with the revamping between them – which represents the approach adopted in Project R (scenario A), and the execution of one longer experimental campaign aimed to carry out 48 successful experiments without any revamping at constant of 21% as success rate (scenario B).
Results for the scenarios are:

Scenario A

For scenario A the overall costs of two experimental campaigns, including the revamping, is equal to

$$\text{Overall Costs} = 121\text{X} + 25\text{X} = 146\text{X}$$

where X is the average cost of one experiment. It is assumed that the equivalent cost of the revamping is approximately equal to the cost of 25 experiments.

Scenario B

For scenario B, the number of experiments to be carried out to get 48 successful experiments is

$$\text{expected number of eperiments} = \frac{61 \cdot 48}{13} = 225$$

The overall cost of a longer experimental campaign amounts to 225X, where X is the average cost of one experiment.

Scenario A is the best choice; in fact, the extension of the experimental campaign without considering any revamping would turn in an overall cost that is 1,5 times the cost that has actually been incurred.

These results conceptually strengthen the efficiency of the control process proposed in chap. 3: testing and iterating technical solutions at the same time allows controlling the project progress and, at the same time, to have significant money-saving. Additionally, the choice turns into a more efficient plant for future experiments to be potentially carried out.

6 Conclusions

In previous chapters, R&D projects were described and analysed; their peculiarities complicate the control process. Although in the last years of 1900 [9], [10] the introduction of flexible methods and frameworks has strongly changed the way to manage some kind of projects (mainly software ones [10], [20], [21]–[28], [29], [30]), they cannot be applied straight forward to projects that include in their scope the construction of a pilot plant and the subsequent execution of experimental campaigns.

In the present work, it is maintained that the problem related to R&D project control is, essentially, in the planning phase that is made more complex by uncertainties, which are one of R&D project characteristics (chap. 3). In addition to flexible methods and frameworks, literature offers a good number of examples and attempts to model such uncertainty with stochastic methods [53]–[57].

The analysis of the problem from a different perspective, with respect to statistical computation, draws inspiration from the observation that stochastic methods cannot provide any accurate result if simulations are run with inaccurate data.
The new control process is proposed as a solution. Limitations related to the previously mentioned methods were addressed by improving planning, introducing the detection and classification of risk, prioritizing them and inserting in the schedule some timespans devoted to test and verify unconventional technical solutions.

The control proposal accuracy was tested taking as reference the Acid Gas Purification project: quantitatively speaking (chap. 5), the new control process is proved to improve these aspects. Although MAPE analysis was limited to a single project, the control process proposal was theoretically validated by three senior project managers, which guarantees the extension of the results to projects different from the Acid Gas Purification one.

In addition, the new control process safeguards the project team: tests allow to promptly verify the functionality of units before inserting them in the plant system. This choice minimizes the corrections to apply once the project is expected to be concluded and to abandon the project whenever technical unfeasibility is encountered.

The Acid Gas Purification project was studied and some considerations are here reported.

The Project was managed quite in accordance with the new control process: although the original planning did not include the cooling system test, an iteration phase was introduced later under the vendor's proposal.
In this sense, it has to be underlined the importance to work with a qualified and expert vendor who can provide better estimates in the planning phase.
The major difficulties were encountered while tuning the pilot plant operability and during the experimental campaign. The current work demonstrated that the clear separation between troubleshooting and experimental activities enables an improves progress measure as well as better identification of the phases that accumulate delay.

Collaterally, the new control process was roughly studied under an economical point of view.
Based on the analysis done in chapter 5, it would be difficult to state if the new control process has consistent advantages on money-saving: a more detailed analysis – which could not be performed due to confidentiality reasons – would be required. Abandoning the theoretical field, an accurate study on time and costs impact would provide a more pragmatic sensitivity which, in case of savings, would strengthen the control process here proposed.
Even if the R&D goal is not guaranteeing the production of goods optimizing costs, the perspective to save money is for sure appealing.

6.1 Limitations

Besides the improvements apportioned, the new process brings a limitation. In chapter 3 it is suggested that timespan for testing and iteration are quantified with a conservative approach. It is not excluded that the timespan allocated for a specific activity exceeds the actual amount of time needed: in this case, the project time advantage would be lost. Although new planning can be done, for project phases characterized by scarce flexibility, this could be vane (one thinks to procurement phase, where orders are already fulfilled).

6.2 Further research

Seen the limitation reported in par. 6.1, a deeper study on an (eventual) method to estimate the timespans could be carried out: the method should consider the high number of uncertainties and the lack of historical data references, which are the starting points for current fuzzy-based methods for variance computation. Sensitivity analyses among literature methods can be done as well as the development of an original computation method.

