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Application of Advanced Project Planning Methodologies for Nuclear Infrastructure Projects at the European Council for Nuclear Research

CERN

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ABSTRACT

Application of advanced planning methodologies for a nuclear infrastructure project at CERN.

The European Council for Nuclear Research is an international research organization that operates the largest particle physics laboratory in the world. CERN, main function is to provide the particle accelerators and other infrastructure needed for high-energy physics research and as a result numerous experiments have been constructed at CERN through international collaborations.

A Nuclear Infrastructure project, the Nano-Lab is currently in his design phase. It is an extension of an existing building and will be comprised of a radioactive material storage area and two laboratories for manipulating uranium nano-particles. The project manager assigned to the Nano-lab project is responsible for initiating, planning, executing, controlling, and closing projects. The Nano-lab project planning since the project is critical in nature owing to the complex scientific environment at CERN and the potential risks associated with it.

The aim of this work is to analyze the classical planning tools employed for this project, review their limitations and drawbacks, study and implement alternative and advanced planning methodologies. The conventional tool involves identifying the project activities, estimating the activity duration, determine the necessary resources i.e. cost. Gantt chart is used as the main tool for the development of a documented project plan. The key point of the analysis is the estimates made for time and cost for the Nano-Lab project. Estimates are made based on historical data form other successfully implemented projects, professional experience ‚Äì Technical and managerial expertise.

The potential risks associated with the Nano-Lab project are related to quality, cost, and schedule with an impact on the use and coordination of activities and resources. The traditional project planning methodologies puts special emphasis on linear processes, upfront planning, and prioritization. As per classical methods like WBS, Gantt chart, time, and budget are fixed, and requirements are variable due to which it often faces budget and timeline issues. The classical methods are not able to interpret the uncertainty with the activities done in parallel by different cross-functional teams in case of involving multiple stakeholders, hence any delay in work can lead to additional complexities and will have an impact on both time and budget. All these risks cannot be reflected upon the Gantt chart which becomes difficult to monitor and control.

Use of Advanced planning methodologies like Monte-Carlo can address these uncertainties that pose potential risks for the Nano-lab project. Monte -Carlo simulation is used in case of a complex estimation scenario that involves a high degree of complexity and uncertainty to analyze the likelihood of meeting the objectives.

Monte-Carlo simulation was conducted for the Nano-Lab project for total time and cost and to determine the likelihood of meeting the objectives in order to assess risks and implement where mitigation actions are required. A network diagram is created considering the overlaps due to parallel activities for project planning. The results displays likelihood of completion in terms of probability along with values of final completion-variables in terms of time and cost. The results are validated by comparing them with the traditional planning estimates by the project manager, the variations can be used to review and monitoring the planning and scheduling objectives and helps in making informed project decisions.

Monte-Carlo is useful to find the likelihood of meeting project milestones and immediate goals. It can also predict the likelihood of schedule and cost overruns, hence efficient in adapting to the changes by tracking the immediate goals and the milestones of the project. Further, sensitivity and uncertainty analysis can be done for risk variables of the project along with Earned Value Management.

Monte-Carlo is a valuable advanced planning methodology as the results are validated with the actual estimates for schedule and cost and the activities performance can be tracked and it's easy to revise schedule accordingly. It is concluded that a combination of both classical tools and Monte-Carlo proves to be an incredible technique to govern processes and control variables for project management.

Dedication and acknowledgments

First and foremost, I would like to thank my both supervisors Prof. Sergio Terzi from Politecnico Di Milano and Dr. Luigi Serio at European Council for Nuclear Research CERN.

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I would like to dedicate this work to my life-coach my Late mother Bimla Kandhol, who had always encouraged me to achieve growth and success in life. I always miss your voice and presence.

NOTE OF CONFIDENTIALITY

This thesis is based on internal, confidential data of information on CERN - European Center for Nuclear Excellence, Geneva. This work may be available to first and second reviewers and authorized members of the board examiners. Any publication and duplication of this work is prohibited. Any inspection by the third parties requires the expressed permission of the author and the organization.

