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Treball Final de Màster

Optimization of the PERT/CPM project management methodology by implementing the Lean and Agile philosophies.

Optimització de la metodologia de gestió de projectes PERT/CPM implementant les filosofies Lean i Agile.

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REPORT

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1 SUMMARY

Companies need to tackle investment projects in order to be more competitive. The proper management of such projects is a key factor for the company's results. In particular, the construction phase is a critical point since it is the stage where time and/or resources constraints do not often meet, mainly because of the susceptibility to the acceptance of potential changes. In order to comply with such restrictions, project managers are supported by different management techniques, such as the widely implemented PERT/CPM (Program Evaluation and Review Technique/ Critical Path Method) Also, some other novel methodologies are being developed, such as Lean or Agile, in the field of project management.

The objective of this study is to assess the impact of an improved, novel combination of such project management methodologies, on the achievement of time and resource constraints. As a methodology, a real case-study has been addressed by showing a comparison of the results obtained with the use of the conventional PERT/CPM methodology to the implemented of the new project management methodology proposed. The case-study focuses on the construction phase of a revamp project in an Ethylene Glycol plant, which consists on changing the existing structured packing from a MEG (monoethylene glycol) distillation column to a high performance one, in order to increase capacity, while keeping the same efficiency.

The main constraints that apply this project refer to limited affordable plant shutdown time due to commercial reasons and also to the strictly planned availability of a specialist technician, responsible of the most critical task, to fit in the new structured packing.

This study begins with the implementation of the PERT/CPM methodology to programme the construction phase. Although this technique allows to identify the critical path and therefore determine the total duration of the project, it has substantial limitations. The main one, is the lack of tools to optimize the planning either to meet the project constraints or even to make it more reliable. The study reveals that just applying the conventional PERT/CPM methodology based on timings experienced in previous similar projects does not allow to accomplish with the required constraints.

For that reason, a novel methodology is developed to ensure the accomplishment of time and resources constraints. A SWOT analysis is run to identify weaknesses and potential threats which are overcome through the introduction of Lean and Agile techniques. As a result, a modified PERT/CPM with Agile and Lean methodologies have been developed. Whereas PERT/CPM sets the operative basis for the project management, its upgrade with the philosophies Agile and Lean provides a combined framework, which not only addresses the timely organization of the activities, but also provides tools to deal with time and resources constraints. The report reveals that this innovative combined technique

ensures compliance with the established deadlines while increasing the reliability of the project's results.

Finally, the present study proposes the implementation of a risk assessment as an objective and rigorous methodology for the proper resource assignment, an issue which in today's project tends to be done either arbitrarily or on the background of previous project experiences, resulting in inefficient resource management and high financial losses

In conclusion, because of the flexible framework provided by this innovative methodology, it can also be applied in small improvement projects, in other sectors different from the chemical industry and even in maintenance activities that have to be organised on a daily basis in production plants.

2 INTRODUCTION

In order to be competitive, chemical companies need to tackle investment projects continuously. They could be either oriented to the maintenance of production units or growth projects to gain competitiveness in the market. The proper management of such projects is a key factor for the company's results. For example, the delay of a project, whose implementation may require from the shutdown of the plant, entails large monetary losses (Amendola, 2017). In particular, the construction phase is a critical point since it is the stage where time and/or resource constraints do not often meet. According to a study by IDC Technologies, nearly 90% of shutdown turnaround experience an increase in project scope of between 10-50%, which results in consuming more time and resources than initially established (VIZIYA, 2019).

The most common tool used to programme the construction phase of projects is known as "PERT/CPM" (Program Evaluation and Review Technique/ Critical Path Method) which is classified as a waterfall technique due to its sequential approach. This methodology groups the project activities sequentially, thereby identifying the critical path, which defines the duration of the project and the activities that cannot be delayed, which would negatively impact the overall duration of the project (Hillier, 2000). Nevertheless, this technique merely provides information on the critical path, but does not offer guidelines to reduce the risk of not complying with deadlines and/or resources. Thus, even though it is a widely applied methodology, it is susceptible to be improved.

It is therefore essential, at the present time, to develop a project management methodology for the chemical company that allows to improve the results obtained with the typical PERT/CPM methodology, particularly in construction projects that are characterised by being very susceptible to the acceptance of changes. The existing literature provides alternatives, such as Lean and Agile methodologies. Lean is oriented to eliminate unnecessary activities, called *waste*, so as to improve the efficiency of the project management, whereas Agile provides tools to manage changes efficiently in the projects. Nevertheless, none of these methodologies individually are able to cover all requirements. This study aims to develop a new project management methodology, which ensures to meet time and resources constraints on construction projects. Through a case study based on a revamping of the packing in a distillation column, the benefits of the application of this novel methodology in comparison to the traditional waterfall approach, PERT/CPM technique, will be assessed.

The novel methodology joins together the benefits of known techniques, such as PERT/CPM, Lean and Agile. An issue, which is still poorly covered, such as optimizing the distribution of resources, is addressed by completing this methodology with a newly developed risk analysis technique for the

activities identified as critical in order to assign resources in the optimal way and, thereby, to reduce the risk of not meeting the planning.

The selection of such methodologies to integrate the newly developed project management technique arises from the application of a SWOT analysis (strengths, weaknesses, opportunities, and threats).

Despite the new methodology has been developed for a construction project within the petrochemical sector, it is also applicable in the construction phase of many other projects of different size and sector such as pharmaceutical or pulp and paper industry.

In addition, this methodology could also be suitable to other stages of an engineering project where planning phase is required and, therefore, it has wide field of application.

3 OBJECTIVE

The objective of this project is to develop a project management methodology to ensure the accomplishment of time and resource constraints.

In order to achieve this objective, the following milestones are set:

- Investigate the current methodologies and tools for project management by means of literature search.
- Developing an innovative project management methodology based on data collected.
- Through a case-study of a construction project, verify the impact of implementing this new methodology in terms of meeting and/or optimising the project constraints, in comparison to the PERT/CPM method.

4 BACKGROUND

4.1 DEFINITION OF THE TERM “PROJECT”

A project is deemed as a work or assignment with a defined and unique scope, which is bound by a set of constraints.

Regarding the above definition, defined scope is understood as everything that is expected to be achieved at the end of the project. Furthermore, all projects have certain new or different features that make them different from what has been done before. For this reason, the scope of the project is also deemed to be unique. These singularities such as constraints, which are specific to each project, make it necessary to undertake a prior analysis and planning. This is the main reason why project management is separated from operations management.

Projects are deemed to be a core business activity in the company's organisation as it is reflected in Figure 1. Therefore, the technical success of projects, as well as the fulfilment of time and resources constraints is key for the results of the company.

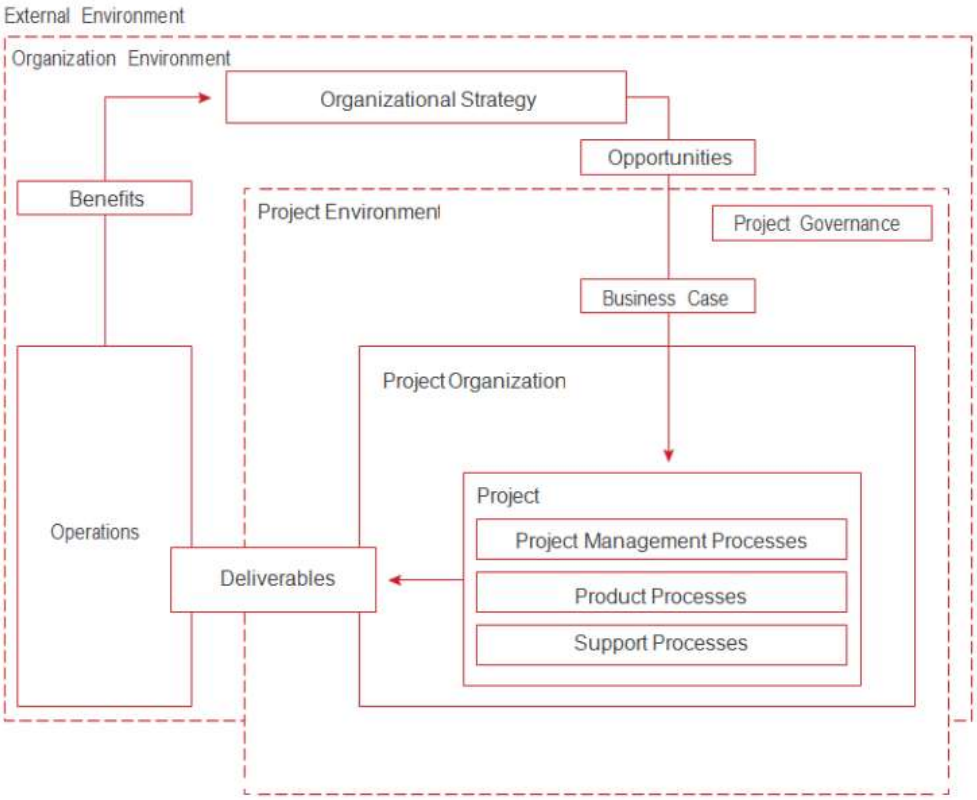


Figure 1: Organization Environment extracted from (Lachapelle, Hundozi, & Ajvazi, 2015))

The above framework represents the organization where the activities are executed. This organization has a strategy to achieve its objectives. According to these, the organisation identifies opportunities and analyses them to assess which ones are feasible and profitable. The opportunities that are finally approved lead to projects, which generate, as a result, a series of deliverables that are incorporated into the organisation's operational activities. The organization uses them in its daily activities to generate benefits that are returned to the organization.

Therefore, the projects can be seen as “The way in which companies take advantage of opportunities and integrate them into their operations to generate benefits in order to be more competitive” (Garriga, 2018)

4.2 PHASES OF AN ENGINEERING PROJECT

Every engineering project has the following life cycle as it is shown in Figure 2:

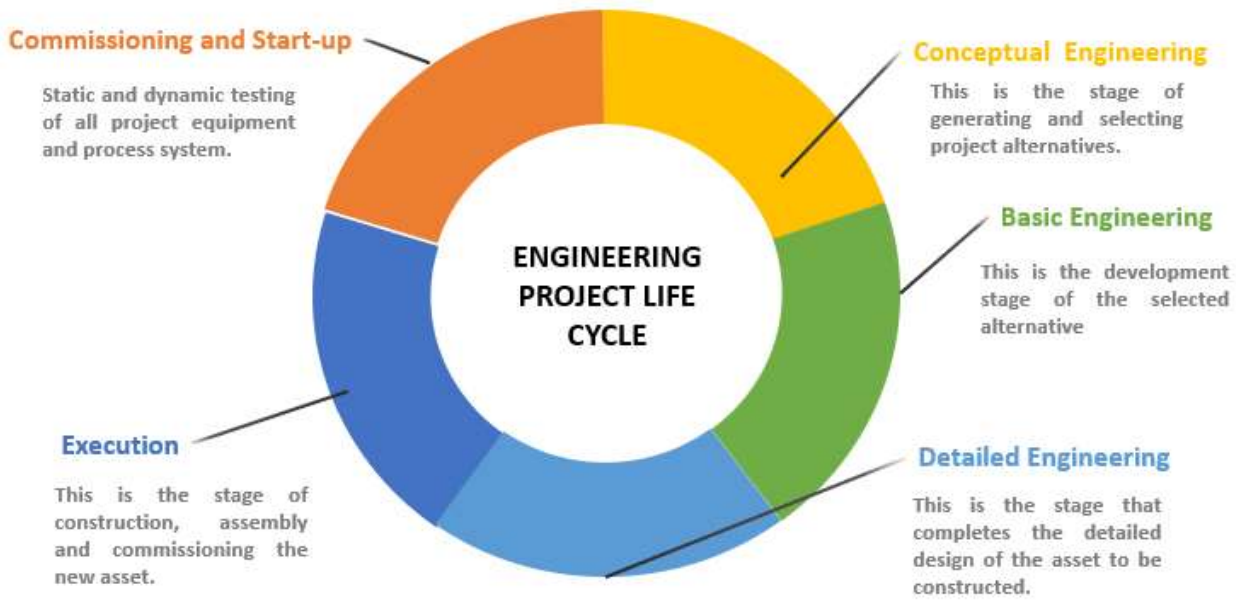


Figure 2: Phases of an engineering project (adapted from (Ciclo de Vida de Un Proyecto de Ingenieria - Equipo PLC, n.d.)

A more detailed explanation of each of the phases is given below:

Conceptual Engineering: This is the first stage of an engineering project, in which the problem or specific need posed by client is understood and different solution alternatives are conceived. These alternatives are evaluated under technical, economic, and social criteria (safety and environment), and the results are presented, giving a priority order to the alternatives analysed. The client, either unilaterally or jointly with the contractor, chooses the most convenient alternative. Typically for this phase, an accuracy in the range of 25% to 35% in investment costs is estimated.

Basic Engineering: In this phase, the alternative selected in the conceptual engineering stage is developed to such a level of resolution that a very clear idea of how the project will "look" is obtained; the general dimensions of the system are established, the scheduling of the construction stages and the calculation of budgets for global items. The aim is to achieve a degree of precision that allows for decision-making. Typically for this phase, an accuracy in the range of 15% to 25% in investment costs is estimated.

Detailed Engineering: Detailed engineering is the final design stage of a project, it is developed with all the technical specifications necessary for the construction and assembly in all the specialties involved in the project, from a technical, economic, temporal and legal point of view. Accuracy is estimated to be in the range of 5% to 15%.

Execution or Construction: This is the realization of the project. In this stage all components and systems are procured, built, and installed, according to the designs and technical specifications developed in the detailed engineering stage, within the budgeted time and cost.

Commissioning and start-up: In this stage, all equipment and systems are tested to finally carry out the start-up of the process unit before the operation. In addition, the end of this stage is known as project closure because it is the moment when the project is transferred to the client, compiling all the necessary documents for its official handover: history, development, manuals and updated plans; terminating each and every one of the contracts.

It is noteworthy to mention that this study is focused on the construction phase and particularly on its planning as it is the most time- and resource-sensitive block (Amendola, 2017).

4.3 PROJECT MANAGEMENT

As it is briefly mentioned in 4.1, each project is limited by several constraints such as limited resources, the need to meet the budget, the completion time stipulated by client, etc., which requires an efficient use of resources, a good eco-economic analysis and detailed planning, among other tasks, in order to comply with such constraints. Hence, it is in this context where the figure of the project manager is conceived; "Project management arises from the need to achieve the scope of the project by respecting, or even optimizing, its constraints" (Garriga, 2018)

Therefore, in the planning phase, the aim is to define a feasible way to reach the scope, while respecting the constraints of the project. Once the planning is defined, the execution will start, where the project must be guided and controlled to ensure that it follows the planning, implementing the necessary contingency measures in case of deviations.

A key point is the fact that the execution of a project is not always perfect. In many cases, there are requests for changes, contingencies, delays, etc., deviations that the project manager will have to deal with. Fixing these issues at an advanced stage of the project can cause cost overruns and may result in not respecting the previously agreed constraints, especially in terms of time. For this reason, the planning should not only be viable but also as accurate as possible, considering these potential variances from the outset. In brief, changes that are likely to appear in the future must be prevented in the planning phase.

According to this, project managers are supported by different management techniques that assist them to manage the project properly. This linkage is known as project management. In a nutshell, "Project management is understood as a set of defined actions that ensure the fulfilment of an objective within a specific deadline, during which resources, tools, methodologies and talents are used" (Raffino, 2020)

4.4 PROJECT MANAGEMENT METHODOLOGIES

According to PMI (Project Management Institute) a methodology is a system of practices, techniques, procedures and rules used by those who work in discipline.(Muslihat, 2021)

Below, the most commonly implemented tools and methodologies for project management will be outlined.