Another aspect worthy of deepening is the choice of the control metric. In this discussion, greater importance was given to the baseline and its construction, considering the metric as a secondary aspect. As confirmed by the interviewed project managers, although the major problem is the baseline strong deviation from reality, it cannot be excluded a priori that some metrics could provide more detailed and accurate information about the project progress.
The research for an algorithm could be done comparing the performances of different metrics that are described in the literature or that are elaborated ex novo.

Additionally, another point to consider is the proposal for a new system for contingency computation.
FEED and EPC contingencies are assumed to be a percent value of the overall project budget: this assumption can be done because historical data are recorded and activities variance is typically very limited. For the considerations reported in chapter 3, it appears that the same reasoning cannot be applied to R&D projects with the same statistical confidence. Suggestions for contingency allocations could be proposed evaluating the economic response of a large set of R&D projects.

Finally, given the actual developments and changes occurring worldwide, it is fair to think that the impact of these variations would be observed also at the project level: environmental circumstances and constraints could induce new needs and, for this reason, it cannot be excluded that nowadays non-R&D projects will be managed differently. In this sense, the control proposal described in the present discussion represents an innovative process that could be tested on non-R&D projects.

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Executive summary / Sommario esteso

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Appendix A: Project managers' interviews

The projects used to validate theoretically the new control process are here described. Further information provided by the Project Managers about uncertainties, risk and control tools is reported.

A.1 Acid Gas Purification

The "Acid Gas Purification" Project description can be found in chapter 5, par. 5.2.

A.1.1 Uncertainties

Which were your activities characterized by uncertainties?

In the Acid Gas project, the activities characterized by uncertainty were:

a) the shifting of the experiments planned in the schedule. This condition can occur, for example, because of delays in the plant preparation following a maintenance intervention, limited resources availability, etc.;
b) number of workshop days that have to be spent in troubleshooting, in order to have, after the end of an experiment, the plant ready for a new one;
c) the effective number of experiments to be performed in order to collect a set of experimental results that are enough to validate or confute the theory: this uncertainty is the consequence of the operation of an experimental apparatus that could work inappropriately during the execution of the single experiment.

How did you reduce the uncertainties associated with planned activities?

In the project, uncertainties related to activities were:

a) planning an experimental campaign, lasting six months, with two or three tests on average per week. These tests were planned to be alternated with activities devoted to plant modification and repairs. The organization of the campaign included an increase in the frequency of the tests and a decrease over the same period of workshop activities. An allowance of one month was allocated for the execution of the aforementioned activities;

b) increasing the number of planned experiments (for the first campaign, 80 tests were forecast) to enlarge the numerousness of the successful experiments.

Also, in case the results of the first campaign had not allowed the technology validation – because of the scarce number of successful tests or because of the contradictory results obtained – a second experimental campaign would have been planned.

A.1.2 Risks

Which were, at the early stages, your uncertain and undesired events and their effects?

The project uncertain and undesired events were identified as:

a) a gap between the plant basic design (carried out by Tecnimont) and the detailed design (activity assigned to the plant constructor) by the choice of the constructor to implement detailed technical solutions which can be very different from the ones proposed in the basic design phase. This can cause an extension of the project schedule;
b) a conflict between the constructor and the operator: in case of problems in the plant operations (for example poor plant performance during the experiments), it is difficult to decide who has the responsibility to fix the problem. Also, this condition can bring to time dilatations in the schedule;
c) non-fit for purpose of technical components that could not be tested prior to the execution of the experiments (because they are ad hoc or customized item/units);
d) limits in the design of plant subsystems caused by limited knowledge of chemical/physical phenomena that are the subject of scientific research. This can lead to plant unsuitability;
e) insufficient operating margins for exploring the domain of the physical quantities subjected to the experimental research.

It is worth mentioning that the listed events would have had a negative impact on the project, most likely, prolonging times and increasing its overall costs.

Another undesired and uncertain event is that the investment does not lead to any useful result (meaning that the experimental campaign does not lead to a clear validation or confutation of the theory). The construction of a small-sized plant is itself a choice that minimizes the overall project costs. The discussion about the choice of the optimal size of the experimental plant, and the related risk-benefit balance, is not included in this dissertation's purposes.

Is it possible to consider risk mitigation actions for uncertain events?