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Chapter 1

Fundamental Concepts of Project Management

1.1 Project Management

A project is a temporary endeavor undertaken to create a unique project, service, or result[17].

According to ISO 21500, project consists of unique set of processes consisting of coordinated and controlled activities with start and end dates, performed to achieve project objectives. Achievement of the Project objectives requires the provision of deliverables conforming to specific requirements. A Project may be subjects to several constraints. Although many of the projects can be similar, or each project can be unique too. Project differences can occur due to the following reasons:

- Provision of the deliverables,
- Stakeholders influences,
- Usage of Resources,
- Constraints,
- Tailoring of processes to ensure deliverables.

Every project has a predetermined beginning and end dates and mostly project is divided into several phases along with defined objectives and goals of the project.

"Project management is the art of creating the illusion that any outcome is the result of a series of predetermined, deliberate acts when, in fact, it was damn luck." - Harold Kerzner

Project management is the application of the various methods, techniques, tools and competencies to a project. It is a discipline that gives principles, techniques and tools to accomplish project goals within time and budget constraints. Project management involves integration of various phases of the complete project life cycle. Project management consists of number of interlinking processes. A process is a sequence of actions who work towards same goals and objectives. These processes should be aligned in a systemic view. Each phase of the project life cycle have specific deliverables and should be reviewed regularly during the project to meet all stakeholders requirements.

Project management comprises of planning, organizing, motivating and controlling all the resources to achieve intended goals. The first step of the project management is to ensure that the project delivers within the pre-defined limits and constraints. They could range from time to budget and other situational risks. The subsequent step is to optimize the allocation of resources and to integrate the inputs required to achieve those pre-defined goals / requirements. To accomplish these goals, project manager has to control and monitor them actively.

Project management enables the managers to run a project from beginning to the end phase in an efficient and effective manner keeping in mind all stakeholders interests.

According to the Project Management Institute [16], the term Project Stakeholder refer to "an individual, group, or organization who may affect, be affected by, or perceive itself to be affected by a decision, activity, or outcome of a project". ISO 21500 uses a similar definition.

Stakeholders for the projects are individual or group entities whose interest lies within a given project. They can be both internal and external to an organization which either funds a project, have interest or gain upon success of the project or may have a positive or negative influence on project completion,

Owing to the dynamic and complex nature of business needs, managing resources and ensuring effective communications among team is a real challenge. Hence, Project management has become eminent for managing performance of business and industrial needs. As every project is unique, even the approach defined to project management can be different. It depends on the type of business, sector and constraints defined by the clients.

Project management [4] is a combination of art and science, as so many authors has stated that it is a mix of knowledge and skills , some acquired , others developed , some intrinsic characteristics traits of any individual or a group of persons, tools and techniques which constitutes of scientific, qualitative and quantitative which supports the decision-making process in project management.

Often, project management is defined by a triangle called "Triple Constraint" [6]. The three most important factors are time, cost and scope. These three factors form the vertices of the triangle with quality as the central theme.

The triple constraint has four elements:

1. Project must be completed within allocated cost,

2. Project must be completed on time

3. Project deliverables must be in within scope

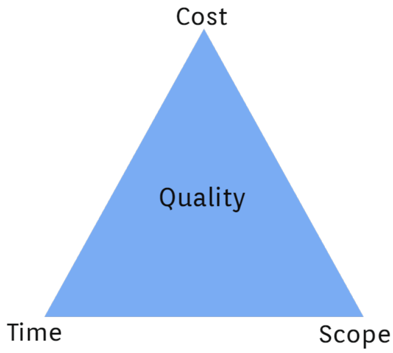

FIGURE 11. The Triple Constraint

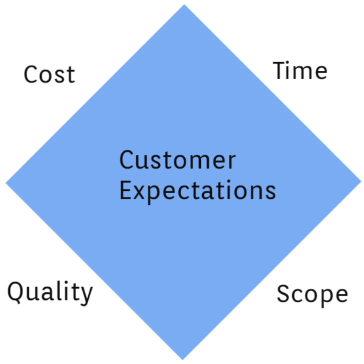

FIGURE 12. The Diamond Constraint

4. Project must meet user quality requirements.

In recent years the project management triangle has given a way to the project management diamond [1] with cost, time, scope and quality as the four vertices and user expectations as the central theme. No two users have same requirements and expectations, it is important have a clear understanding of user generic and specific requirements.

1.1.1 Project Management lifecycle

According to the PMBOK 2008 (Which edition), the PMBOK guide (the standard guidebook for project managers around the world) the project management lifecycle comprises of the five types of processes such as Initiating, planning, executing, monitoring and controlling and closing. These processes are elaborated as below:

It is important to define the goals, objectives and critical success factors of the project:

1. **Initiating:** In the initiation phase, there is a need to identify the project goals, after carefully investigating all the options to come up with the meaningful solution. Recognize

and define the beginning of the project and the smooth continuity of one phase to another during the project. Initiation process keeps the team focused on the project goals. Initiating is the most critical stage in project management. It also halts the project if it fails to meet the customer expectations. It will create a domino effect, disrupting all the following stages as well the final outcomes.

2. **Planning:** After clearly defining the scope of the project, the next phase is planning. It is the second most important phase of every project lifecycle because each project is unique and requires special approach. It is an ongoing process which continues through the entire project lifecycle. It answers all the questions as we create a feasible scheme which includes clearly defined activities, cost estimates, schedule development and resource planning.

3. **Executing:** It is the part of the project management lifecycle where we physically construct the deliverables and present them to the user, who then decides upon it. It is usually the longest phase and also directly depends upon the duration of the project. The project manager controls activities, resources and costs while the team is performing the required activities. To carry out the process and ensuring accurate and complete information flow and team formulation.

4. **Monitoring and Controlling:** Despite good planning and careful execution, projects fails if they lack control, mechanisms for the processes involved within the project. Monitoring the key performance indicators for the project and control the quality of the project results, observing the significant changes and making necessary adjustments as per requirements. To keep everything under control following checks are made, collecting data from spreadsheets and completed tasks, comparing it with the plan (like schedule and budget estimates). Another technique called Earned Value Management is used to measure performance of the project. It is a systemic process used to find variances in projects based on differences between task performed and tasks planned. It is used to control the schedule and the costs and can be useful for project forecasting too.

5. **Closing:** Project closure allows the team to evaluate and document the complete information about the project. In the closing phase, we assess the project performance (in terms of objectives, scope, deliverables, schedule and cist), evaluate team member‚Äôs performance, list down project achievements and failures and keep data for future prospective projects. Formal acceptance of the project deliverables and dissolution of all the elements required to run the project. To gather all necessary data to validate the completed project.

Project life cycle is the series of the phases that the project which passes from its start to its completion. It also provides the basic framework for project management. The phases of the project lifecycle may be sequential, iterative, or overlapping.