PMI/PMBOK - is an acronym for Project Management Body of Knowledge. It's a book, published by PMI (Project Management Institute), that collects the processes, best practices, terminologies, and guidelines that are the accepted norm in the industry. The text breaks down a project into five process groups: initiating, planning, executing, controlling, and closing.(Wilson, 2020)

WATERFALL – It is a process in which the phases of the project flow downward. The model requires that you move from one phase to another only once that phase has been successfully completed. Waterfall often makes use of a Gantt chart for planning and scheduling.(Kerzner, 2017)

PERT – It is a project management tool used to schedule, organize, and coordinate uncertain tasks within a project. The technique studies and represents the tasks undertaken to complete a project, to identify the least time for completing a task and the minimum time required to complete the whole project.(Kerzner, 2017)

CPM – It is an algorithm used for planning, scheduling, coordination, and control of activities in a project. In contrast to PERT technique, CPM assumes that the activity duration is fixed and certain. CPM is used to compute the earliest and latest possible start time for each activity by identifying the duration of each activity and the dependencies between them. The process differentiates the critical and non-critical activities in order to identify which activities can't be delayed in order to meet the deadline stablished. (Wilson, 2020)

CCPM- It's a less technical method of project management that doesn't put as much emphasis on task order or scheduling, but rather on balancing resources such as teams, equipment, office space, etc. and keeping them flexible.(Kerzner, 2017)

Agile – It is an iterative, flexible, and '*build process*' methodology that helps project managers to come up with better results. The agile process is based on reviewing decision making and activities whenever a change or arrangement is required, whether the client wants something new or the project team has come up with a better idea. Its target is making the project less susceptible to changes.(Muslihat, 2021)

Scrum – It is a framework that shares agile philosophy, focused on breaking the tasks and activities into further sub-tasks – called "*sprints"* – to execute and handle them in a better way.(Muslihat, 2021)

Kanban – it is a tool rather than a methodology based on agile approach, focused on reducing the work in process, get things done faster, and have the best collaborative processes by allowing every member of the project team to see the timeline in real-time. Each task of the project can be labelled as, for instance, 'in progress', 'completed' or 'delayed' and can be viewed by everyone.(Wilson, 2020)

Lean – It is all about reducing the waste and in so doing increase value. Nowadays, teams run Lean processes to focus on end user feedback and increased value. There are five main principles to Lean:

specifying value by the customer, identify value stream, make product flow continuously, introduce pull through each step and manage towards removing unnecessary steps (work).(Muslihat, 2021)

Adaptive project framework (APF) – APF is suitable in projects with uncertain requirements since it is open to change. In fact, it thrives on change, learning by iterative delivery and driven by a deep client involvement. In a nutshell, APF takes advantage of agile approach but it tries to make it even more pragmatic.(Wilson, 2020)

Extreme project management (XPM) -XPM is a short and flexible method. It allows to alter project plan, budget, and final outcome to fit changing needs no matter what stage the project is in. Because of its emphasis on short duration, XPM is more suitable for projects that take only weeks or even days long.(Coolman, 2015)

Six Sigma **–** It works to improve quality by identifying what is not working in the project. It applies quality management, including empirical statistics and employs personnel who are experts in these disciplines. Its implementation takes the whole organization, from the top down, to sustain quality in a project.(Muslihat, 2021)

Crystal method **–** It is a methodology focused on "human element" rather than processes. Crystal methodology implies that if the team is managed well, it will work with better understanding and produce super results. This also means that processes and tools can be adjusted to fit the requirements of the team.(Kerzner, 2017)

PRiSM **-** PRiSM is a principle-based sustainable project management methodology. it incorporates a value-maximization model that focuses on the total asset lifecycle by reducing project level risk, from an environmental, social and economic perspective while expanding the range of benefits to be gained.(GPM, 2018)

A more detailed explanation of the methodologies involved in this project will follow.

4.5 PROJECT MANAGEMENT METHODOLOGIES INVOLVED IN THIS PROJECT

4.5.1 WATERFALL

The waterfall methodology arises from the need to set up a standardized process for software development. In 1985, the United States Department of Defence published Standard 2167 (DoD-STS-2167) known as the waterfall model. This standard was based on a paper called "Managing the Development of Large Software Systems" written in 1970 by Winston Royce (Alaimo, 2018).

The waterfall model provided a sequential approach to software development management by deconstructing the project into steps with the start of one phase depending on the completion of the previous one. The different stages were sequentially followed flowing from top to bottom one after the

other like a waterfall: "Requirements, Analysis, Design, Coding, Testing and Operation" as shown in Figure 3:

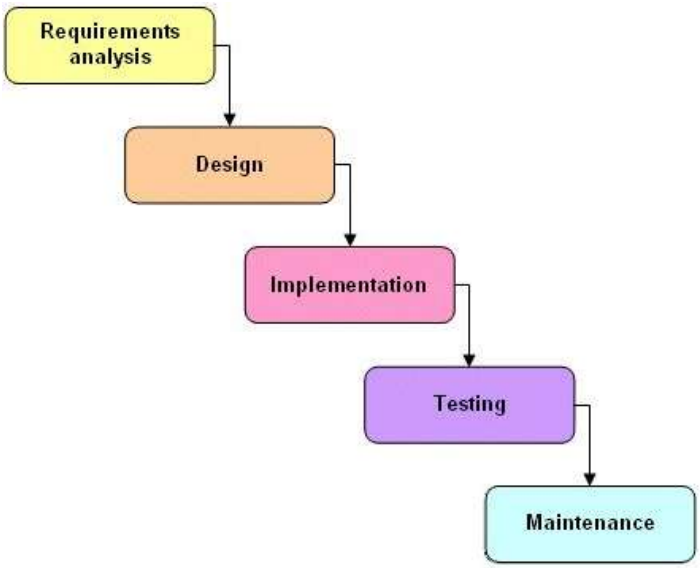


Figure 3: Stages of Waterfall methodology (adapted from (Pimparkhede, 2018) *)*

It is worth mentioning that its author, Winston Royce, does not recommend this method, but foresees its risks and suggests that it should be iterated at least twice. In the paper, he mentions that this process "invites failure".

Therefore, this methodology is more suited for stable projects such as construction projects, where the requirements are clearly defined and are not expected change or minimum contingencies during the development process.(ON-TIME, 2020).

However, unfortunately, this is not the case of most construction projects.

On the other hand, more flexible methodologies such as Agile are applied for software projects.

Two core Waterfall project management techniques are Critical Path Management (CPM) and Project Evaluation and Review Technique (PERT). Both are based on a sequential approach as WATERFALL methodology but with a more sophisticated procedures for the planning-control of the activities throughout the project in order to address the shortcomings of the traditional waterfall method.

4.5.2 PERT/CPM

PERT/CPM methodology is a derivation of the waterfall technique based on assist project managers in coordinating the numerous activities throughout the organization. In addition, it allows to develop a realistic schedule and, then, monitoring the progress of the project.

This methodology is composed of two techniques: PERT and CPM. Although both techniques differ in significant aspects, they also have a great deal in common that has led them to merge into a singly acronym; PERT/CPM.

Descriptions of each technique are given below.

4.5.2.1 PERT

Project Evaluation and Review Technique (PERT) is a project management tool used to schedule, organize, and coordinate tasks within a project. It is basically a method to analyse the tasks involved in completing a given project, especially time needed to complete each task and to identify the minimum time needed to complete the total project.

PERT uses probabilistic time estimates to know the duration of the activities, based on three different stages: optimistic time (to), realistic time (tm) and pessimistic time (tp). The expected time (te) is computed using the formula:

te= (to + 4*tm +tp) /6 *(eq.1)*

It is used in projects where there is a high degree of uncertainty about the individual activity duration and when time is the major factor rather than cost. (Carstens et al., 2016)

4.5.2.2 CPM

The critical path method (CPM) is a step-by-step project management methodology for process planning that defines critical and non-critical tasks with the goal of preventing time-frame problems and process bottlenecks. It is used to complete projects on time by focusing on key tasks which make up the critical path; the shortest duration in which the project can be completed. (Carstens et al., 2016)

CPM technique employs one time estimate and one cost estimate for each activity contrarily PERT tool which uses three different stages. A useful approach to see their main difference is Table 1. Regarding Table 1, we can conclude:

PERT System

Strong points:

- It is useful in research based on complex activities with high-risk of uncertain duration.
- It allows to evaluate and apply better alternative
- It makes a kind of forward-looking control possible

Weak points:

- It is not useful when no reasonable time estimates of time schedule can be made
- It emphasises time but not cost.

CPM system:

Strong points

- It discovers and makes dependencies visible
- It shows the critical path and identifies critical activities that require special attention
- It helps you to assign the float to activities and flexibility to float activities.

	PERT	CPM
Definition	A technique of planning and control time	A method to control cost, resources and time
Model	Probabilistic	Deterministic
Focuses on	Time	Time-cost trade-off
Estimates	Three times estimates	One-time estimate
Appropriate for	High precision time estimate	Reasonable time estimate
Management of	Unpredictable Activities	Predictable activities
Nature of jobs	Non-repetitive	Repetitive
Critical and Non-critical activities	No differentiation	Differentiated
Suitable for	Research and Development Project	Non-research projects, like civil construction ship building etc.

Table 1: Comparison between PERT and CPM (adapted from (Hillier, 2000) *)*

Weak points:

- It always assumes that all resources are available; it does not consider resource dependencies.
- There are chances of forgetting float or slack causing non-critical activities to turn into critical activities.

Based on the above information, it is easier to understand why these two techniques are combined. Lastly, the PERT/CPM methodology's general structure is set out.

4.5.2.3 PERT/CPM FRAMEWORK

Key concepts

Sequential methodology -The sequence of activities leading from the starting point of the diagram to the finishing point is called a path. The path with the longest total time is then called the "critical path". It determines the completion date of the project. In this path, the activities can be performed sequentially without interruption. Therefore, the activities on this critical path are the critical bottleneck activities where any delays in their completion must be avoided to prevent delaying project completion. Hence, every project manager must be focused on keeping these particular activities on schedule in striving to keep the overall project on schedule. Furthermore, if one wants to reduce the duration of the project, critical activities are the main ones where changes such as more resources, for example, should be delivered in order to reduce their duration and, consequently, the project duration.

However, managers can also gain valuable insight by examining paths other than the critical path. Since these paths require less time to be completed, they can often accommodate slippage without affecting the project time. For example, allocating fewer resources in these paths and taking advantage of the remaining resources for activities which belong to the critical path in order to reduce the risk in complex activities.

Therefore, the key conclusion is that the estimated project duration equals the length of the longest path through the project network. This longest path is called the critical path. (if more than one path ties for the longest, they all are critical paths)

Slack and Float - The difference between the length of a given path and the length of the critical paths is known as slack. Slack time allows an activity to start later than originally planned, while float time allows an activity to take longer than originally planned.

PERT/CPM rules

- All activities on any given path must be done one after another with no overlap
- When a given activity has more than one immediate predecessor, all must be finished before the activity can begin

PERT/CPM procedure

The procedure is based on scheduling individual activities putting on ES, EF, and LS, LF time concepts.

Where:

ES = Earliest start time

EF= Earliest finish time

LS= Latest start time

LF= Latest finish time

For ES and EF, there are key points that must be outlined:

1) It is assumed that there are no delays, therefore the duration of each activity is the same as its estimated
2) Each activity begins as soon as its predecessors are finished
3) The procedure is based on starting with the initial activities and work forward in time toward the final activities to calculate all the ES and EF values, **forward pass.**

Then:

ES – Earliest start time for a particular activity

ES= EF for predecessor activity

In case of more than one predecessor, the rule is "the earliest start time of an activity is equal to the largest of the earliest finish times of its immediate predecessors".

ES = largest EF of the immediate predecessors

EF- Earliest finish time for a particular activity

EF= ES+ (estimated) duration of the activity

For LS and LF, the key points are the following ones:

1) It assumes that some activity could take longer than its estimated duration
2) An activity's immediate successors cannot start until the activity finishes. Therefore, the activity must finish in time to enable all its immediate successors to begin by their latest start times.
3) The procedure is to start with the final activities and work backward in time toward the initial activities to calculate all the LF and LS values, **backward pass**

Then:

LS- Latest possible time that a particular activity can start without delaying the completion of the project)

LS = LF - (estimated) duration of the activity.

LF- Latest possible time that a particular activity can finish without delaying the completion of the project

The latest finish time of an activity is equal to the smallest of the latest start times of its immediate successors.

LF= smallest LS of the immediate successors.

For the finish node-activity, LF=EF

Working on that basis ensure that even if an activity starts and finishes by its LS and LF there will remain no delay to the project. However, to allow for unexpected delays, it would be better to stick instead to the earliest time schedule whenever possible in order to provide some slack in parts of the schedule.

Identifying Slack

If the start and finish times for a particular activity are later than the corresponding earliest times, then this activity has some slack in the schedule. Identifying this slack allows to find the critical path.

To identify the slack, it is convenient to combine the latest times and the earliest times into a single figure as it is shown in Figure 4:

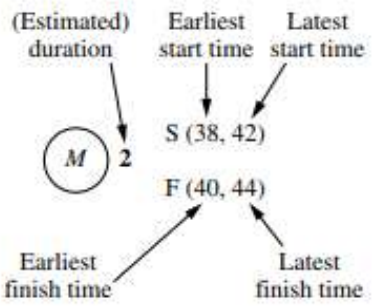


Figure 4: Example of Earliest/ Latest-Start/Finish times for a given activity (extracted from (Hillier, 2000) *)*

The slack for an activity is the difference between its latest finish time and its earliest finish time.

Slack=LF – EF *(eq.2)*

Since,

LF - EF = LS – ES *(eq.3)*

either difference actually can be used to calculate slack.

Therefore, the key concept is that each activity with zero slack is on a critical path through the project network such that any delay along this path will delay project completion.

Lastly, PERT/CPM method include other techniques in order to make the method more profit. These techniques, called involved techniques are mentioned below.

Involved techniques

- Fast tracking - a schedule compression technique in which activities or phases normally done in sequence are performed in parallel in order to finish a job earlier than normal or planned.
- Crashing – a technique used to shorten the schedule durations for the least incremental cost by adding resources. *(usually implemented for the critical activities)*
- Pruning – cutting critical path activities.

It is noteworthy to mention that, despite PERT/CPM is a useful control technique, it does not allow to optimize project planning in order to accomplish with time and resources constraints or having more room for manoeuvre.

4.5.3 AGILE

Agile is a methodology for developing projects that require both speed and flexibility. Based on agility definition, whose meaning in terms of a project is known as the ability to both create and respond to change in order to profit in a turbulent business environment , Agile “chunks” each project into small parts that must be completed and delivered in a few weeks. The goal is to develop quality products and services that meet the needs of customers whose priorities change throughout the project.

Unlike the PERT/CPM methodology, Agile believes that changes are unavoidable and therefore recommends not to fix the scope but to manage it as an ongoing task according to the development of the project. Whereas PERT/CPM is a methodology that is very susceptible to changes, since by setting the scope according to the client's initial specifications, any change implies a new planning of the forecast, which leads to a loss of agility in the project.

Agile claims that it is easier to understand the complexity of the project through decomposition, thus minimizing risk, controlling scope, and enabling measurement of progress. Therefore, scope should only be defined as far as we are currently truly able to comprehend and prioritise it from the perspectives of value realisation and risk mitigation. Thus, the project must be treat as a process and not as a serious of pre-scoped milestones/ gateways (Owen & Koskela, 2019). Figure 5 shows this approach.

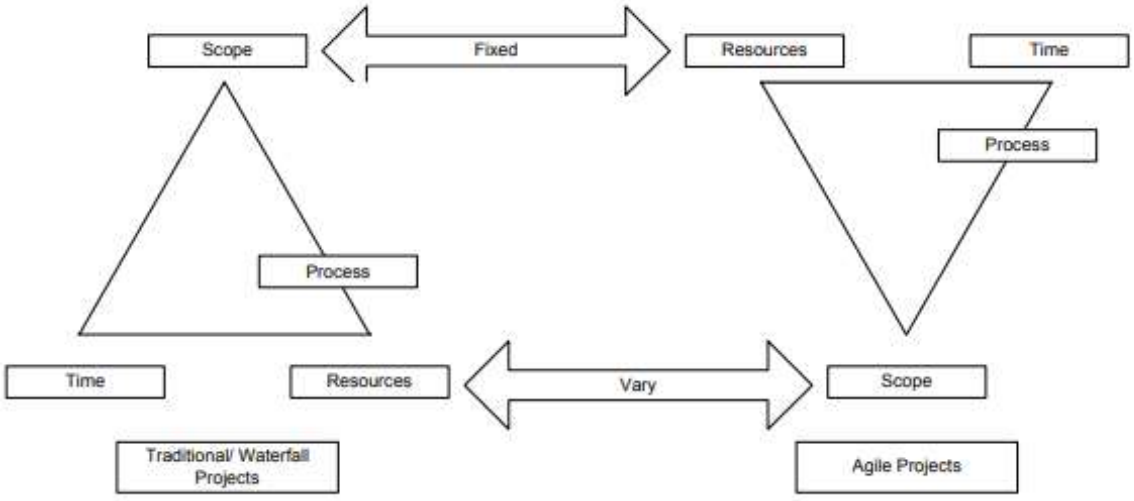


Figure 5: Changing from Waterfall to Agile Project Management (extracted from (Owen & Koskela, 2019)

Regarding Figure 5, it is important to bear in mind that whilst this illustration can easily be mapped to any design or product development process, its application to production scenarios requires caution. For example, construction resources are unlikely to remain fixed if scope is changed.

However, agile mindset could be useful in a construction phase since, although designs are quite completed and clear, significant uncertainties remain as to what is to be constructed. Hence, with the implementation of some agile guidelines, the project will be less susceptible to these potential changes.

Another of the most distinctive features of agile methodologies is the implementation of multidisciplinary teams working together, side by side, throughout the process.

Agile teams hold daily sessions in which each member has to explain three things: what tasks they have completed, what they are going to do and, if there are any, point out the impediments that have prevented them from moving forward.

These meetings, called 'dailys', help everyone on the team to know where they are in their work and to be aware of how they can work together to keep the project moving forward (Tena, 2020).

Thus, together with faster, earlier, and more frequent deliveries, the resulting product is exactly what the customer is demanding.

The two key concepts advocated by agile approach are to be more responsive to requests for change and to implement those changes more quickly and easily. In order to apply these two concepts efficiently, agile methodology uses the following guidelines:

Agile methods enable projects to be more responsive to requests for change by: (Appleton et al., 2003):

- Using short and frequent iterations to minimize the time between specifying a requirement and seeing it implemented so that adjustments to functionality and priorities can be recognized sooner rather than later.
- Requiring developers and customers to communicate and work together daily (co-located together if possible) so that change-control decisions can be made and communicated quickly and face-to-face with minimal waiting and documentation.
- Allowing and accommodating changes in scope and priorities via a highly collaborative agreement process that informs the customer of impact and risk. Puts the customer in control of the scope and priorities.
- Authorizing and empowering team members to correct problems with the code's behaviour and structure without having to suffer delays waiting for formal change proposal, review, and authorization of such corrective changes (proactive mindset).

Agile methods enable projects to implement changes more quickly and easily by: (Appleton et al., 2003):

- Working in short but complete cycles on the smallest possible "quanta" of work with tight feedback loops (e.g., short iterations, test-driven development, pair programming, continuous integration, etc.)
- Mandating simple design to make the code as simple and easy as possible to change if it is necessary.
- Minimizing the number and size of non-code artifacts that must be produced or updated in order to implement a change.
- Working only on the features scheduled for the current iteration.