Yes, it is. Mitigating measures were respectively taken:

a) during detailed design a continuous exchange of information ensured that the proposed technical solutions were in line with the original scope of work;
b) the tasks for the construction and operation of the plant were assigned to the same vendor;
c) during the feasibility study, suppliers of plant items fit for the purpose were pre-selected; when this was not possible, an investigation was made in order to ensure that the preselected items could be customized by the vendor chosen for the plant construction;
d) whenever possible, items and plant subsystems were tested before the completion of the plant;
e) ensuring that, to a certain extent, the plant that was built could be easily modified.

Is it possible to assign a value for risk related to undesired events?

Yes, it is, hence a qualitative risk analysis was implicitly performed. To each undesired event, a qualitative score for impact and occurrence probability was assigned. In this way, it was possible to categorize risks and identifying risk mitigation measures actions.

Which uncertain events considerably affected the project?

The uncertain events that occurred during the project were basically two: 1) the lack of functionality of the ad hoc designed cooling system, and 2) the malfunction of the process pump. Both events had a negative impact on the Project.

How were managed the associated risks?

For what concerns the cooling system, the unavailability of detailed knowledge about the fluid physical properties (ethanol) at the operating temperature (-100°C) led the project team to choose between a preliminary functionality test or to verify the behaviour of the unit once the plant was completed. The decision to carry out a preliminary test during the construction of the plant turned into an extension of the construction schedule and in an increase of costs; on the other hand, the opposite decision (i.e. testing the system once the plant is completed) would have resulted in a more expensive and time-consuming activity, leading to an increase of the schedule and the costs.

The second event was the unsuitability of the process pump to work stably at the desired process conditions, turning into the practical impossibility to perform the experiments. In detail, the original seals of the pump, designed to work at a minimum temperature not lower than -40°C, were subjected to a shrink due to the very low temperature of the liquefied process fluid, causing a loss of tightness of the process pump and consequent leakage outwards of the liquefied mixture. This problem was not unexpected, but it must be remarked that the behaviour of the pump could not be verified before the start of the experimental campaign, and during the market investigation no pump designed to match all the process conditions was found.

Four different alternatives were identified for this problem:

a) the manufacturing, at site workshop of new pump seals;
b) the order to a qualified seals producer, of ad hoc special energized seals;
c) the manufacturing at site workshop, of a custom type pump;
d) the order, to a qualified pump provider, for the manufacturing of a multiple-stage vane pump, magnetically driven, obtained by the customization of a product available in its catalogue.

The proposed solutions, having different impacts in terms of costs and lengthening of the overall schedule, were discussed. The decision was taken to proceed in order with solution a), b) and d). Solution c) was rejected because of the scope creep it would have generated: the production of a custom type pump would have been a project itself whose times and costs could not be quantified.

The order of implementation of the solutions was based on increasing impacts (in terms of required time for the implementation and related cost). The adoption of this strategy is justified by the observation that, in this case, having to deal with solution proposals for never posed problems, the success probability associated with the implementation of each solution was not known a priori. Any solution had, hence, the same success and failure probability: for this reason, the discriminant for the choice of the best option was the analysis of consequences related to the single option. By this means, the traditional risk analysis was reduced to an impact analysis.

Could a preliminary analysis of possible corrective actions be useful?

It could be useful if meant as a first Go/No-Go analysis: if corrections and mitigations can be individuated for an uncertain and undesired event, then it could be worth continuing the project. If it is found out that a possible problem does not have any solution, then abandoning the project could be an option.

Do you think that dealing with critical items/project phases first could diminish the impact on project times and costs?

Yes. In general, any early problem (and solutions) identification activity is meant to increase the success probability of the project since the acquired knowledge allows to better face successive problems.

A.1.3 Applied project control techniques

How did you control the activities?

The project was controlled using the techniques currently applied in Tecnimont for the service projects. Progress has been computed as the ratio between the spent hours and the planned ones.

The baseline for the experimental campaign was the simple planning of the days devoted to the experiments (which were alternated to equipment maintenance days). Since the experimental program included a set of experiments that were independent – meaning that the outcome of previous experiments did not affect the results of the successive – precedence diagrams were not adopted. Differently, in the engineering and the construction phases, the CPM was used jointly with precedence diagrams. As an example, the original construction schedule is reported below.