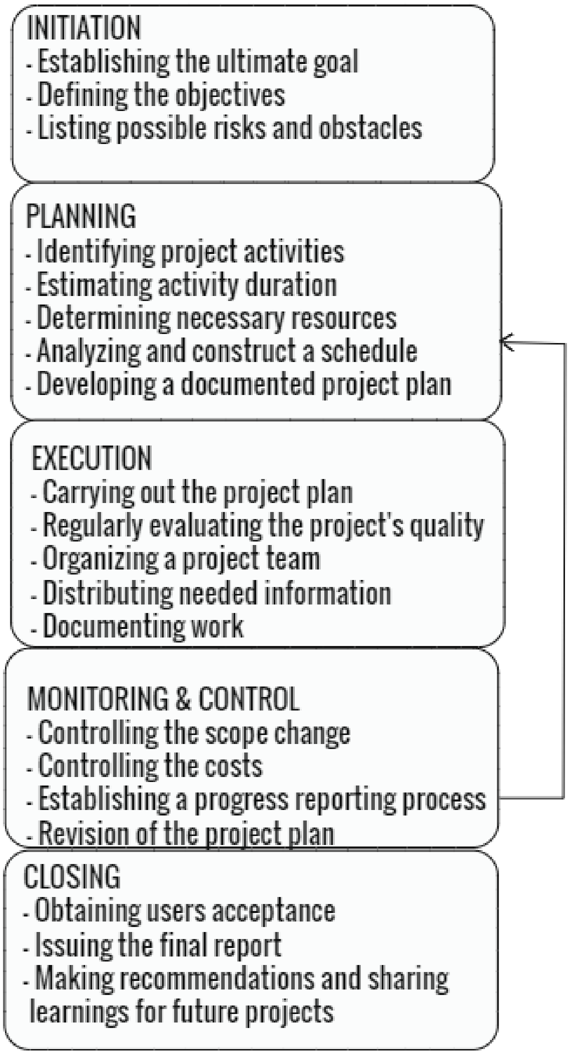

FIGURE 13. Project life cycle

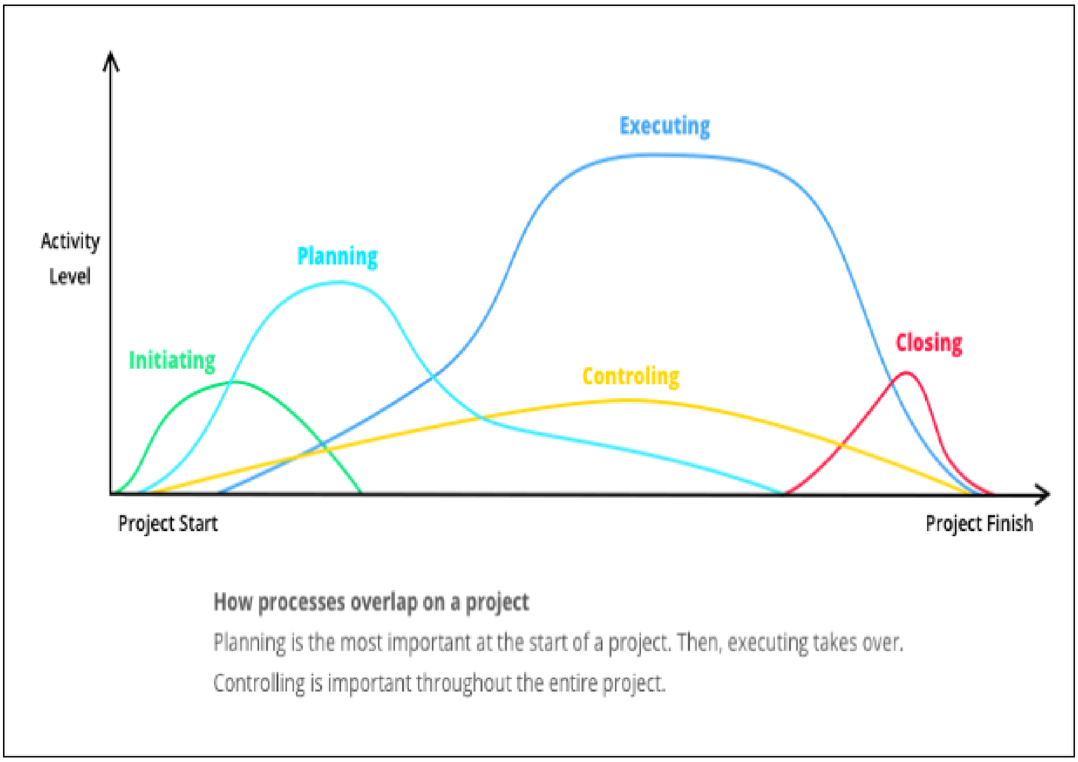

FIGURE 14. How processes overlap each other

Project lifecycles can be predictive or iterative, within a project lifecycle, there are generally one or more phases associated with the development of the results. These are called development life cycle, they can be predictive, iterative, incremental, adaptive, or hybrid model.