In a nutshell, the key success factors of agile management are the use of iterative and incremental development with short feedback cycles, and close collaboration with frequent face-to-face interaction between developers and customers.

Agile approach is highly recommendable in projects with a significant risk of changes, where the client's requirements are not well-defined or the project itself is very uncertain. In these cases, breaking up the project into small parts allows any modification to be carried out in a short time and with a minimum additional cost, as only the part concerned is affected.

Within agile methodologies, there are different frameworks to achieve this goal. One of these is called Scrum.

Under Scrum framework, tasks are broken into small increments with fixed-duration time cycles called sprints.

Each iteration involves an integrated team working in all functions: planning, requirements analysis, design, coding, testing and release. The team “burns down” the overall number of tasks/ features by completing a sprint. At the end of the iteration, a working product is demonstrated to stakeholders. This minimizes overall risk and allows the project to adapt to change quickly. It also enables a user to provide timely feedback to the team in order to modify features if it is necessary.(Albaladejo, 2018). Figure 6 shows this approach.

Figure 6: Scheme of SCRUM framework (extracted from (Calvo, 2018))

As it is mentioned, Scrum divides development up into iterations called *sprints*. Each *sprint* is approximately 2-4 weeks and delivers an executable product increment of agreed upon functionality from the product backlog which represents all the features that the client desire. The sprint backlog is the list of all requests to work in the current iteration. Only the product owner (the person empowered to represent customer priorities) may prioritize the backlog. The content of the sprint backlog is agreed upon by the product owner at the beginning of planning for the sprint. During the sprint, there is a daily scrum meeting in which each team member must answer the following three questions(Schiel, 2012):

1) What have you done since the last scrum?
2) What will you do between now and the next scrum?
3) What got in your way of doing work?

Issues that arise which may impact a task are raised during the daily scrum and might be added to the sprint backlog or the product backlog based upon the customer's decision. At the end of a sprint, a sprint review is held to present the product increment to the customers for evaluation to ensure it has met the agreed upon sprint goals and satisfied the specified requirements for each request in the completed sprint backlog (Ken Schwaber & Jeff Suther, 2020) .

Lastly, it is worthy to present Agile Manifesto which is based on twelve principles that are part of the DNA of today's agile projects.

Agile Manifesto

The Agile Manifesto emerged from a meeting in 2001 where 17 software developers participated to discuss the most effective development methods. In this document, the basic principles that any agile approach should have are detailed. These principles are mentioned below:

1. Customer satisfaction by early and continuous delivery of valuable software
2. Welcome changing requirements, even in late development
3. Deliver working software frequently (weeks rather than months)
4. Close, daily cooperation between businesspeople and developers
5. Projects are built around motivated individuals, who should be trusted
6. Face-to-face conversation is the best form of communication (co-location)
7. Working software is the primary measure of progress
8. Sustainable development, able to maintain a constant pace
9. Continuous attention to technical excellence and good design
10. Simplicity—the art of maximizing the amount of work not done—is essential
11. Best architectures, requirements, and designs emerge from self-organizing teams
12. Regularly, the team reflects on how to become more effective and adjusts accordingly

4.5.3.1 GLANCE OF AGILE AND WATERFALL

Regarding Figure 7, an iterative approach as Agile conceives is not appropriate for construction projects as they are typically very sequential in nature and changes are expensive as projects move further down the life cycle; (design to construction, construction to testing, etc). A change during design might cost $1, but during active construction will cost $100 to implement (Glenn, 2015).

Therefore, for construction projects a waterfall methodology is more suitable to be adopted but including some of the principles that agile stands for, especially in terms of co-cooperativeness.

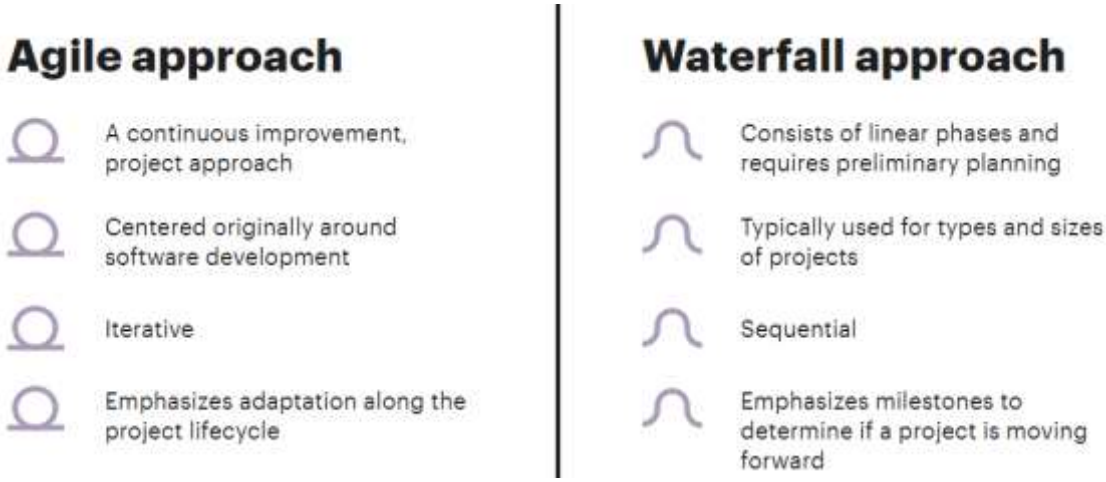


Figure 7: Main features of Agile and Waterfall methodologies (extracted from (Pass, 2017) *)*

4.5.4 LEAN

Projects are temporary production systems. Therefore, systems which are structured to deliver the product while maximizing value and minimizing waste, they are said to be "lean projects" (Ballard & Howell. A, 1993). Waste reduction has been characterized in terms of minimizing what is unnecessary for task completion and value generation. The wastes which are commonly known as "TIMWOODS" are the following ones (Nawras Skhmot, 2017):

T- Transportation, I- Inventory, M- Motion, W- Waiting, O- Overprocessing, O- Overproduction, D- Defects.

Therefore, the aim of Lean methodology is delivering a successful product while maximizing value and minimizing wastes (Ballard & Howell. A, 1993). In other words, making only quality assignments. Lean approach holds stop working rather than allow defective documents.

Another important aspect that Lean methodology provides is based on decisions. Because of Lean design -focused on minimizing waste therefore more time is available - decisions can be taken until the last responsible moment in order to allow more time for developing and exploring the best alternatives; those which are the most appropriate according to the features of the project. Moreover, Lean mindset allows the project to go back to the initial definition if the ongoing search of value reveals opportunities.

Lean methodology focuses on a detailed control of the project's constraints. To this end, it uses the ADM tool (Activity Definition Model) which provides the primary categories of constraints: directives, prerequisite work, and resources. Therefore, the model is used as a guide to explode scheduled tasks into a level of detail at which their readiness for execution can be assessed and advanced. Figure 8 shows its configuration.

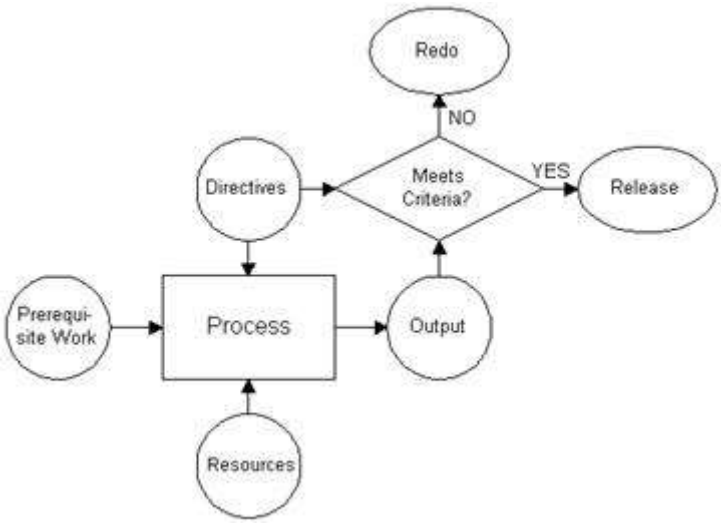


Figure 8: ADM for a give activity (extracted from (Talley, n.d.) *)*

No activity is allowed to retain its scheduled date unless the planners are confident that constraints can be removed in time. Following this rule assures that problems will be surfaced earlier and that problems that cannot be resolved in the lookahead planning will not be imposed on the production level of the project, whether that be design, fabrication, or construction.

On the other hand, Lean methodology considers how to allocate the available resources in such a project in the most appropriate way, which is an important aspect in almost all projects because resources are limited, by means of implement pull technique tool. A rule of 'pulling' is only to do work that releases work to someone else. It is based on working from a target completion date backwards, which causes tasks to be defined and sequenced so that their completion releases work. Working backwards from a target completion date not only eliminates work that has customarily been done although does not add value, but also allows resources to be allocated in the most appropriate way for the success of the project (Ballard & Howell. A, 1993).

In order to know the amount of work done and what is actually worthwhile for the project, LEAN uses the PPC "per cent plan complete" concept based on tracking the percentage of assignments completed in each plan period (usually 3-4 weeks).

Increasing PPC leads to increased performance, not only of the production unit that executes the *weekly-monthly* (period) work plan, but also of production units downstream as they can plan better when work is reliably released to them. Moreover, when a production unit gets better at determining its upcoming resource needs, it can pull those resources from its upstream supply so they will be available when needed (Ballard & Howell. A, 1993).

This key parameter makes it possible to monitor the project's progress at any given moment and to implement corrective actions if necessary – ongoing improvement-.

Once the Project planning is done by means of a Pull technique, focused on a detailed control of constraints and making only quality assignments, then the team is next invited to re-examine the schedule for logic and intensity (application of resources and methods) in order to generate a bigger gap and more float -in the most sensitive activities- following the follow key rule:

- Assign to the most uncertain and potentially variable task durations; *rank order the fragile activities by degree of uncertainty*

It is important to mention that a misuse of the LEAN methodology particularly in terms of information leakage - considered to be non-value adding to the project - can lead to defective design outputs because something previously known was forgotten or neglected.

4.5.4.1 COMPARISON LEAN AND AGILE

Table 2 shows the difference between Lean and Agile approach:

LEAN	**Agile**
Lean is an umbrella term for any approach based on Lean Manufacturing	Agile is an umbrella term for several software development methods such as Scrum
Lean is all about eliminating waste	Agile is all about individuals and interactions
It emphasizes on maximizing customer value and increasing efficiency	It is a collective collaboration between teams and end users
It defers commitment and values processes over customer requirements	It values iterative delivery by welcoming changing requirements
It follows a systematic plan to development by avoiding unnecessary meetings and documentation.	It believes in end results through response and feedbacks
It responds in a disciplined manner to changing requirements rather than predicting the future	It foresees future by responding to changes rather than following a plan

Table 2: Lean and Agile difference (adapted from (Agile VERSUS Lean | Difference Between, n.d.)

Whereas PERT/CPM is a control technique the combination with Agile and Lean allows to optimize project planning in order to accomplish with time and resources constraints.

4.5.5 SWOT ANALYSIS

SWOT analysis is a technique used in strategic planning. SWOT is an acronym for Strengths, Weaknesses, Opportunities, and Threats and is a structured planning method that evaluates those four elements of an organization, project, or business venture. The SWOT analysis allows to understand the company's position which will encourage ideas and decision-making on how to build on strengths, exploit opportunities, minimize weaknesses and to protect against threats.

Among the initiatives that can be analysed are projects, since they consist of carrying out a certain scope, within a certain situation of the environment, within an organisation and with a particular team. Therefore, the SWOT analysis provides a view on the situation of the project team and the environment where it is conducted by analysing the four points mentioned above.

SWOT elements in project management

Strengths and weaknesses

- These two parameters are usually related to internal resources. These are typically aspects that can support in dealing with planning constraints, or weaknesses that challenge the viability of the project.

Opportunities and threats

- These two factors correspond quite directly to the risks. In fact, SWOT analysis is one of the recommended techniques for risk identification. Threats would be the negative risks that should be considered in planning, while opportunities would be the positive risks.

To sum up, the final aim of the analysis will be identifying aspects, actions, or precautions to be taken that will improve the planning and management of the project and increase its chances of success (Garriga, 2018).

5 METHODOLOGY

A novel project management technique will be developed, highlighting its advantages over traditional methodologies by means of a case study based on a revamping of the packing in a distillation column. The case-study begins with the application of the sequential PERT/CPM methodology to plan the project. However, the results reveal that it does not meet the constraints of the project nor does it allow the optimisation of time and resources. Therefore, the need to improve this method of project management is uncovered.

For this reason, this novel methodology is enriched by a SWOT analysis, mainly focused on identifying potential weaknesses and threats, whose neglect would represent a risk for the success of the project as it might lead to the possible emergence of some change downstream of the project. After analysing them, the most suitable management techniques will be suggested to tackle each of them. These

techniques are Lean and Agile methodologies. So, resulting in a modified PERT/CPM with Agile and Lean.

Whereas PERT/CPM sets the operative basis for the project management, its upgrade with the philosophies Agile and Lean provides a combined framework, which not only addresses the timely organization of the activities, but also provides tools to deal with time and resources constraints.

However, once this assessment is done, there is still a weak point to be solved: the distribution of resources. This challenge is addressed by means of a risk assessment for critical activities.

Ultimately, this unique methodology integrates the three most common management methods to date; PERT/CPM, Agile and Lean. It also includes tools such as a SWOT analysis applied to change management and a risk analysis.

Although each technique by itself is not a novelty, the arrangement in which they are integrated in a project management framework is.

The purpose of integrating all of these methods and tools into one single methodology is because of each project is unique; there are a number of singularities (specific characteristics) that would be impossible to manage with a unique technique, as SWOT analysis will be able to reveal, and therefore, a combination of several methodologies and even the inclusion of new strategies are needed.

6 CASE-STUDY

6.1 PROJECT OVERVIEW

6.1.1 TITLE

Change of structured packing in a distillation column in order to increase capacity; treat more m^3/h of feed with the same efficiency.

6.1.1.1 BACKGROUND

An Ethylene Glycol production plant, placed in a petrochemical site, is to be revamped. The owner company aims to increase production while keeping the same quality for its products. The Ethylene Glycol process consists mainly on the reaction of Ethylene Oxide (EO) with an excess of water, followed by evaporators and vacuum distillation columns to remove the excess of water and to separate the three glycols produced: Monoethylene glycol (MEG), Diethylene glycol (DEG) and Triethylene glycol (TEG) respectively. After a careful review of the original design, it is concluded that several equipment in the plant needs to be modified in order to accomplish the new reference capacity. This project particularly concentrates on the MEG distillation column, which is the core of the distillation section. The original design of this column consisted on a Mellapak structured packing bed provided by Sulzer, working at vacuum pressure. Such configuration provides a high MEG purity, but it is

limited taking to the maximum flow rate to be processed. There are evidences that, when increasing the flow rate supplied to the distillation column, the pressure drop across the packing bed increases out of the limits, exhibiting also partial flooding. Therefore, the MEG distillation column needs to be revamped in order to attain the new reference capacity, while keeping the purity of the products. For this purpose, Sulzer has suggested to install a Mellapak Plus structured packing.

6.1.2 SCOPE AND OBJECTIVE

The scope of this project is focused on the plant operation to change the existing Mellapak structured packing in the MEG distillation column by the latest generation called Mellapak Plus, which is also a structured packing. Therefore, the project concentrates on conducting the construction phase of the revamp project for the MEG column. Within the tasks included in this project scope, are the following ones: (i) Stop, drain and clean the distillation column for the field work, (ii) Remove the original packing, (iii) Installation of the new packing (iv) start-up of the revamped distillation column.

The main goal of the project is to achieve the successful completion of the structured packing change operation in compliance with quality and safety standards through the optimal planning of the activities and meeting project constraints.

6.1.3 DESCRIPTION

6.1.3.1 GENERAL CONCEPTS

The column is the equipment component that provides the environment where gas and liquid phases of each component can reach equilibrium, aided by different contact media. Within the column, there are different structures that promote contact between the phases by providing the required interfacial surface for mass transfer takes place(Montoya, 2012). There are two types of contacts: staged or continuous, the first one is achieved by using plate columns, while the second one is achieved with the use of packed columns(Navas, n.d.). The choice depends on the characteristics of the column and the properties of the compounds to be separated. Table 3 shows the advantages and disadvantages of each type of contact.

As it can be seen in the section 6.1.1.1, the unit operation involved in this case-study is a vacuum distillation which is a key factor in determining that the column has to be a packed column rather than a plate column as Table 3 points out.

For that reason, a more detailed explanation of the packing is therefore given below.

Packed columns

Packed columns are used for different types of processes such as absorption, liquid-liquid extraction, and distillation. In these types of columns, the liquid-gas contact is continuous and not stepwise as in the plate column (Montoya, 2012).