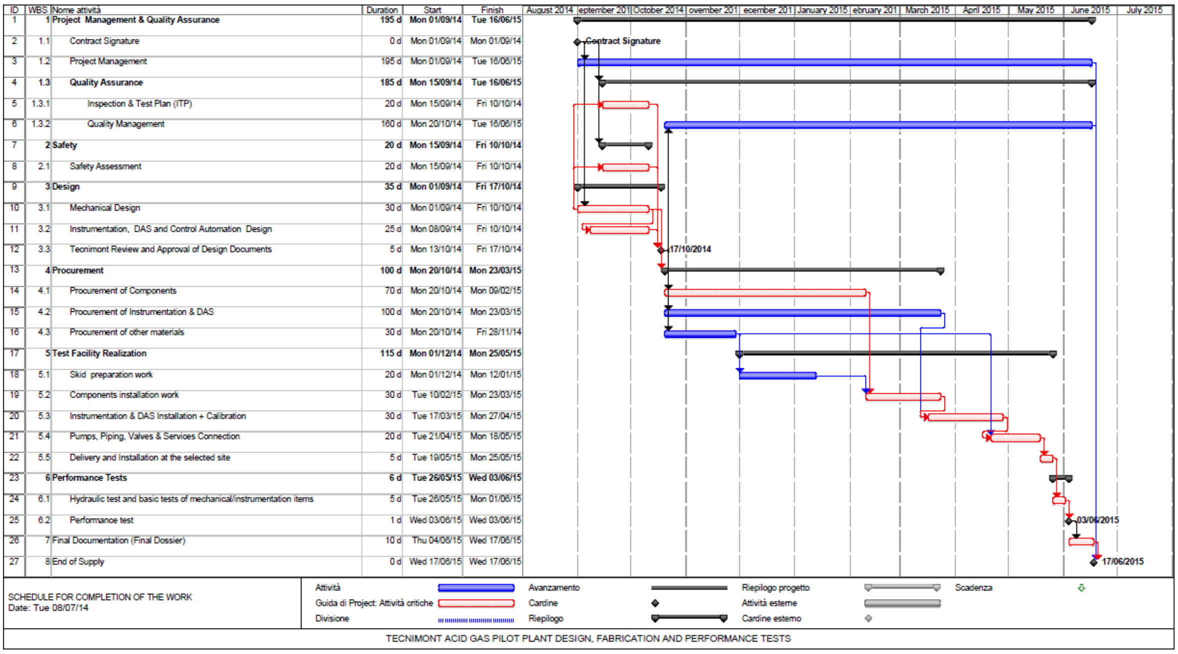

Figure A-1: Original construction schedule for Acid Gas Purification project

Was there any problem in controlling the project?

The main problem was the inefficiency of control in the experimental campaign phase. In particular, the problem consisted in the loss of meaning of the planned baseline: planned activities could not be performed because of equipment problems. As a result, it was useless comparing the expected progress with null progress.

Why did control problems occur?

Problems occurred because of the outbreak of factors that caused great disturbance. In the case of the Acid Gas Purification project, the repetitive malfunctioning of the process pump led to the interruption of the experimental campaign. Since the progress was measured as the ratio between the spent hours and the planned hours allocated for the project, while the time passed, no activity was actually performed. This brought to a large creep that could not be taken into account by the control metric adopted.

Do you think that the adoption of a different control metric would have better represented the project progress?

In the project manager's opinion, a different metric would not have guaranteed a more efficient control of the project. This assertion is motivated by the fact that the project manager tried to apply retrospectively the typical Earned Value Method metric. The result is shown in the graph below.