Plate column & Packed column		
	Advantage	**Disadvantages**
Plate	Plate columns can handle wide range of gas and liquid flow rates.	Foaming system reduces the performance of plate columns. Anti-foaming agents can be used for suppressing the foam.
	Plate efficiency can be predicted more accurately	Liquid hold up is very high. Therefore, pressure drop is very high.
	Plate column operation is considerably smooth.	For corrosive liquids, the cost of a plate column is too high due to use of corrosion resistant material.
	Cooling arrangement can be provided in plate column.	Supporting structure required is costly.
	Plate column provide stage wise contact.	
	When the liquid cause fouling or deposition of solids, even though the tray is blocked up, it is easier to clean it and manholes can be provided over the plate.	
Packed	Packed columns are more suitable for low capacity operations.	HETP and HTU prediction may not be very accurate.
	Packed columns are particularly useful in the field of vacuum distillation. Here column pressure drop is of paramount importance to minimize the pressure and temperature at the bottom of the column.	Packed columns are not suitable for very low liquid rates.
	For separating heat sensitive materials packed columns are useful because the liquid holds up is low.	Provision of cooling arrangement is difficult in packed columns.
	When corrosion is a problem packing may be the only answer.	Removal of side stream is not possible in packed column.
	Pressure drop per unit length is less in packed column.	
	Packed column provides continuous contact between the vapor and liquid phases.	
	Packed columns are suitable for handling foaming system.	
	Modern high capacity pickings are available in practically any material.	
	Total weight of packed column is less due to use of low weight and high capacity packing.	

Table 3: Pros and cons of plate and filler columns (adapted from (Rao, 2020)

The liquid stream flows down the column passing through the packing as small droplets via a liquid distributor, placed at the top of the column, which ensures that the liquid uniformly wets the entire packing and does not move towards the walls (*Columnas de Relleno*, n.d.). On the other hand, the gas rises along the column towards the top of it.

Key parameters:

For any packed column design, a prior decision must be made as to whether the desired objective is to increase capacity or to improve efficiency (higher purity) as this will depend on the characteristics of the packing.

- Improving efficiency – means maximising mass transfer.
    - The specific area is increased. I.e. minimising the void fraction (porosity). As a consequence, the pressure drop increases (less free space). This implies higher pressure - increased operational costs.
    - The void fraction is kept but the column height is increased. As a consequence, the pressure drop increases (height (L) increases). This implies higher pressure - increased operational costs.
- Increase capacity- process more m^3/h.
    - The void fraction (porosity) needs to be maximized in order to avoid column flooding. The pressure drop decreases. As a consequence, the contact area decreases and therefore the efficiency of mass transfer is reduced.
    - The void fraction is kept but the diameter column is increased.

In both cases, the column design must consider whether the column is new and, therefore, if it is possible to modify column dimensions or whether it is an existing column, where the only option is to match the most suitable packing with appropriate specifications to accomplish the purpose.

There are two types of packing; Structured and Random, which mainly differ in geometry, materials, and sizes.

Random: This type of packing is relatively cheap and tends to be made of corrosion-resistant materials (metallic, ceramic or plastic). One of the most well-known and widely used is the Rashig rings, although nowadays they have been replaced by more efficient ones such as Pall's rings (*Columnas de Relleno*, n.d.). Because of its easy replacement and storage, random packing is deemed as the ideal choice for systems with heavy fouling or corrosion where packing is frequently replaced (*Sulzer*, n.d.).

Structured: This type of packing is substantially more expensive per unit volume than random packing, but it offers far less pressure drop per stage and has higher efficiency and capacity (*Columnas de Relleno*, n.d.)

6.1.3.2 PROCESS DESCRIPTION

A detailed description for the Ethylenglycol production is now provided.

The ethylene glycol process produces MEG, DEG and TEG from water and EO as raw materials. A crude ethylene glycol mixture is produced by the hydrolysis of EO with water under pressure and temperature. Water is added in excess. Therefore, once the reaction step is finished, the water-glycol mixture is fed to evaporators where the water is recovered and recycled. Fractional distillation under vacuum is then used to separate the (MEG) from the diethylene (DEG) and triethylene glycols (TEG). (Reed Business Information Limited, 2020).

The proportion obtained for the three glycols is dependent on the ratio water/EO reacted. This proportion was fixed on the original design of the plant, based on consumer research conclusions. This decision is a key factor since it determines the design of the distillation train. See the layout in Figure 9.

Glycol Separation Train

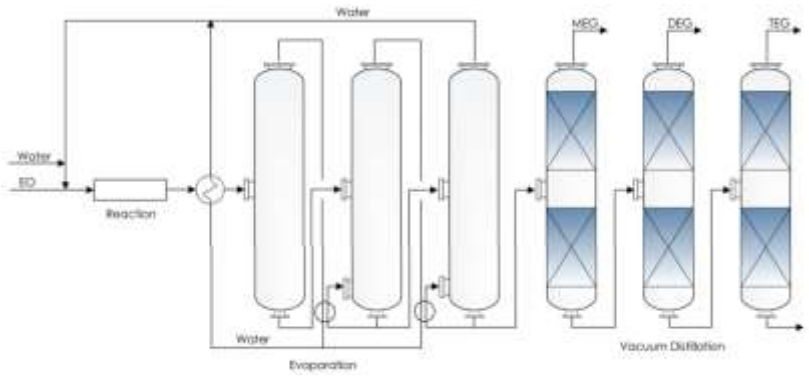


Figure 9: Ethylene glycol process (extracted from (KOCH-GLITSCH, 2012)

According to these process characteristics, structured packing is preferred compared to random packing or fraction trays since it can provide lower pressure drop through the column which is a key parameter to minimize the bottom temperature and the product loss due to degradation. (KOCH-GLITSCH, 2012)

Therefore, the packing to be replaced is of a structured type. In addition, advantage is taken of the replacement operation to install a new packing which provides lower pressure drop, thus increasing the capacity of the column while maintaining the existing dimensions (revamping project).

The general layout of a packed column is shown in Figure 10.

Revamping key points:

The operation is carried out in first column of the train vacuum distillation (MEG production) Regarding the mentioned column, only the upper packing bed is replaced. The old packing is replaced by one that offers lower pressure drop, increasing the capacity of the existing column.

Specific particularities for this case study's column:

- Column diameter is 2m
- The total height of the column is 8m.
- The column is composed by 2 packing beds.
- There are two manholes located at the top and bottom of the column. This arrangement makes it necessary to remove the upper distributor in order to be able to dismantle the old filling from the first packing bed.

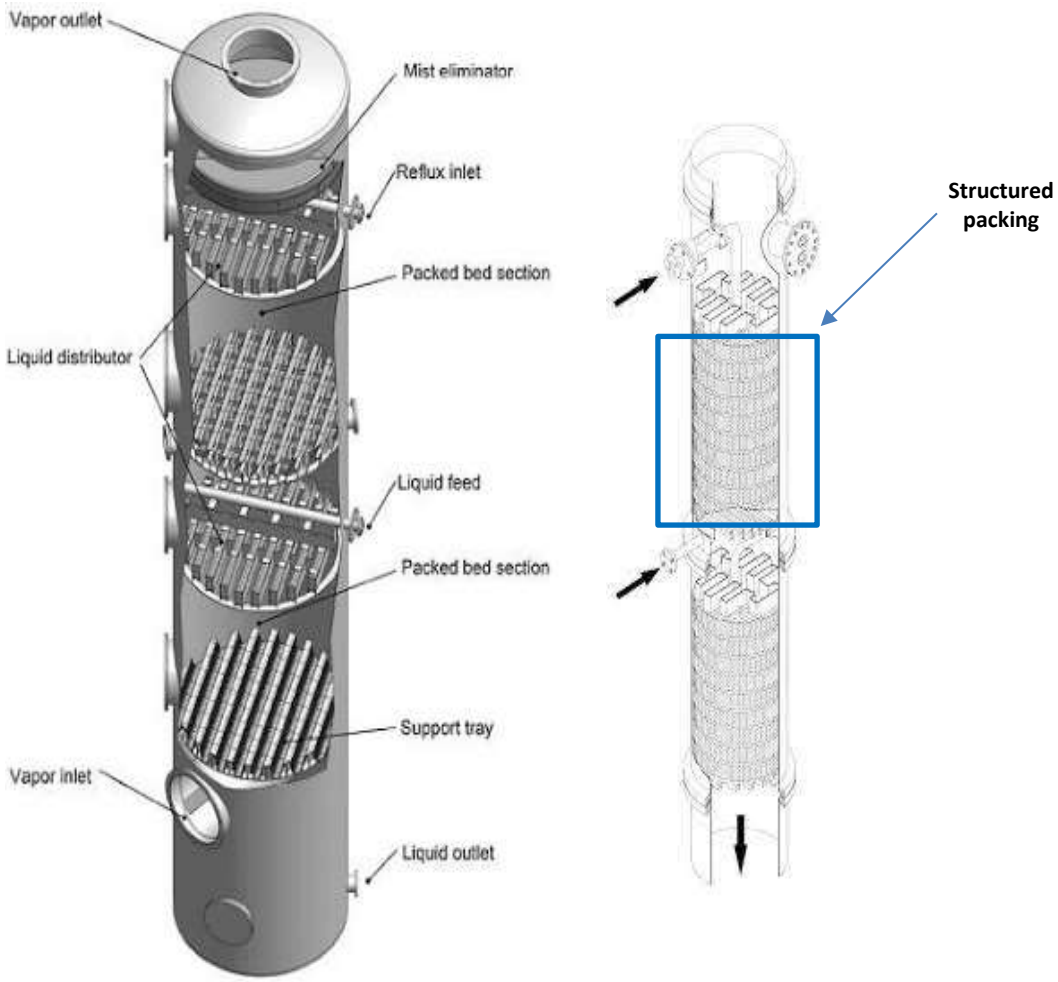


Figure 10:Column internals structured packed (extracted from ((Column Internals-Saiptech Co.,Ltd, n.d.) and (Sulzer Chemtech, 2015))

- The equipment operates continuously 24 hours a day. Shift operation is established in order to cover the total number of hours.

Features of the packing

Existing packing:

The existing structured packing is the "Mellapak" from Sulzer. Its high versatility, operating in vacuum conditions with relatively low pressure drop and thus allowing for increased capacity, makes it the ideal candidate. The main features are listed below (Sulzer, 2020):

- Pressure drop per theoretical stage 0.3 - 1.0 mbar
- Pressure drop at 70-80% flooding about 2 mbar/m
- Minimum liquid load approximately 0.2 m^3/m2h
- Maximum liquid load up to more than 200 m^3/m2h (typically in desorption columns)

Preferred applications:

- Vacuum to moderate pressure

- Increasing capacity of existing tray and packed columns

New packing:

The supplier is SULZER, the same as for the existing packing, but for this revamping project, the chosen range of the structed packing is the one called “MellapakPlus”, the latest generation of structured packing. With the enhancement of the geometric structure of conventional Mellapak, the pressure drop is much lower, and the maximum capacity can be extended by 50% compared to Mellapak[1].

Main benefits:

- MellapakPlus for existing columns results in a higher capacity at the same efficiency.
- MellapakPlus has to up 50% higher capacity at the same number of theoretical stages per meter compared to conventional Mellapak.

The graphical justification is shown in Figure 11.

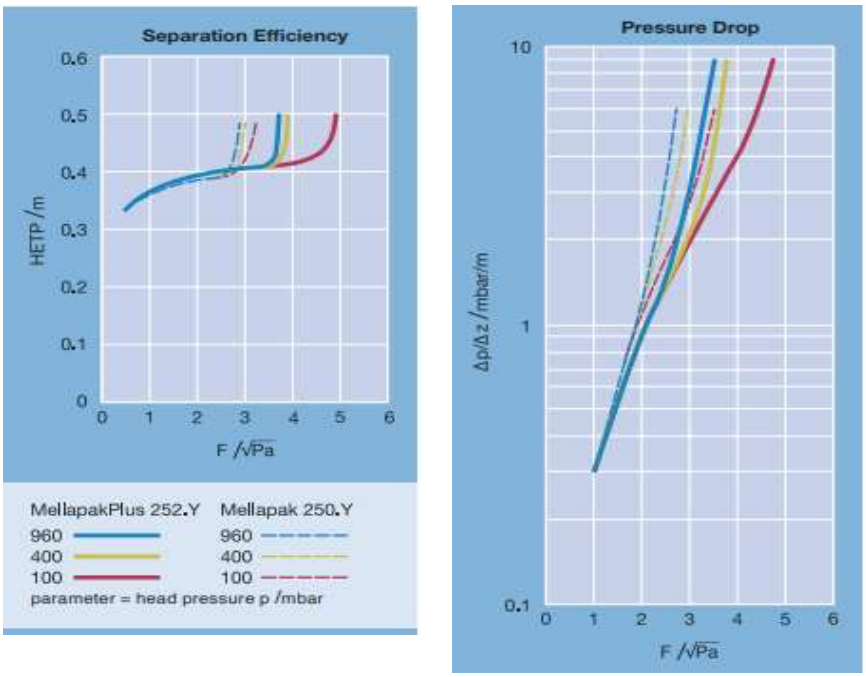


Figure 11: Comparison between Mellapak and MellapakPlus (extracted from (Sulzer, 2020) *)*

6.1.4 CONSTRAINTS:

As mentioned before, the main objective of the planning job that will be done in this project is to accomplish the column revamp while respecting time and resources constraints. These are the particular constraints that apply to this project:

[1] See *Key parameters*

- Unit shutdown is limited to **15 days** imposed by the owner of the plant because of commercial reasons.
- Availability of the packing specialist from SULZER – **One person and 7 consecutive days.** The only 7 days availability for the specialist is a matter of commitment. He or she is an in-house employee of the company who also works on other projects for other clients who must meet the established deadlines.

Both constraints are further explained below.

6.1.5 OPERATIONS INVOLVED

This section aims to briefly describe what operations need to be done to change column packing.

1) Shutdown, drain and clean: the operation shift working 24 h/d, 7 d/week
2) Remove original structured packing. Several aspects to take into consideration:
   a. Diameter of the column to fit people inside
   b. Location of the manholes
   c. First remove the distributor
   d. State of the old packing (clogged, dirty....)
3) Place the new packing. Once the packing has been replaced, the distributor is fitted again.
4) Finally, start-up

6.1.6 PLANNING GUIDELINES

Shutdown period

For this project, the shutdown is set between 3rd of May to 18th of May assumed that it is a period of lower sales but with sufficient availability of resources.

Shutdown overall knowledge

The interventions involving production stoppages are decided by the company's commercial department. These usually correspond to holiday periods when there is less demand - lower sales - as well as depending on stock capacity or other circumstances, such as, availability of resources, regulatory inspections of important plant equipment, etc.

After setting the shutdown period, the activities are distributed in the most optimal way regarding tasks, resources, and their simultaneity. Within the shutdown, there are time windows for each unit, with defined periods according to stop/start times for each unit in relation to the others. It is in these windows that the necessary time is analysed in order to be able to accomplish the work without a resources peak that might not be real.

As a rule, subcontracted employees do not demobilise from site until their last task has been completed. Therefore, the hours available restriction means that in this period of time the specialist has to finish

all tasks he/she is involved in. This is not a time constraint for working hours but for time mobilised to the site.

Planning strategy:

Work will be undertaken on public holidays, including Saturdays and Sundays. The aim is to minimise the amount of time the plant is out of operation. Note that for every day of downtime, the company is losing money. Besides, even if a particular equipment is intervened, it depends on others, resulting in inactivity that may affect other process units.

The established working hours/day for each activity correspond to the workday that is usually set for shutdown. Duties will be performed in shifts of 24 hours/day, provided that natural light is not required, when 12 hours/day will be the norm. In addition, for this particular project where only one operator is able to work at a time due to the dimensions of the column, it is necessary to work 24 hours a day with shifts of 12 hours per day in order to reduce the time that the equipment is inoperative.

Reducing downtime by allocating more resources will be prioritised, regardless of whether this means increasing the cost. Keeping the plant inoperative for a longer period of time is always more expensive than allocating more resources as long as it is coherent and does not imply an unrealistic peak of resources (Amendola, 2017)

Whenever possible, activities outside the shutdown will be considered.

In view of the criticality of the replacement operation, external resources (not belonging to the plant itself) are considered, assuming that this type of resource is generally more expensive. The goal is to convey reliability and certainty to the activities to undertake as well as to minimise the risk on the critical path.

Activities and its predecessors:

All of the required activities for this project as well as their interdependencies (predecessors) are based on actual on-site experience from projects where the same operation was performed.

Time estimate:

For certain tasks; inspection of the new packing; *Disassembly of the upper manifold, Cleaning of the manifold, Disassembly of the packing bed, Product in accordance with specification*, the estimated time has been used based on the calculation of 3 probabilistic scenarios using the Equation 1 depicted in the PERT section.

This is because it is difficult to foresee the duration of such activities, but there is a background of how similar projects have gone in the past.

Therefore, the times defined for such activities are based on field experience.

On the other hand, for an unknown activity that has not been historically performed and, therefore, no experience is present, e.g. *Placing the new packing*, the approach is to rely on the opinion/expertise of the expert who performs the assembly as well as the supplier who provides it.

Even so, it is worth mentioning that there is no straight engineering procedure to establish the hours per activity. It is based on experience from previous similar projects, understanding the peculiarities of each project and, above all, considering resource-time constraints.

6.2 APPLICATION OF THE CONVENTIONAL PERT/CPM METHODOLOGY

6.2.1 ACTIVITY AND RESOURCES LIST OF THE CONVENTIONAL METHODOLOGY

The list of activities to be undertaken is presented with their times, working days and predecessor activities.

Conventional methodology (PERT/CPM)

Activities	Description	Activity duration (h)	Working day (h)	Predecessors activities
A	Establishment of the contractor's company at the site; SULZER's packing specialist	18	12	-
B1	Inspection of the new packing	24	12	A
B2	Preparation of the new packing	30	12	B1
C	Cut feed to the column	6	24	B1
D	Empty the column	6	24	C
E	Washing column	18	24	D
F	Drain column	6	24	E
G	Fitting insulation blanking flanges	12	24	F
H	Steaming	30	24	G
I	Opening manholes	12	24	H
J	Certifying insulation	12	24	I
K	Venting	12	24	J
L	Dismantle upper distributor	24	12	K
M	Clean upper distributor	24	12	L
N	Dismantling the bed packing	30	12	L
O	Placing the new packing	60	12	N, B2
P	Fitting the distributor	24	12	O, M
Q	Closing manholes	12	24	P
R	Perform leak test	6	24	Q
S	Removing blind flanges	12	24	R
T	Feeding product	12	24	S
U	Specification product	12	24	T

Table 4: List of activities- conventional planning (adapted from real experience)

This activities schedule has been graphically represented in APPENDIXES 1 by an arrow flowsheet diagram.

Resources allocation:

According to actual experience from similar projects, for this particular operation, the resources required per activity are shown below.

Activities	Description	Resources
A	Establishment of the contractor's company at the site; SULZER's packing specialist	A crane to unload the packing and a specialist supervising
B1	Inspection of the new packing	Specialist
B2	Preparation of the new packing	Specialist
C	Cut feed to the column	Common resource-operational shift
D	Empty the column	Common resource-operational shift
E	Washing column	Common resource-operational shift
F	Drain column	Common resource-operational shift
G	Fitting insulation blanking flanges	Plant maintenance technician
H	Steaming	Common resource-operational shift
I	Opening manholes	Common resource-operational shift
J	Certifying insulation	Equipment safety technician
K	Venting	Maintenance worker miscellaneous trades
L	Dismantle upper distributor	Specialist
M	Clean upper distributor	Maintenance worker miscellaneous trades
N	Dismantling the bed packing	Specialist
O	Placing the new packing	Specialist
P	Fitting the distributor	Specialist
Q	Closing manholes	Common resource-operational shift
R	Perform leak test	Common resource-operational shift
S	Removing blind flanges	Plant maintenance technician
T	Feeding product	Common resource-operational shift
U	Specification product	Common resource-operational shift

Table 5: List of resources- conventional planning (adapted from real experience)

Overall resources involved:

Resources		
Externals		Internals
Common	Non-common	
1 crane	Specialist	Common resource-operational shift
Maintenance worker miscellaneous trades		Equipment safety technician
Plant maintenance technician		

Table 6: Overall required resources - conventional planning

Resources explanation:

- 1 crane- At the beginning of the year, in accordance with the planning/needs of the company, an agreement is signed with a crane company. This contract includes the crane itself + 1 crane operator who can use it.
- Packing specialist – Technical profile from the supplier company of the new packing, in this case-study from SULZER, mobilized on site to supervise and perform the tasks defined within the agreed scope with the plant as vendors of the packing.
- Plant maintenance technicians - At the beginning of the year, depending on the planning/needs of the plant, a contract is assigned with a company specialising in mechanical works which will provide temporary workers prepared for this need.
- Maintenance worker miscellaneous trades- At the beginning of the year, according to the planning/needs of the plant, a contract is awarded with a company specialised in equipment maintenance that will provide temporary workers qualified in this area.

In the organisational structure of a manufacturing company, there is a maintenance department. The company has hired an engineer who is responsible for all the work in the speciality (mechanical in this case) and some middle managers or supervisors who report to the engineer. These supervisors are personnel with an intermediate level of formation, whose function is to supervise the works that are being executed and to ensure that these are done in accordance with the requirements of the property (in terms of quality, quantity and safety). They assess the expected workloads/peaks and sign contracts by subcontracting external personnel from specialist companies.

- Equipment safety technician- Internal resource specialist in security. For example, they are in responsible for the validation of the equipment's sealing.
- Common resource-Operational shift- A regular resource of the plant's own who is assigned for production work - operational tasks. They report to the production supervisors.

The most completed activities-resources table is shown in Table 7.

Activities	Description	Activity duration (h)	Working day (h)	Predecessors activities	Resources
A	Establishment of the contractor's company at the site; SULZER's packing specialist	18	12	-	A crane to unload the packing and a specialist supervising
B1	Inspection of the new packing	24	12	A	Specialist
B2	Preparation of the new packing	30	12	B1	Specialist
C	Cut feed to the column	6	24	B1	Common resource-operational shift
D	Empty the column	6	24	C	Common resource-operational shift
E	Washing column	18	24	D	Common resource-operational shift
F	Drain column	6	24	E	Common resource-operational shift
G	Fitting insulation blanking flanges	12	24	F	Plant maintenance technician
H	Steaming	30	24	G	Common resource-operational shift
I	Opening manholes	12	24	H	Common resource-operational shift
J	Certifying insulation	12	24	I	Equipment safety technician
K	Venting	12	24	J	Maintenance worker miscellaneous trades
L	Dismantle upper distributor	24	12	K	Specialist
M	Clean upper distributor	24	12	L	Maintenance worker miscellaneous trades
N	Dismantling the bed packing	30	12	L	Specialist
O	Placing the new packing	60	12	N, B2	Specialist
P	Fitting the distributor	24	12	O, M	Specialist
Q	Closing manholes	12	24	P	Common resource-operational shift
R	Perform leak test	6	24	Q	Common resource-operational shift
S	Removing blind flanges	12	24	R	Plant maintenance technician
T	Feeding product	12	24	S	Common resource-operational shift
U	Specification product	12	24	T	Common resource-operational shift

Table 7: Overall activities table- conventional planning

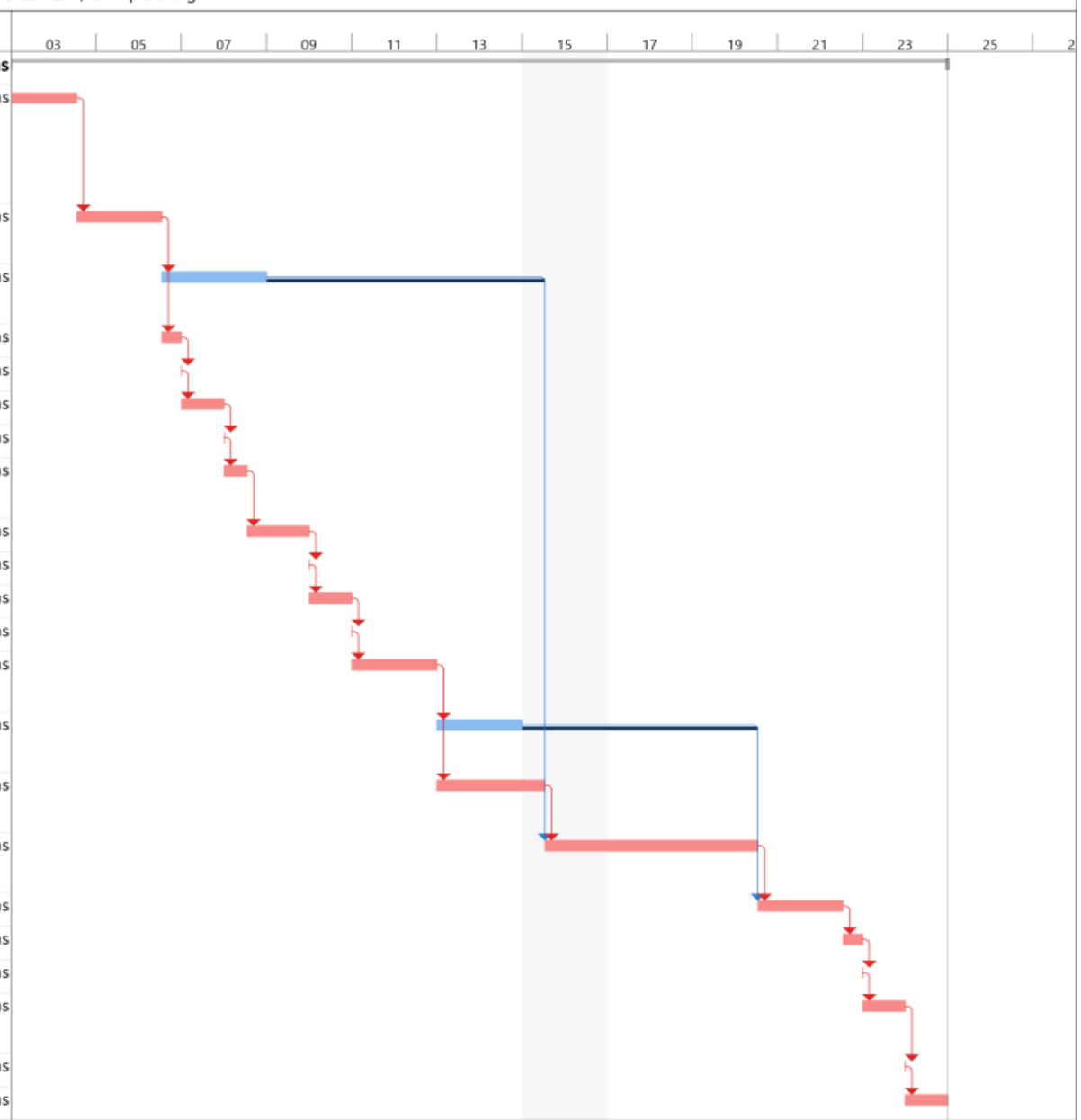
Note: *Due to the dimensions of the column, each activity within the column can only be performed by 1 person.*

6.2.2 CONVENTIONAL PLANNING GRAPHICAL REPRESENTATION

Using MS Project software, which incorporates PERT/CPM procedure, the Gantt chart for the project planning is shown below:

Conventional PERT/CPM planning

Id	Nombre de tarea	Duración	Comienzo	Fin	Predecesoras	Margen de demora total
0	**Conventional planning**	**128 horas**	**lun 03/05/21**	**lun 24/05/21**		**0 horas**
1	Establishment of the contractor's company at the site; SULZER's packing specialist	18 horas	lun 03/05/21	mar 04/05/21		0 horas
2	Inspection of the new packing	24 horas	mar 04/05/21	jue 06/05/21	1	0 horas
3	Preparation of the new packing	30 horas	jue 06/05/21	sáb 08/05/21	2	78 horas
4	Cut feed to the column	6 horas	jue 06/05/21	jue 06/05/21	2	0 horas
5	Empty the column	6 horas	jue 06/05/21	vie 07/05/21	4	0 horas
6	Washing column	18 horas	vie 07/05/21	vie 07/05/21	5	0 horas
7	Drain column	6 horas	vie 07/05/21	sáb 08/05/21	6	0 horas
8	Fitting insulation blanking flanges	12 horas	sáb 08/05/21	sáb 08/05/21	7	0 horas
9	Steaming	30 horas	sáb 08/05/21	dom 09/05/21	8	0 horas
10	Opening manholes	12 horas	dom 09/05/21	lun 10/05/21	9	0 horas
11	Certifying insulation	12 horas	lun 10/05/21	lun 10/05/21	10	0 horas
12	Venting	12 horas	lun 10/05/21	mar 11/05/21	11	0 horas
13	Dismantle upper distributor	24 horas	mar 11/05/21	mié 12/05/21	12	0 horas
14	Clean upper distributor	24 horas	jue 13/05/21	vie 14/05/21	13	66 horas
15	Dismantling the bed packing	30 horas	jue 13/05/21	sáb 15/05/21	13	0 horas
16	Placing the new packing	60 horas	sáb 15/05/21	jue 20/05/21	3;15	0 horas
17	Fitting the distributor	24 horas	jue 20/05/21	sáb 22/05/21	14;16	0 horas
18	Closing manholes	12 horas	sáb 22/05/21	dom 23/05/21	17	0 horas
19	Perform leak test	6 horas	dom 23/05/21	dom 23/05/21	18	0 horas
20	Removing blind flanges	12 horas	dom 23/05/21	dom 23/05/21	19	0 horas
21	Feeding product	12 horas	dom 23/05/21	lun 24/05/21	20	0 horas
22	Specification product	12 horas	lun 24/05/21	lun 24/05/21	21	0 horas

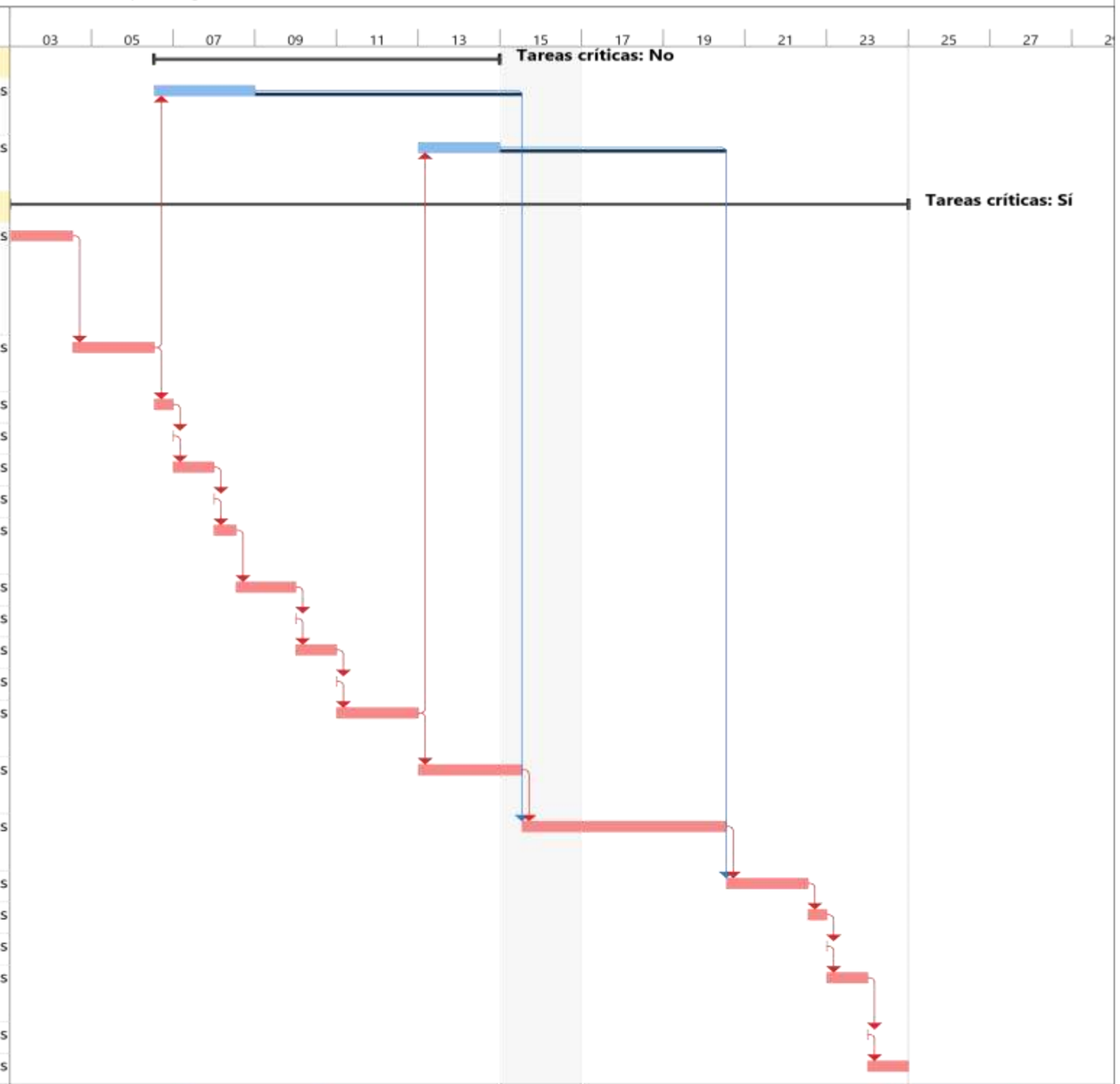


Proyecto: Conventional plannin
Fecha: lun 07/06/21

Tarea
División
Hito
Resumen
Resumen del proyecto
Tarea inactiva
Hito inactivo
Resumen inactivo
Tarea manual
solo duración
Informe de resumen manual
Resumen manual
solo el comienzo
solo fin
Tareas externas
Hito externo
Fecha límite
Tareas críticas
División crítica
Progreso
Progreso manual
Margen de demora

Conventional PERT/CPM planning

Id	Nombre de tarea	Duración	Comienzo	Fin	Predecesoras	Margen de demora total
	Tareas críticas: No	**52h**	**jue 06/05/21**	**vie 14/05/21**		
3	Preparation of the new packing	30 horas	jue 06/05/21	sáb 08/05/21	2	78 horas
14	Clean upper distributor	24 horas	jue 13/05/21	vie 14/05/21	13	66 horas
	Tareas críticas: Sí	**128h**	**lun 03/05/21**	**lun 24/05/21**		
1	Establishment of the contractor's company at the site; SULZER's packing specialist	18 horas	lun 03/05/21	mar 04/05/21		0 horas
2	Inspection of the new packing	24 horas	mar 04/05/21	jue 06/05/21	1	0 horas
4	Cut feed to the column	6 horas	jue 06/05/21	jue 06/05/21	2	0 horas
5	Empty the column	6 horas	jue 06/05/21	vie 07/05/21	4	0 horas
6	Washing column	18 horas	vie 07/05/21	vie 07/05/21	5	0 horas
7	Drain column	6 horas	vie 07/05/21	sáb 08/05/21	6	0 horas
8	Fitting insulation blanking flanges	12 horas	sáb 08/05/21	sáb 08/05/21	7	0 horas
9	Steaming	30 horas	sáb 08/05/21	dom 09/05/21	8	0 horas
10	Opening manholes	12 horas	dom 09/05/21	lun 10/05/21	9	0 horas
11	Certifying insulation	12 horas	lun 10/05/21	lun 10/05/21	10	0 horas
12	Venting	12 horas	lun 10/05/21	mar 11/05/21	11	0 horas
13	Dismantle upper distributor	24 horas	mar 11/05/21	mié 12/05/21	12	0 horas
15	Dismantling the bed packing	30 horas	jue 13/05/21	sáb 15/05/21	13	0 horas
16	Placing the new packing	60 horas	sáb 15/05/21	jue 20/05/21	3;15	0 horas
17	Fitting the distributor	24 horas	jue 20/05/21	sáb 22/05/21	14;16	0 horas
18	Closing manholes	12 horas	sáb 22/05/21	dom 23/05/21	17	0 horas
19	Perform leak test	6 horas	dom 23/05/21	dom 23/05/21	18	0 horas
20	Removing blind flanges	12 horas	dom 23/05/21	dom 23/05/21	19	0 horas
21	Feeding product	12 horas	dom 23/05/21	lun 24/05/21	20	0 horas
22	Specification product	12 horas	lun 24/05/21	lun 24/05/21	21	0 horas



Proyecto: Conventional plannin
Fecha: lun 07/06/21

Tarea
División
Hito
Resumen
Resumen del proyecto
Tarea inactiva
Hito inactivo
Resumen inactivo
Tarea manual
solo duración
Informe de resumen manual
Resumen manual
solo el comienzo
solo fin
Tareas externas
Hito externo
Fecha límite
Tareas críticas
División crítica
Progreso
Progreso manual
Margen de demora

Figure 12: Gantt chart for the conventional planning

6.2.3 CONVENTIONAL PLANNING CONCLUSIONS

The PERT/CPM plot shows clearly that the two constraining criteria, resources, and time, are not respected.