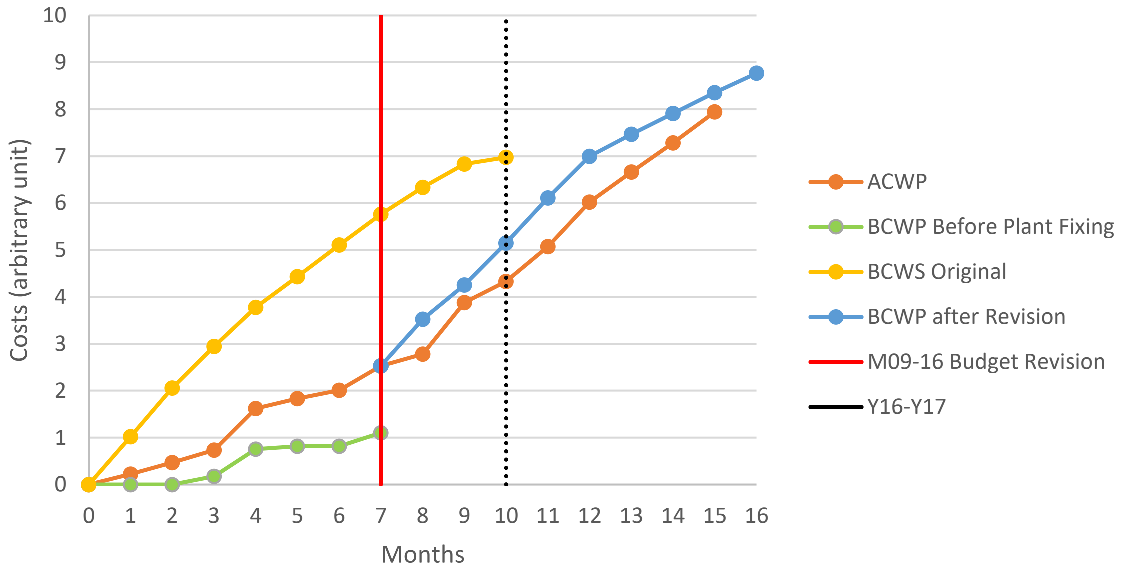

Figure A-2: EVM retroactive application to Acid Gas Purification project

The graph refers to the planning of the first experimental campaign.

This, according to the original planning, was supposed to last 9 months. Due to the occurrence of several problems since the first tests, there is a large creep between the BCWS and the BCWP which makes the project control lose its significance. In fact, the BCWP does not approach absolutely the BCWS: this is not due to mistakes in the planning but is the direct consequence, in particular, of the occurrence one of the events already mentioned (the malfunction of the process pump), and its strong impact on the original schedule. So, the schedule performance index (chap. 2, par. 2.1.4) does not produce a meaningful value. The same considerations can be done for the cost performance index (chap. 2, par. 2.1.4): the ACWP, in this case, is not representing any money-saving but a lower expense caused by the impossibility of proceeding with the planned activities. Only after a substantial fixing (months 3-6), and the revision of the schedule (month 7), there is a stronger agreement between the planned and actual parameters used for the control (hence, the blue line resembles the yellow line behaviour).

It must be underlined that this retroactive attempt to apply EVM demonstrates that, for projects that are not so complex – as in this case – it is worth to adopt the simplest metric. The metric, then, is established by the Company guidelines that, up to now, do not consider more sophisticated algorithms.

Do you think that (for the issues identified in the risk analysis) the introduction of a timespan for testing and iteration would allow better control?

In the project manager's opinion, if a proper amount of time is assigned to test and iteration, control can provide results that are more consistent with reality.

A.2 DEMETO

DEMETO is an example of a project that is coherent with NextChem's mission. The project is developed in the framework of the European Union Horizon 2020 program[58]. The technology, industrialised by the project, has the goal to create a new source of raw materials for the plastics market that guarantees the strong advantage over the currently existing main alternatives: direct monomers production from fossil fuel and mechanical elaboration of waste to offer R-PET[58]. The project success is reached proving and validating the innovative technology on a semi-industrial scale: the technology can be considered validated if the recovered monomers have similar characteristics – in terms of purity – of the same molecules produced conventionally. To achieve the stated objectives, the project scope is mainly focused on the construction and management of a pilot plant having a capacity of 60 kg/h of inlet PET.

DEMETO technology allows to recycle PET and to treat very contaminated and coloured PET flakes (where other chemical recycling processes fail). Unlike other materials (i.e. aluminum or glass), PET is reused and not recycled: each time PET is reused the quality of the polymer degrades. By adopting a chemical recycling, i.e. hydrolysing the polymer through an alkaline depolymerization reaction, PET monomers are recovered and purified to be addressed to the production of new virgin PET. The alkaline depolymerization reaction is assisted by microwave radiation: microwave irradiation, compared with conventional thermal heating, provides some advantages such as rapid change of temperature with high specificity without contact with material and shorter reaction times.

The project technology was already tested in a small pilot-scale plant realized and managed by GR3N, a project partner and owner of the knowledge of the technology. As the experimental phase was successfully completed for the original pilot, the design of the demonstration plant was partially based on results and indications derived from it.

The project started on 1st September 2009 and is planned to end on 30th November 2020. It included a first phase (18 months) devoted to the process development by designing a demo plant; the second phase (21 months) is ongoing and related to the pilot plant construction and experimentation to validate the technology.
The project schedule has been elongated due to design modifications during the engineering execution phase. The design of the plant was reviewed, switching from continuous operation to batch one due to the limited budget for equipment procurement. Because of the above modifications, cost analysis is still in progress. In addition to design modifications, another critical issue was the delivery time for some components for the demo plant: this had the potential to affect the overall development of the project increasing its costs.
Up to now, no problem related to the technology showed up: this can be explained by the fact that issues are usually faced in the construction of a laboratory pilot plant, which is not the case. No problems ware encountered in the equipment procurement; in fact, it was available on the market without any need for customization for the semi-industrial scale. The unit's behaviour with process mixtures has to be studied.