As the following graphs show, the time constraints of the project are not met. The total time allowed is 15 days and the PERT/CPM result are **22 days** (from 7:00h on 3/05/21 to 12:00h on 24/05/21).

An unacceptable delay bearing in mind that this project involves a plant shutdown and, therefore, the entire time that the unit remains inoperative results in a large financial loss.

Another aspect to consider is the specialist's availability. According to this planning, the specialist would be mobilised on the side from 7:00h on 3/05/21 (Establishment of the contractor's company at side) until 00:01h on 22/05/21 (Fitting the distributor). A total of **19 days** that exceeds the 7-day restriction on the specialist's availability.

A further point to be considered is the project's criticality. Out of a total of 22 activities only 2 are NOT critical. This means that **91%** of the project activities are critical and cannot suffer any delay. As this is a revamping project, where the fact that the equipment is existing leads to frequent unforeseen events causes a high risk of overrunning tasks with no buffer time to prevent a delay in the overall project. In the hypothetical event that the constraints were fulfilled.

It is therefore clear that such planning needs to be optimised to meet the constraints of the project whilst reducing the critical path where possible.

6.3 APPLICATION OF THE OPTIMIZED PERT/CPM METHODOLOGY

The results of the conventional PERT/CPM methodology reveal that the planned schedule does not meet the constraints of the project. Keeping in mind that this methodology is merely indicative - pointing out where to focus through the critical path representation but not providing guidelines to improve the planning - it becomes necessary to consider new strategies to optimize the planning.

The strategy is founded on two main aspects:

- Meeting project constraints
- Foreseeing potential incidents so that if they materialise it does not affect the overall planning.

6.3.1 SWOT ANALYSIS

Therefore, the first step is to analyse the project morphology and which aspects are susceptible to improvement. For this purpose, a SWOT analysis becomes an effective tool.

The SWOT analysis of the concerned project is shown in Table 8.

SWOT Analysis	
within the project	**out of project scope**
WEAKNESSES	**THREATS**
key to meet shutdown deadline	Strong probability of changes during construction phase
Short term project	Uncertainty of equipment state (new packing)
Narrow/small work area inside the column	Uncertainty of equipment state (old column internals)
Limited internal and external resources	Any threats on calendar such as festivities, where it is difficult to find external resources if necessary)
Key to do the job as planned on dates	First equipment with such packing. Therefore, no refill /spare available at the plant
STRENGHTS	**CHANCES**
Multidisciplinary team working together	Take advantage of possible changes in order to improve the project
Good relationship with client and stakeholders	Take advantage of client engagement (by several meetings) to accomplish their expectations
Employees with years of experience working in this type of project	Perform an exhaustive forecast planning focused on critical activities in order to complete the project on schedule despite deadlines are very short: *gain money in short period of time*
Experience of similar jobs in the site concerning to time activities	Optimize resources in order to save money/ to reduce cost
	Big industrial site with the same packing inventoried as a refill

Table 8: SWOT Analysis

The study of the present threats and weaknesses in this project reveals that all of them are likely to be eliminated or at least minimised by means of previously studied project management techniques.

The relationship between target (weakness & threats) and potential technique to cope with them is shown in Table 9.

As Table 9 illustrates, the chosen techniques are Lean and Agile in addition to the already studied PERT/CPM. A more detailed explanation of Table 9 and the reasons for the selection of these techniques are given below.

Regarding the needs of the project, **PERT/CPM** methodology will help project manager in the following aspects:

- Key to meet shutdown deadline
- Key to do the job as planned on dates
- Any threats on calendar (Festivities, where it is difficult to find external resources if necessary)

Technique	**WEAKNESSES**	**THREATS**	*Technique*
PERT/CPM	key to meet shutdown deadline	Strong probability of changes during construction phase	**AGILE**
LEAN	Short term project	Uncertainty of equipment state (new packing)	**AGILE &LEAN**
LEAN	Limited internal and external resources	Uncertainty of equipment state (old column internals)	**AGILE**
PERT/CPM	Key to do the job as planned on dates	Any threats on calendar such as festivities, where it is difficult to find external resources if necessary)	**PERT/CPM**
LEAN	Narrow/small work area inside the column	First equipment with such packing. Therefore, no refill /spare available at the plant	**AGILE**

Table 9: Appropriate techniques for project weakness and threats

The highlight of this type of construction project, known as "revamping", is the shutdown of the plant. Every shutdown means financial losses for the company from the moment the plant is closed. It is therefore critical to complete all activities before the deadline in order to slow down production as minimum as possible. In line with the above, PERT/CPM will help the project manager to know the overall duration of the project and which activities require more effort and control (critical activities). In addition, due to its design that allows for a detailed planning of activities, it is easier to identify problems that may occur because of scheduling issues and would affect the project's progress.

Concerning the weaknesses of the project, **LEAN** methodology will help project manager in the following aspects:

- Short term project
- Limited internal and external resources
- Narrow/small work area inside the column
- Uncertainty of equipment state (new packing)
- First equipment with such packing. Therefore, no refill /spare available

The aim of Lean methodology is delivering a successful product while maximizing value and minimizing waste known in terms of minimizing what is unnecessary for task completion and value generation. Therefore, when the target is to meet the allowed shutdown time, Lean methodology becomes the best manner to manage the project since this type of project philosophy is based on removing or minimising all non-essential work for the execution of the project, e.g. by removing from

the critical path certain activities susceptible to be performed out of the plant shutdown. Such a mindset reduces the overall project duration - by focusing only on critical activities - and also provides a buffer in case of delays. Another important aspect that Lean methodology provides is based on decisions. Because of Lean design -focused on minimizing waste therefore more time is available - decisions can be taken until the last responsible moment in order to allow more time for developing and exploring the best alternatives-those which are the most appropriate according to the features of the project. With regard to the above, the fact that the area within the column is quite small is a critical point in this project, as employees will be limited in terms of space, so the project manager needs to find the best alternative for a successful, safe and time-saving replacement of the column filling. Lastly, Lean methodology considers how to allocate the available resources in such a project in the most appropriate way which is an important aspect in almost all projects because resources are limited as it is in this project. Lean faces this weakness by different tools. One of this, is called pull technique. A rule of 'pulling' is only to do work that releases work to someone else. Following that rule eliminates the waste of overproduction. Working backwards from a target completion date eliminates work that has customarily been done but does not add value.

Finally, the most convenient methodology to face almost all the threats that may appear in this project will be the **AGILE** methodology. As the SWOT analysis reveals, these mentioned threats are:

- Strong probability of changes during construction phase
- Uncertainty of equipment state (new packing)
- Uncertainty of equipment state (old column internals)

Looking at the above threats, it is clear that there is a high degree of unforeseen change during the construction phase. In particular, in revamping projects where work is carried out on existing units, unexpected events are more likely to occur due to uncertainty about the current state of the equipment (e.g. the degree of fouling). In this context, the Agile methodology will support project managers since its design is focused on taking the right action in changing situations and to prevent future unforeseen events - identifying where risk can take place because of uncertainties - by considering them in the planning phases to apply the required actions at the proper time.

Another aspect advocated by Agile methodology is the training of the employees involved. For a successful project, employees must be the right people with the right knowledge.

6.3.2 OPTIMISATION OF INVOLVED ACTIVITIES

The key points of the optimisation are described below:

1. To reduce uncertainty and ensure reliability in meeting the shutdown deadline, the strategy is to conduct an initial SWOT analysis, in which weaknesses and threats will be detected. To overcome them, new management techniques within the framework of Lean and Agile have been introduced in the project.
2. In order to ensure that the plant shutdown lasts only 15 days, the number of operations involved in the critical path and/or its duration will have to be reduced.
3. In order to ensure that the 7-day attendance limitation of the packing specialist is enough to complete the dependent activities, the task planning must be redesigned.

In order to comply with points 2 and 3, the following specific considerations are given:

a. The task of "Review of new packing", although it does not require a great deal of expertise and is not considered a critical activity in terms of construction, does entail a very high risk at the planning level. On the one hand, it consumes the time of the packing specialist and, on the other hand, there is the possibility that the packing is damaged and that would destroy the whole planning because it would mean requesting the delivery of new packing. Moreover, as the packing is new, there is no spare packing available in the plant itself.

Having said that, the optimal procedure to adopt is as follows:

The packing test is not done at the plant, but rather at the supplier's own site. An independent expert will be hired to move to the supplier's site to check that the specifications of the packing are right, according to engineering and quality standards. As a result, this task is directly removed from the construction phase planning. In the conventional planning, the column tasks could not start before ensuring that the packing was in a good condition. As the packing was checked by the specialist, this meant that the specialist was on site from the beginning of the construction phase, and once the dismantling of the internals column started, the specialist was no longer involved until the dismantle/assembly of the packing tasks, resulting in a low cost-effectiveness of the resource. In contrast, in this new planning, removing the "Check the packing" activity from the plant shutdown enables the specialist to be mobilised just when he or she is needed, thus optimising his or her time on site. Additionally, the uncertainties risk is mitigated. This is a typical activity that can be carried out outside of shutdown, with no impact on the plant's operability. For instance, 1 month before the shutdown, packing can be checked in order to have a buffer in case of unexpected incidents.

The aim is to ensure that the specialist focuses exclusively on tasks that require "expertise". In other words:

- For the "Contractor's establishment", bureaucratic formalities will be expedited prior to the contractor's presence and two construction cranes will be provided in parallel in order to unload the material. Thus, the time of 1.5 days, estimated in the conventional planning, will be reduced to 1 day.
- For the task "Preparation of the new packing" for the subsequent assembly, the specialist will be assisted by non-specialist technicians working under his supervision. Therefore, the preparation time is reduced from 30 hours to 12 hours.
- The tasks "Dismantling of the distributor" and "Dismantling of the old packing" will be performed by a parallel contracting company with an intermediate knowledge. Despite not being specialists, they have expertise in the dismantling of column internals as well as the packing itself. This company will also assemble the distributor once it has been cleaned.
- The task " Cleaning of the distributor " will be carried out by a specialist cleaning company and will be conducted in parallel with the packing assembly operations.

b. The reliability of the operation is guaranteed by removing operations with uncertainty from the critical path (cleaning the distributor, checking the packing, etc.); and, at the same time, the success of the new assembly of packing is ensured by taking advantage of the knowledge of the independent expert, who has previously checked the packing, to supervise the specialist's work. Instead of supervising the plant's own staff (who have no specific formation), the independent expert will do so, and this staff can dedicate their time to provide another service that allows cutting the time of the critical path. In short, the completion time is reduced by allocating resources optimally and the construction risk is reduced by assigning experienced profiles to critical activities (fewer hours - more knowledge). For example, if the packing is misplaced, due to an error or carelessness, and then the column does not operate properly, it would be an absolute disaster, since production would have to shut down again and the whole operation must be repeated.

c. A diagnostic test on the column, which can be done while production is ongoing, is carried out to reduce uncertainty. It consists of an X-ray, which provides a view of the internal distribution of the liquid in the column. This test allows to intuit the degree and location of the dirt, which can cause problems in the dismantling of the packing and the distributor. It also helps to predict the required time in order to clean the distributor and the potential difficulties that may be encountered.

d. To reduce critical path times:

Beforehand, it is planned and prepared the operation "Dismantling of the distributor": through radiography, the fouling can be foreseen and with the drawings, the dismantling points can be defined. Even so, the same number of hours required for the activity is maintained, as there are many operations to be carried out to dismantle the distributor that remain unaffected by whether or not it is dirty. Given that the size of the column does NOT allow the work of two operators at the same time, there will be two operators working in 12-hour turns. In this way, by working 24 hours in this operation, the time is reduced from 2 days to 1 day.

- For the task "Dismantling of the existing packing", knowing the degree of fouling of the old packing allows to reduce the number of hours required for the activity since the operation is relatively simple -removing the old packing from the column-. In conventional planning, a buffer of hours is needed in case the packing was dirty and required more time to remove it. Whereas in optimised planning, through the radiography of the degree of soiling, it is possible to reduce this buffer of time and, therefore, reduce the total hours needed to carry out the task. In terms of resources, the same procedure is adopted: By forecasting the state of the packing via the diagnostic test and with two operators working individual 12-hour shifts, the time is reduced from 2.5 days to 0.75 day.
- For the activity "Assembly of the distributor", the same procedure will be followed in terms of resource allocation: 2 employees working in separate 12-hour shifts. This reduces the time from 2 days to 1 day.

All three tasks (disassembly/assembly of the distributor and disassembly of the existing packing) require relatively little knowledge. Therefore, in order to save the time of the SULZER’s packing specialist and to enable him to dedicate himself for the tasks that require more expertise, the experienced maintenance technicians, subcontracted by the company, will do it.

Table 10 shows the different optimisations that have been implemented in this project.

OPTIMITZATIONS CARRIED OUT					
nº	**Restriction to be met**	**Realised optimisation**	**Profit made**	**Weakness & Threats (table 8)**	**Applied methodology**
1	7-day attendance of the packing specialist from SULZER The plant shutdown lasts only 15 days	Request a second crane to place the packing on side (space available)	Saving the time of the packing specialist on side as well as shortening project duration. Prioritise the specialist to handle only tasks that require a high level of expertise and allocate new resources to perform tasks that require less expertise.	Short term project	LEAN- Allocate resources appropriately so that enough time is available for tasks that require only the expertise of the specialist. Focusing the efforts of the packing specialist to dedicate only to the highest value-added tasks, i.e. those requiring high knowledge
2		Assign two technicians to assist the specialist in the preparation of the new packing.			
3		Recruit experienced maintenance technicians in static equipment to undertake the disassembly/assembly of the distributor and the dismantling of the existing packing			
4		Hire an independent expert to move to the supplier's site to check that the specifications of the packing are right		Short term project Uncertainty of equipment state (new packing)	LEAN- reduce the number of critical activities by leaving only those that add value in the construction phase AGILE- Removal of a potential uncertainty that could affect the project duration

OPTIMITZATIONS CARRIED OUT					
nº	**Restriction to be met**	**Realised optimisation**	**Profit made**	**Weakness & Threats (table 8)**	**Applied methodology**
5		Drawing on the knowledge of the independent expert to supervise the packing specialist's work	Ensure that the supervision of the assembly of the new packing is done by a qualified person; reduce construction risk, as well as reallocate staff to reduce project duration; cutting critical path time.	Short term project Limited internal and external resources Strong probability of changes during construction phase First equipment with such packing. Therefore, no refill /spare available at the plant	LEAN - assign the most qualified personnel to the most critical tasks of the project; those that entail the greatest value. AGILE -Removal of a potential uncertainty that could affect the project duration -For a successful project, employees must be the right people with the right knowledge
6	The plant shutdown lasts only 15 days	Hire a specialised firm for cleaning of the column internals.	Ensure that even if the distributor is polymerised (soiled), the necessary equipment will be available to carry out an effective and fast cleaning without exceeding the foreseen time.	Short term project Uncertainty of equipment state (old column internals) Strong probability of changes during construction phase	AGILE- Removal of a potential uncertainty that could affect the project duration
7		Performing a diagnostic test of the column to detect the degree and location of the dirt (polymerisation)	Knowing the degree of column polymerisation allows a more accurate estimation of the time needed to dismantle the distributor and the packed bed. In this way, the time can be reduced as no extra time is needed in case of severe polymerisation. On the other hand, the uncertainty of the column internals' condition can be reduced.		

Table 10: Optimizations implemented in the new planning

6.3.3 ACTIVITY AND RESOURCES LIST OF THE OPTIMIZED METHODOLOGY

The list of activities to be undertaken is presented with their times, working days and predecessor activities.