A.2.1 Uncertainties

Which were your activities characterized by uncertainties?

In DEMETO project, the activities characterized by uncertainty were:

a) possible elongation of testing phase due to budget constraints that imposed the process to operate in batch: tests time are longer with respect to the originally planned continuous process;

b) the possibility of incurring in extra times and costs due to the poor knowledge about the behaviour of the reaction mixture in semi-industrial scale equipment.

How did you reduce the uncertainties associated with planned activities?

In the project, uncertainties related to activities were addressed by:

a) planning in advance experimental tests and times related to them have been optimized; lack of time is due to deadlines imposed by EU. By this way, the minor number of measures needed for technology validation and for future industrial construction can be taken;
b) establishing a strong collaboration with partners and suppliers, during the procurement phase, to select the right equipment for all the operation.

A.2.2 Risks

Which were, at the early stages, your uncertain and undesired events and their effects?

The project uncertain and undesired events were identified as possible:

a) corrosion problems due to the material selected for the construction of some equipment installed in the demo plant;
b) non-efficient operations (mostly terephthalic acid crystallization): they were selected according to literature but had not been tested on laboratory and pre-pilot scale.

The effects for both undesired events would not affect DEMETO project directly: hence, the core idea behind the demonstration plant is obtaining parameters for the construction of an industrial plant by testing the behaviour of some materials used for unit construction and testing technology operations. In case materials and operations would not suit the process, corrective measures will be taken when designing the industrial plant.

Is it possible to consider risk mitigation actions for uncertain events?

Yes, it is. The equipment has been designed to allow changing operative parameters in order to modify them to achieve product specifications.

Is it possible to assign a value for risk related to undesired events?

Yes, it is. For DEMETO project, a risk map was produced. It qualitatively assesses the impact and the probability of occurrence of undesired events. Tab. A-1 represents the formalization of the quantitative risk analysis performed for the project.

Table A-1: Qualitative Risk Analysis for DEMETO project

Description of risk	Level	Likelihood	Overall risk	Actions to prevent/manage
Analysis Risks:				
Unsatisfactory initial definition of end-user's requirements and constraints can influence the possibility to draft properly the pilot plant functional architecture	Medium	Low	Low	The project fosters an integrated approach, promotes strong commitment of key actors, and early involvement of all the partners. This minimizes this risk. Moreover, the technical content of DEMETO is the result of several years of development and analysis through various TRL, meaning that the understanding of requirements and constraints for a pilot plant is already very advanced.
Development Risks:				
Failure in the reference specifications of the functional architecture of the pilot plant	High	Low	Low	DEMETO's key partners are international experts in the two complementary fields of expertise required by the project (mechatronic conception and process design and construction) with several years of experience in innovation project, both with EC research programs and at industrial level. In addition, the reference process for the pilot plant has already been designed and studies at lower TRL levels, leading to an extensive understanding of its complexities, which have been covered by involving experts of the corresponding fields. Even if there is no possible backup solution to this risk, resulting in the failure of the project, the likelihood is extremely low.
Unforeseen design complexities limit the functionalities of the Reactive Unit prototype	Medium	Low	Low	The Reactive Unit is the aggregation, in a modular configuration, of more than one reactor to sustain flexible productivity of a plant. Since the project starts from industrialized design of the single reactor, the

				engineering effort required to finalize the design is limited; in addition, the different subsystem have been divided in parallel tasks' activities, decoupling the risks. Finally, even in case of reaching a non-optimal solution, the functional requirements of the Reactive Unit would still be reached (because they depend on the reactors), leaving the opportunity of further refinement during industrialization.
Failure in down-sizing the pilot plant design with respect to a full-size plant	Medium	Low	Low	The pilot plant is a down-sized version of what will be an average de-polymerization plant. While the Reactive Unit is modular in its conception, the Treatment Unit can have some difficulties in adapting to this reduced flows. The risk is still low because it does not involve functionalities but efficiency of the process, that would be automatically solved when dealing with bigger plants.
Implementation Risks:				
Delay in realization phase hinders the validation of the pilot plant	High	Medium	Medium	This is clearly the highest risk of the project, because several parallel realization tasks need to be accomplished to reach the functional and commissioned pilot plant. The following measures have been considered to reduce the risk: an initial shared plan is devised together with all partners, establishing a common framework for activities since the beginning; Reactive Unit and plant construction are parallelized, followed by different teams and can reach independently a high degree of maturity even in case of delay of the other component; all non-innovative activities are identified at the beginning of the project and planned in advance, considering also the provision of services from sub-contractors; finally, senior engineer experts in commissioning of process industry plants are involved within the project since the beginning.

Failure to meet the initial requirements in the validation phase	High	Low	Low	Tasks are specifically set up so that the end-users are involved in a detailed scenario requirements definition, meant to steer the project efforts towards effective demonstration. Thus, it is minimized the chances that the requirements are not met.
Demonstrators failure, not demonstrating industrial benefits	Medium	Low	Low	DEMETO's is built on top of several steps of TRL evolution, which has progressively verified at different levels of complexity the functionalities and performance of the technology. The pilot plant realization will allow the first time demonstration of all process steps together, but since they have been all confirmed previously at lower TRL, this risk is very low.
Acceptance risks:				
Failure to design a market acceptable business model	Medium	Low	Low	The technology of DEMETO is disruptive and conceived to be commercially deployed on an existing and mature value chain. In addition, the two major customer segments are involved explicitly into the project to validate and correct the quality and numbers of the business plan.

Which uncertain events considerably affected the project?

The uncertain events that affected the most the project were:

a) the non-optimal process development caused by the poorness of the experimental data (related to unit design) generated by project partners. This caused a delay in the further development of the project, today quantifiable in 5-6 months;
b) the fixed budget available for the construction of the plant. The budget was developed and approved by the European Union during the proposal stage and cannot be modified. It strongly affected/s all the decision phases of the project. This event caused a general elongation of the project.

How were managed the associated risks?

Risks were managed respectively by:

a) adopting a detailed plan to validate the laboratory results: laboratory tests were repeated in different sites while being monitored by NextChem. Literature was reviewed;
b) as mitigation action, part of the budget was moved from different cost items. As last mitigation measure, for the expenses exceeding the budget, the Company asked for further assistance to local government (tax credits).

Could a preliminary analysis of possible corrective actions be useful?

It is thought that a preliminary analysis can represent a Go/No-Go analysis. In the actual Project, this analysis was performed and all factors studied represented a Go gate for DEMETO.

Do you think that dealing with critical items/project phases first could diminish the impact on project times and costs?

Yes. Unfortunately, for DEMETO it was not adopted because criticalities showed up only during the project execution.

A.2.3 Applied project control techniques

How did you control the activities?

Project progress is computed registering spent hours and comparing them with planned hours (according to what request by EU and to the usual NextChem operations).

How was the baseline built?

A schedule of the project was created during the proposal stage (as required by EU). The timing was and is periodically updated taking into account adjustment deriving from uncertainties and unexpected events. The schedule was built dividing the overall scope of work into work packages that were assigned times and resources. The order for activities was established using precedences according to what is done in the CPM. Each work package was divided into activities to which roles and responsibilities were assigned. NextChem was in charge of coordinating all the tasks: the fulfilment of deliverables is meant to complete the planned milestones and achieve the results forecasted. Each deliverable is subjected to strict deadlines.

Why did control problems occur?

NextChem is the leader of the Consortium for the actuation of the project. One of the critical topics is the difficulty to check the progress of several EU partners. In particular, NextChem is not intended to do a capillary control over all the tasks to be performed: the Company is in charge of controlling how the partners invest resources. Creeps are examined by EU that can choose to approve costs and time deviations.

Do you think that the adoption of a different control metric would have better represented the project progress?

In the Project Manager opinion's it could be possible, but she also underlines that – for projects developed under the rules of the European Union, this could cause big issues. EU establishes many constraints, especially for the procurement activities: these could represent obligations and establish some procedures which are different from the currently used by the Company. Control, in general, is done in accordance with the proposal and the budget approved and granted by the EU.

Do you think that (for the issues identified in the risk analysis) the introduction of a timespan for testing and iteration would allow better control?

Although NextChem is not applying a capillary control, introducing a phase for testing and iteration is, in the project manager's opinion a valid proposal. The project manager adds that the insertion of the aforementioned timespan should be added in the early scheduling of the European Union projects: by this means, the addition of the phase would comply with the established deadlines.

A.3 H_2S Cracking

As environmental regulations are becoming more stringent, Kinetics Technology has developed an innovative process; thanks to a catalytic cracking partial oxidation, the CO_2 emissions are reduced and valuable products, such as hydrogen, and sulphur are recovered.