Optimized methodology (PERT/CPM + Lean + Agile)

Activities	Description	Activity duration (h)	Working day (h)	Predecessors activities
A	Establishment of the contractor's company at the site; SULZER's packing specialist	12	12	-
B2	Preparation of the new packing	12	12	A
C	Cut feed to the column	6	24	-
D	Empty the column	6	24	C
E	Washing column	18	24	D
F	Drain column	6	24	E
G	Fitting insulation blanking flanges	12	24	F
H	Steaming	30	24	G
I	Opening manholes	12	24	H
J	Certifying insulation	12	24	I
K	Venting	12	24	J
L	Dismantle upper distributor	24	24	K
M	Clean upper distributor	24	12	L
N	Dismantling the bed packing	18	24	L
O	Placing the new packing	60	12	B2, N
P	Fitting the distributor	24	24	M, O
Q	Closing manholes	12	24	P
R	Perform leak test	6	24	Q
S	Removing blind flanges	12	24	R
T	Feeding product	12	24	S
U	Specification product	12	24	T

Table 11: List of activities- optimized planning (adapted from real experience)

This activities schedule has been graphically represented in APPENDIXES 2 by an arrow flowsheet diagram.

Resources list

In view of the optimizations made, the resources required per activity are shown below.

Activities	Description	Resources
A	Establishment of the contractor's company at the site; SULZER's packing specialist	Two cranes to unload the packing and a specialist supervising
B2	Preparation of the new packing	Specialist and two plant maintenance technicians reporting to him/her
C	Cut feed to the column	Common resource-operational shift
D	Empty the column	Common resource-operational shift
E	Washing column	Common resource-operational shift
F	Drain column	Common resource-operational shift
G	Fitting insulation blanking flanges	Plant maintenance technician
H	Steaming	Common resource-operational shift
I	Opening manholes	Common resource-operational shift
J	Certifying insulation	Equipment safety technician
K	Venting	Maintenance worker miscellaneous trades
L	Dismantle upper distributor	Experienced maintenance technicians (static equipment)
M	Clean upper distributor	Specialist firm
N	Dismantling the bed packing	Experienced maintenance technicians (static equipment)
O	Placing the new packing	Specialist supervised by the independent expert
P	Fitting the distributor	Experienced maintenance technicians (static equipment)
Q	Closing manholes	Common resource-operational shift
R	Perform leak test	Common resource-operational shift
S	Removing blind flanges	Plant maintenance technician
T	Feeding product	Common resource-operational shift
U	Specification product	Common resource-operational shift

Table 12: List of resources- optimized planning (adapted from real experience)

Overall resources involved:

Resources		
Externals		**Internals**
Common	**Non- common**	
1 crane	1 crane	Common resource-Operational shift
Maintenance worker miscellaneous trades	Specialist	Equipment safety technician
Plant maintenance technician	Independent expert	
Experienced maintenance technicians (static equipment)		
Specialist firm		

Table 13: Overall required resources- optimized planning

Resources explanation:

- 2 crane- At the beginning of the year, in accordance with the planning/needs of the company, an agreement is signed with a crane company. This contract includes the crane itself + 1 crane operator who can use it. As a consequence of the project, a second crane is requested from the same company. Since it is a project-specific resource, it is not considered a regular external resource.
- Packing specialist - Technical profile from the supplier company of the new packing, in this case-study from SULZER, mobilized on site to supervise and perform the tasks defined within the agreed scope with the plant as vendors of the packing.
- Independent packing expert - For this specific project, it is necessary to have a professional with a high level of knowledge related to the assembly of the packing. A one-off contract will be signed with this person at the appropriate time in order to support and supervise the specialist from packing company.
- Plant maintenance technicians - At the beginning of the year, depending on the planning/needs of the plant, a contract is assigned with a company specialising in mechanical works which will provide temporary workers prepared for this need.
- Maintenance worker miscellaneous trades- At the beginning of the year, according to the planning/needs of the plant, a contract is awarded with a company specialised in equipment maintenance that will provide temporary workers qualified in this area.
- Experienced maintenance technicians (static equipment)- At the beginning of the year, depending on your planning/needs, a contract is signed with a company specialized in the maintenance of static equipment which will assign highly qualified technicians to carry out this work.

The same work philosophy detailed in the conventional planning is adopted for the recruitment of maintenance staff and their supervision.

- Equipment safety technician- Internal resource specialist in security. For example, they are in responsible for the validation of the equipment's sealing.
- Common resource-Operational shift- A regular resource of the plant's own who is assigned for production work - operational tasks. They report to the production supervisors.
- Specialist firm- A company specialised in the cleaning of equipment that is contracted at the beginning of the year in view of the different actions that the company will carry out over the course of the year and require its professional services.

The most completed activities-resources table is shown in Table 14

Activities	Description	Activity duration (h)	Working day (h)	Predecessors activities	Resources
A	Establishment of the contractor's company at the site; SULZER's packing specialist	12	12	-	Two cranes to unload the packing and a specialist supervising
B2	Preparation of the new packing	12	12	A	Specialist and two plant maintenance technicians reporting to him/her
C	Cut feed to the column	6	24	-	Common resource-operational shift
D	Empty the column	6	24	C	Common resource-operational shift
E	Washing column	18	24	D	Common resource-operational shift
F	Drain column	6	24	E	Common resource-operational shift
G	Fitting insulation blanking flanges	12	24	F	Plant maintenance technician
H	Steaming	30	24	G	Common resource-operational shift
I	Opening manholes	12	24	H	Common resource-operational shift
J	Certifying insulation	12	24	I	Equipment safety technician
K	Venting	12	24	J	Maintenance worker miscellaneous trades
L	Dismantle upper distributor	24	24	K	Experienced maintenance technicians (static equipment)
M	Clean upper distributor	24	12	L	Specialist firm
N	Dismantling the bed packing	18	24	L	Experienced maintenance technicians (static equipment)
O	Placing the new packing	60	12	B2, N	Specialist supervised by the independent expert
P	Fitting the distributor	24	24	M, O	Experienced maintenance technicians (static equipment)
Q	Closing manholes	12	24	P	Common resource-operational shift
R	Perform leak test	6	24	Q	Common resource-operational shift
S	Removing blind flanges	12	24	R	Plant maintenance technician
T	Feeding product	12	24	S	Common resource-operational shift
U	Specification product	12	24	T	Common resource-operational shift

Table 14: Overall activities table- optimized planning

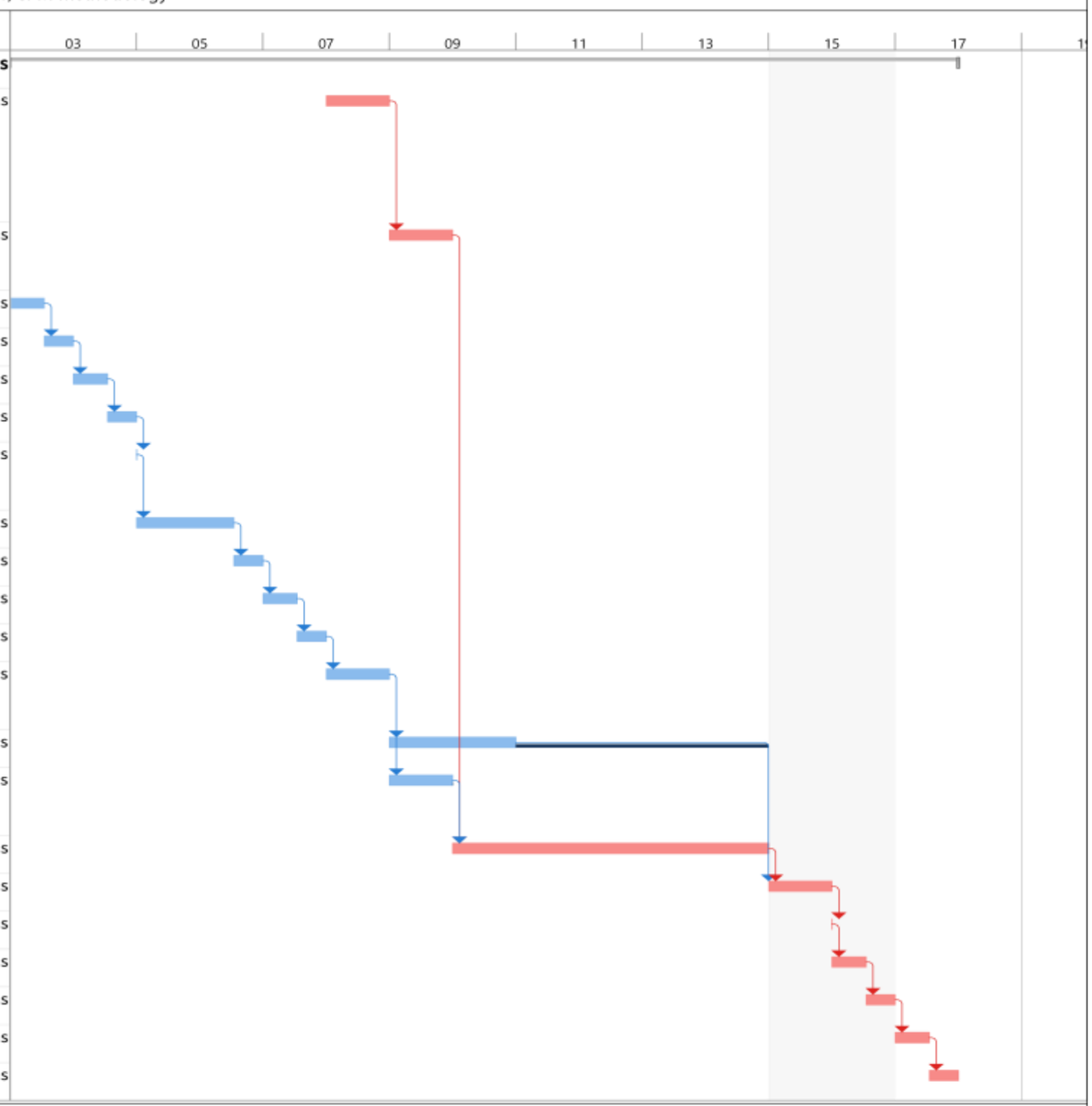
Note: *Due to the dimensions of the column, each activity within the column can only be performed by 1 person*

6.3.4 OPTIMIZED PLANNING GRAPHICAL REPRESENTATION

Using MS Project software, which incorporates PERT/CPM procedure, the Gantt chart for the project planning is shown below:

Optimized PERT/CPM methodology

Id	Modo de tarea	Nombre de tarea	Duración	Comienzo	Fin	Predecesoras	Margen de demora total
0		**Optimized Planning**	**88 horas**	**lun 03/05/21**	**mar 18/05/21**		**0 horas**
1		Establishment of the contractor's company at the site; SULZER's packing specialist	12 horas	sáb 08/05/21	sáb 08/05/21		0 horas
2		Preparation of the new packing	12 horas	dom 09/05/21	dom 09/05/21	1	0 horas
3		Cut feed to the column	6 horas	lun 03/05/21	lun 03/05/21		12 horas
4		Empty the column	6 horas	lun 03/05/21	lun 03/05/21	3	12 horas
5		Washing column	18 horas	lun 03/05/21	mar 04/05/21	4	12 horas
6		Drain column	6 horas	mar 04/05/21	mar 04/05/21	5	12 horas
7		Fitting insulation blanking flanges	12 horas	mar 04/05/21	mié 05/05/21	6	12 horas
8		Steaming	30 horas	mié 05/05/21	jue 06/05/21	7	12 horas
9		Opening manholes	12 horas	jue 06/05/21	vie 07/05/21	8	12 horas
10		Certifying insulation	12 horas	vie 07/05/21	vie 07/05/21	9	12 horas
11		Venting	12 horas	vie 07/05/21	sáb 08/05/21	10	12 horas
12		Dismantle upper distributor	24 horas	sáb 08/05/21	dom 09/05/21	11	12 horas
13		Clean upper distributor	24 horas	dom 09/05/21	lun 10/05/21	12	48 horas
14		Dismantling the bed packing	18 horas	dom 09/05/21	dom 09/05/21	12	12 horas
15		Placing the new packing	60 horas	lun 10/05/21	vie 14/05/21	2;14	0 horas
16		Fitting the distributor	24 horas	vie 14/05/21	sáb 15/05/21	13;15	0 horas
17		Closing manholes	12 horas	sáb 15/05/21	dom 16/05/21	16	0 horas
18		Perform leak test	6 horas	dom 16/05/21	dom 16/05/21	17	0 horas
19		Removing blind flanges	12 horas	dom 16/05/21	lun 17/05/21	18	0 horas
20		Feeding product	12 horas	lun 17/05/21	lun 17/05/21	19	0 horas
21		Specification product	12 horas	lun 17/05/21	mar 18/05/21	20	0 horas

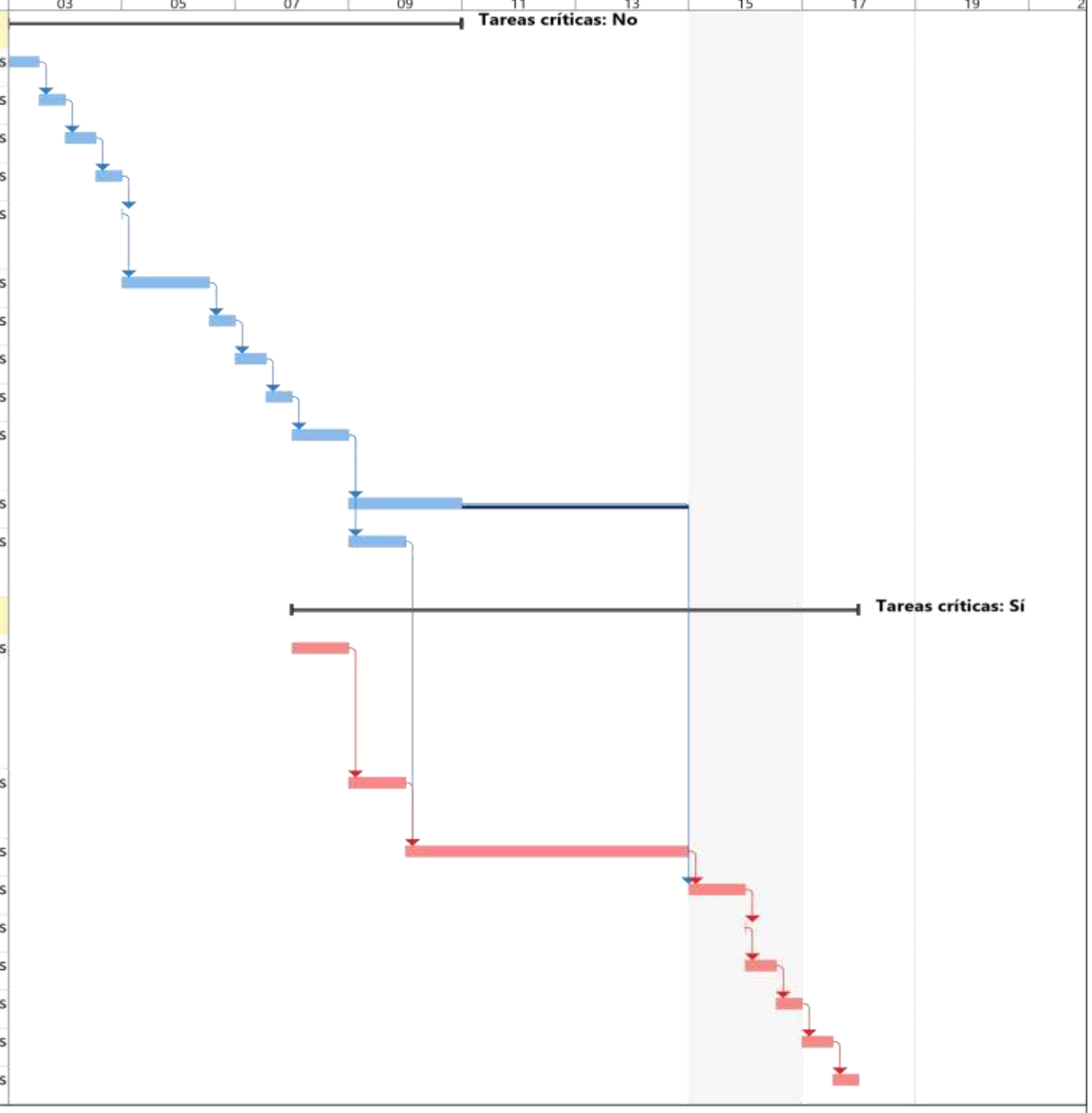


Proyecto: Optimized Planning
Fecha: lun 07/06/21

Tarea	Tarea inactiva	Informe de resumen manual	Hito externo	Progreso manual
División	Hito inactivo	Resumen manual	Fecha límite	Margen de demora
Hito	Resumen inactivo	solo el comienzo	Tareas críticas	
Resumen	Tarea manual	solo fin	División crítica	
Resumen del proyecto	solo duración	Tareas externas	Progreso	

Optimized PERT/CPM methodology

Id	Modo de tarea	Nombre de tarea	Duración	Comienzo	Fin	Predecesoras	Margen de demora total
		Tareas críticas: No	**48h**	**lun 03/05/21**	**lun 10/05/21**		
3		Cut feed to the column	6 horas	lun 03/05/21	lun 03/05/21		12 horas
4		Empty the column	6 horas	lun 03/05/21	lun 03/05/21	3	12 horas
5		Washing column	18 horas	lun 03/05/21	mar 04/05/21	4	12 horas
6		Drain column	6 horas	mar 04/05/21	mar 04/05/21	5	12 horas
7		Fitting insulation blanking flanges	12 horas	mar 04/05/21	mié 05/05/21	6	12 horas
8		Steaming	30 horas	mié 05/05/21	jue 06/05/21	7	12 horas
9		Opening manholes	12 horas	jue 06/05/21	vie 07/05/21	8	12 horas
10		Certifying insulation	12 horas	vie 07/05/21	vie 07/05/21	9	12 horas
11		Venting	12 horas	vie 07/05/21	sáb 08/05/21	10	12 horas
12		Dismantle upper distributor	24 horas	sáb 08/05/21	dom 09/05/21	11	12 horas
13		Clean upper distributor	24 horas	dom 09/05/21	lun 10/05/21	12	48 horas
14		Dismantling the bed packing	18 horas	dom 09/05/21	dom 09/05/21	12	12 horas
		Tareas críticas: Sí	**48h**	**sáb 08/05/21**	**mar 18/05/21**		
1		Establishment of the contractor's company at the site; SULZER's packing specialist	12 horas	sáb 08/05/21	sáb 08/05/21		0 horas
2		Preparation of the new packing	12 horas	dom 09/05/21	dom 09/05/21	1	0 horas
15		Placing the new packing	60 horas	lun 10/05/21	vie 14/05/21	2;14	0 horas
16		Fitting the distributor	24 horas	vie 14/05/21	sáb 15/05/21	13;15	0 horas
17		Closing manholes	12 horas	sáb 15/05/21	dom 16/05/21	16	0 horas
18		Perform leak test	6 horas	dom 16/05/21	dom 16/05/21	17	0 horas
19		Removing blind flanges	12 horas	dom 16/05/21	lun 17/05/21	18	0 horas
20		Feeding product	12 horas	lun 17/05/21	lun 17/05/21	19	0 horas
21		Specification product	12 horas	lun 17/05/21	mar 18/05/21	20	0 horas



Proyecto: Optimized Planning
Fecha: lun 07/06/21

Tarea	Tarea inactiva	Informe de resumen manual	Hito externo	Progreso manual
División	Hito inactivo	Resumen manual	Fecha límite	Margen de demora
Hito	Resumen inactivo	solo el comienzo	Tareas críticas	
Resumen	Tarea manual	solo fin	División crítica	
Resumen del proyecto	solo duración	Tareas externas	Progreso	

Figure 13: Gantt chart for the optimized planning

6.3.5 OPTIMIZED PLANNING CONCLUSIONS

By introducing all these changes, the intended objective is achieved: the critical path is the actual execution of the project (changing of the packing) and not the rest of the activities that do not require the specialist's expertise. It is based on removing from the critical path all tasks that have no impact on assembly-disassembly, as well as providing the necessary information and mitigating the potential threats in the construction phase.

In addition, the main aspects, which are the constraints, are met.

- The total time of 15 days established is achieved; the execution starts at 00:01h on 3/5/21 until 00:01h on 18/5/21. A total of **15 days**.
- The 7 days availability for the specialist is achieved. According to the planning, the specialist is mobilised on the side from 7:00h on 08/05/21 (Establishment of the contractor's company at side) until 19:00h on 14/05/21 (Placing the new packing). A total of **7 days.**

The last point to be considered is the project's criticality. Out of a total of 21 activities, only 9 activities are critical; those that have a direct incidence on the column packing change. This means that less than 50% of the total number of tasks are critical; more specifically, **43%.** By reducing the number of critical tasks, the resources necessary for non-critical tasks can be redistributed to cover the shortcomings that may arise during the construction work.

6.3.6 RISK ANALYSIS

Objective

The objective of the risk analysis is to distribute the available resources, according to the risk of not meeting the established time for each activity. Since the risk analysis focuses on avoiding deviations in the timing planning, it is specifically addressed to the activities identified as critical path in the PERT/CPM analysis. If the critical activities take longer than planned, then the project is bound to experience a delay. Therefore, resources must be assigned to minimize the risk of not accomplishing the planning.

The base principles for the Risk analysis technique are the Lean and the Agile management philosophies.

- Lean establishes as a main principle to “avoid waste, eliminating unnecessary activities”. Therefore, non-critical activities are simplified, so that the resources provided can be reallocated to critical activities, which determine the duration of the project.

- Agile promotes the management of the uncertainty in order to minimize the risk of not accomplishing the planning. In this sense, the reallocation of resources to the critical activities looks forward to minimizing the risk of a deviation from the objective deadline.

List of critical activities:

These are the activities identified as the critical path in the Optimized PERT/CPM methodology. The risk analysis has been conducted for these activities:

A- Establishment of the contractor's company at the site; SULZER's packing specialist

B2- Preparation of the new packing

O- Placing the new packing

P- Fitting the distributor

Q- Closing manholes

R- Perform leak test

S- Removing blind flanges

T- Feeding product

U- Specification product

Description of the risk analysis methodology

A novel risk analysis methodology has been developed, based on the probability and impact of the materialization of a risk.

For each critical activity, the main risks, or contingencies to accomplish the timing planning are identified. Each risk is evaluated upon its probability to happen and its impact on the timing planning of the project. Both, probability, and impact, are combined in order to assess the risk or severity. Table 15 shows the impact matrix that has been used. The risk is calculated upon Equation 4.

$$\boldsymbol{Risk = Severity = probability\ x\ impact/consequence} \qquad \textit{(eq.4)}$$

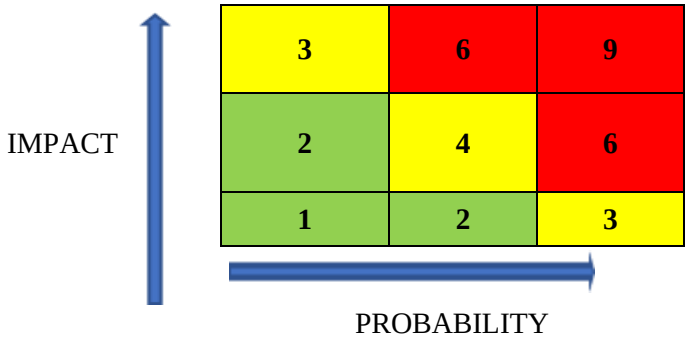


Table 15: Risk matrix

It is a quantitative analysis where numbers are used to assign a value for impact and probability. Thus, for example, a value of 3 for the impact means that in case the incident occurs, the consequences of it would be very severe. Whereas a value of 1 for probability indicates that there is little chance of the incident occurring.

Legend:

1 -2: Low risk

3-4: Medium risk

6-9: High risk

- For the range 1-2, no corrective action required.
- For the range 3-4, corrective actions must be considered, although their implementation depends on the degree of risk acceptance.
- For the range 6-9, it is mandatory to dispose of the financial and human resources needed for the implementation of the corrective measures. Furthermore, these corrective measures must be available (purchased/ accounted for) prior to the execution of the project to prevent any delays.

Risk assessment:

Activity	Risk code	Risk description	Probability	Impact	Severity
A- Establishment of the contractor's company at the site; SULZER's packing specialist	R-1A	Non-compliance with the planned date of arrival at side	1	3	**3**
B2- Preparation of the new packing	R-B2	During the preparation, part of the packing is damaged	2	3	**6**
O- Placing the new packing	R-1O	Misplacement of the new packing	1	3	**3**
	R-2O	The independent expert has a setback and is unable to supervise the specialist	1	3	**3**
P- Fitting the distributor	R-1P	When the distributor is disassembled, its coupling is broken	1	3	**3**
	R-2P	The distributor is still dirty when it is placed back in the column	2	3	**6**
Q- Closing manholes	R-Q	Fall from height by the operator	1	3*	**3**
R- Perform leak test	R-R	A vacuum test is performed on the column and leaks of air into the column are identified	2	3	**6**
S- Removing blind flanges	R-S	Not all blind flanges are removed from the leak test	1	3	**3**
T- Feeding product	R-T	The equipment that feeds the column has broken down	1	3	**3**
U- Specification product	R-U	Product does not reach the required purity	1	3	**3**

** the risk is not associated with a start-up delay but in terms of security*

Table 16: assessment of the associated risk for each critical activity

Note: The numerical assignment for the probability and impact associated with each incident is based on experience with similar projects and typical incidents that may arise during the execution of each critical task.

Corrective actions associated with each risk:

Risk code	Severity	Corrective Action
R-1A	**3**	A meeting is held prior to the contractor's mobilisation to the side (approx. 3 weeks before) to ensure that there are no setbacks, dates will be met, and the packing specialist required will be available.
R-B2	**6**	The supplier of the new packing must provide a spare packing to cover any incident during the "packing change" operation in addition to the already established spare for future replacement operations.
R-1O	**3**	No corrective action is required as it is planned to contract an independent expert to supervise the filling specialist's work. An effective communication between the specialist and the independent expert is encouraged. To this end, a meeting will be held to inform them of their implication in the project so that they are aligned with each other.
R-2O	**3**	The independent expert is asked to report any incidents one week prior to his/her mobilisation. In parallel, the company must ensure that a member of staff has sufficient knowledge (through prior training) to be able to supervise the specialist in the event of an emergency.
R-1P	**3**	As this is a revamping project, the operation is carried out on existing equipment, the company must have a replacement distributor. The company will be asked to notify prior to the project that they have at least one.
R-2P	**6**	No corrective action is required as an internal X-ray of the column is planned to check the degree of polymerisation of the distributor while a specialised cleaning company for column internals has been contracted to ensure the necessary pressure equipment such as pressure cleaning lances.
R-Q	**3**	Review the standards relating to work at height. Any deviation from current legislation must be reported to the client and the project will not be carried out until this has been resolved. For this purpose, all regulations concerning work on site must be reviewed and approved prior to the execution of the project.
R-R	**6**	No corrective action is required. The implementation of Lean philosophy in this project includes the removal of non-critical task resources to assign them to critical tasks in the event of a possible incident, in order not to exceed the time allowed, as in this case. The necessary personnel will be available to check each of the flanges and locate the one with air leaks. In addition, spare flanges/discs are available in case the component needs to be replaced.
R-S	**3**	Prior to performing the leak test, the operators shall list all the discs/blind flanges intended to be installed to insulate the equipment. Once the test has been carried out, while the discs/blind flanges are being removed, each of the list items shall be deleted in order to have an exhaustive control. Until all the items are removed, the column shall not be fed.
R-T	**3**	No corrective action is required. Out of project scope. The client must ensure that the other units feeding the column are operating correctly.
R-U	**3**	No corrective action is required. SULZER must prove, by means of a guarantee test, that the new packing allows to treat more m^3/h of feed without compromising the head product's purity. For this purpose, after the packing specialist has completed his/her work, SULZER undertakes to assign an operations expert to ensure that this condition is fulfilled.

Table 17: Corrective actions for each identified risk

7 CONCLUSIONS

The development of a real case-study highlights the crucial importance of the project management methodology implemented in this report in order to achieve the project goals in terms of reliability, time availability and resources.

Usually, the methodology employed in this type of projects is PERT/CPM, which has enabled to organize the different tasks, identifying which ones are critical and, thus, determine the total duration of the project. Although it is a useful methodology and easily applicable to a wide range of projects, the case-study that has been conducted reveals its limitations. The main, and most significant one, is the lack of tools to optimize the planning either to meet the project constraints or even to make it more reliable.

Over the last years, new techniques such as Lean and Agile, which provide guidelines for a more efficient management, have been incorporated in project management. This study demonstrates that the novel combination of such techniques ensures compliance with the established deadlines while increasing the reliability of the project's results.

Otherwise, even having improved in these aspects, the optimisation of resource assignment has not yet been faced. This area in project management is usually planned based on previous similar experiences, which may not always be representative. In order to overcome this limitation, this project suggests using an objective and rigorous methodology based on risk evaluation.

Although the suitability of Lean and Agile techniques to the specific case-study has been identified through the SWOT analysis based on threats and weaknesses, their implementation holds synergies with the same methodologies, within the scope of continuous improvement, which are being increasingly implemented in companies.

Although this methodology has been developed for an engineering project, for the reason stated in the previous paragraph, it can also be applied in small improvement projects, in other sectors different from the chemical industry and even in maintenance activities that have to be organised on a daily basis in production plants.

8 NOTATION

ADM	Activity Definition Model
CPM	Critical Path Method
DEG	Diethylene glycol
EF	Earliest finish time, hr.
EO	Ethylene Oxide
ES	Earliest start time, hr.
LF	Latest finish time, hr.
LS	Latest start time, hr.
MEG	Monoethylene glycol
PERT	Program Evaluation and Review Technique
PERT/CPM	Program Evaluation and Review Technique/ Critical Path Method)
PPC	Per cent plan complete, %
SWOT	Strengths, Weaknesses, Opportunities and Threats
TEG	Triethylene glycol
te	Estimated time, hr.
tm	Realistic duration, hr.
to	Optimistic duration, hr.
tp	Pessimistic duration, hr.

9 REFERENCE AND NOTES

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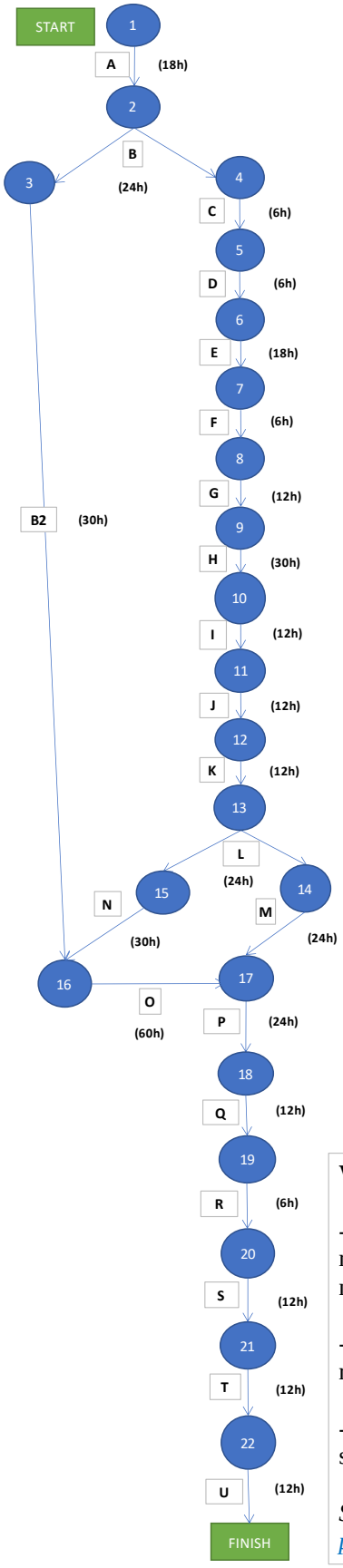
APPENDIXES

1 PROJECT NETWORK FOR THE CONVENTIONAL PLANNING



Where:

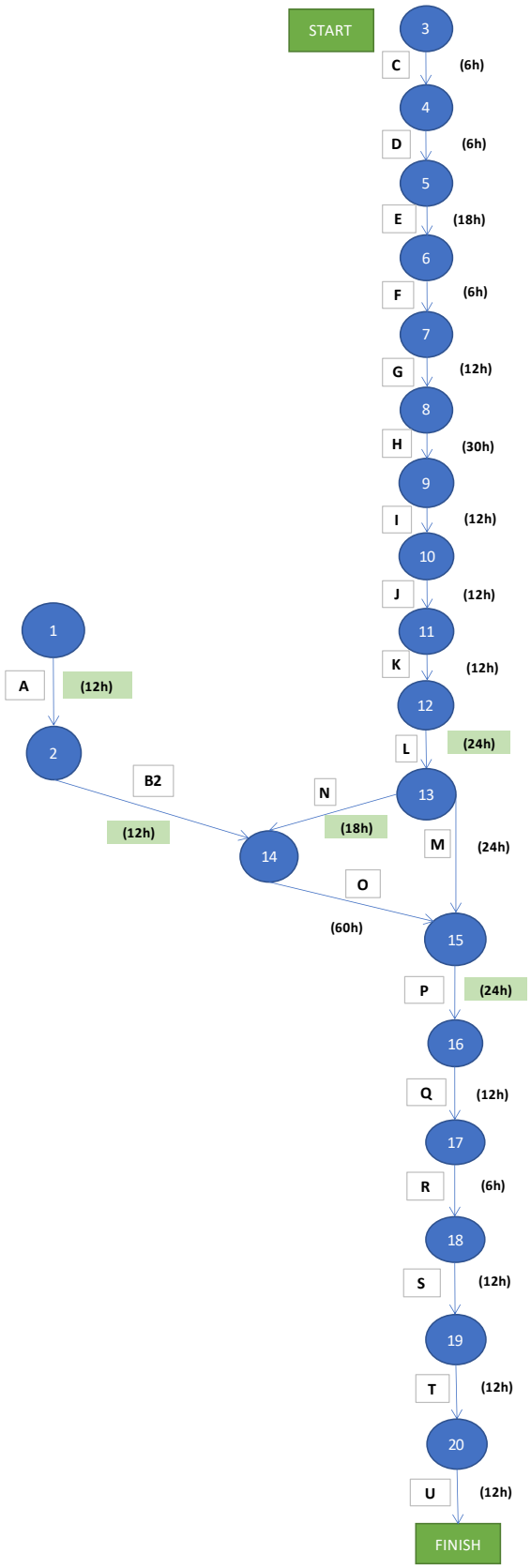
- The blue circle with a number inside represents the nodes. Each activity has two nodes (start - end).

- The blue arrow is the activity itself, represented by a letter inside a rectangle.

- Each activity has a duration and this is shown next to the activity.

See Table 4: List of activities- conventional planning

2 PROJECT NETWORK FOR THE OPTIMIZED PLANNING



Where:

The blue circle with a number inside represents the nodes. Each activity has two nodes (start - end).

The blue arrow is the activity itself, represented by a letter inside a rectangle.

Each activity has a duration and this is shown next to the activity. Durations that have changed compared to the conventional planning are shown in grey.

See Table 11: List of activities- optimal planning