The H_2S cracking reaction mechanism is based on the following reactions:

(1) $H_2S + \frac{3}{2}O_2 \rightarrow H_2O + SO_2$ (Oxidation reaction)

(2) $H_2S + \frac{1}{2}O_2 \rightarrow \frac{1}{2}S_2 + H_2O$ (Partial oxidation reaction)

(3) $2H_2S + SO_2 \leftrightarrow 2H_2O + \frac{3}{n}S_n$ (Claus reaction)

(4) $H_2S \leftrightarrow H_2 + \frac{1}{2}S_2$ (Cracking reaction)

H_2S adsorbs on the proprietary catalyst where it can be partially or totally oxidized (2), (1): these two oxidation reactions produce the heat required for (3) and (4). At the same time, part of H_2S adsorbed over the catalyst reacts with SO_2 according to the Claus reaction (3) and then another part of H_2S produces H_2 by cracking reaction (4).

The proprietary catalyst was studied[59], [60] and developed by the collaboration of KT and University of Salerno (Unisa). A dedicated laboratory plant to test the proprietary catalyst and the Novel Process has been designed, built and is running at University of Salerno.

In 2016, a demonstration plant was currently under construction to validate the new technology.
The plant configuration includes a Sour Gas SOAP™ section and a Tail Gas Treatment Section amine-based. The core part of the plant is the Sour Gas Selective & Oxidative Auto-thermal Process (Sour Gas SOAP™) section, where the H_2S cracking reaction is enhanced by the Innovative KT Proprietary Catalyst[61]. In the Tail Gas Treatment Section, the Claus Tail Gas is mixed with Hydrogen Rich Gas and then it is sent to the Hydrogenation Reactor, where all components containing sulphur are reduced and/or are hydrolysed to H_2S[61]. Tail Gas is then sent to Quench Tower where, through direct contact with circulating water, steam is condensed and gas is cooled down. The H_2S contained in Tail Gas is removed by the use of an amine solution[61]. The amine solution is regenerated through a dedicated section. The Sweet Tail Gas is finally sent to the incinerator before being released to the atmosphere: the

liquid sulphur which is still contained in the sweet gas is treated in a degassing section where H_2S is completely removed and recycled to the Claus.

A.3.1 Risks

Is it possible to assign a value for risk related to undesired events?

Yes, it is possible both to define their occurrence probability and forecasted impact. The project manager refers that, above all for R&D projects, the tool of risk analysis is fundamental because it not only detects potential undesired events, but also it is useful to build a solid budget for the project.

Could a preliminary analysis of possible corrective actions be useful?

It is thought that a preliminary analysis can represent a first Go/No-Go analysis: hence, studying whether some mitigation or corrective measures can be undertaken allows understanding if proceeding with the project or not.

Do you think that dealing with critical items/project phases first could diminish the impact on project times and costs?

Only if critical item/project phases are studied before the construction and operation phases. Simply reversing tasks in the schedule – without any previous study on criticalities – implies extra costs and delays on the project. All the undesired events individuated in the risk analysis should be addressed in the Engineering phase, more specifically during the BASIC study.

It is also pointed out that some criticalities can be missed out during preliminary studies as well as they cannot be studied before the whole plant is constructed; this condition – which is quite typical for R&D projects – can only be accepted: adequate corrective actions will be applied to face potential issues.

A.3.2 Applied project control techniques

How did you control the activities?

Project progress is computed registering spent hours and comparing them with planned hours. The same approach was adopted for materials and services budget.

How was the baseline built?

The baseline was built according to corporate procedures: traditional planning tools and techniques were employed. Activities and milestones were assigned times and resources and organized visually with Gantt charts.

Did some control problems occur?

No control problem occurred during the project execution. This was allowed by the choice to maximize resources in order to achieve the set milestones according to assigned deadlines.

Do you think that the adoption of a different control metric would have better represented the project progress?

The project manager clarifies that, from his perspective, the control metric is uniquely an algorithm that produces a value that should represent the project control: its accuracy depends on the level of knowledge about how activities will be performed (resources, times, etc.).

Do you think that (for problematic activities) the introduction of a timespan for testing and iteration would allow a better control?

Yes. Usually, R&D projects are developed in accordance with corporate guidelines which include some timespan for the most problematic and uncertain activities. Times devoted to test and to verify some unit functionality – or theoretical assumptions – should be included in the schedule related to Engineering studies. In addition, the allocation of contingencies prevents the project to incur into delays.