- Predictive life cycle also called Waterfall, the project scope, schedule and costs are determined in the early phases of the project.
- Iterative life cycle, project scope is generally determined in early phases of the project lifecycle, but schedule and cost are modified in a routine manner.
- Incremental lifecycle, deliverable is produced through a series of iterations that successively add functionality within a predetermined time frame and is considered complete only after the final iteration takes place.
- Adaptive lifecycle are agile, iterative or incremental. The project scope is defined in a detail manner and agreed upon the start of an iteration. Adaptive lifecycles are also referred to as agile.
- Hybrid lifecycle, is a combination of a predictive and an adaptive life cycle.

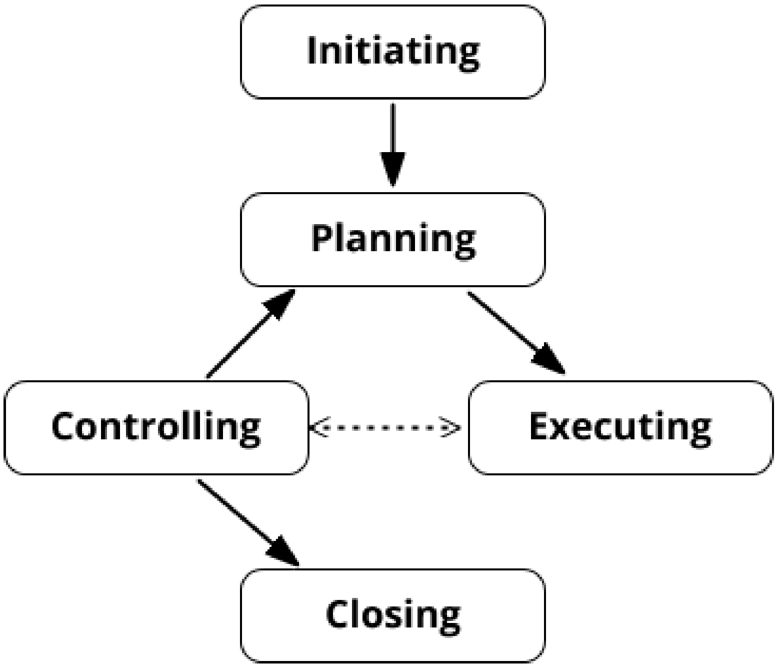

FIGURE 15. Flow of project processes

The process does not necessarily follow the chronological pattern. As in due course of a project, sometimes things do get out of hands and are difficult to control. That is why processes usually overlaps throughout different phases of the project and ultimately become interdependent. All phases of the project life cycle interacts and are linked by their results. Subsequently the project manager sometimes has to return to earlier phases, makes necessary adjustments and amendments and keep continuing with the project management processes.

For example, during the controlling and monitoring phase, if we need to allocate more resources to some activity, we need to modify the planning phase and amend resources planned for that activity. Else, inconsistency can have a major effect on entire project lifecycle.

Processes are linked to each other by their outcomes, as output of one process becomes the input for another. For example, the planning process provides the execution process with a pre-determined project plan. But planning process plays an important role throughout as it updates the plan as the project makes progress into further processes. Project planning is the most significant process as it lays down the project plan with detail of all the work packages and predicts possible obstacles need to overcome along the project run.

It is not easy to achieve success with the project, if we rely completely on clearly defined processes. Project management is both a science and an art.

1.1.2 Role of a project manager

The role of the project manager involves planning and organizing the resources and schedule necessary for accomplishment of projects.

As per Project Management Institute, a project manager is organized, passionate and goal-oriented who understands what projects have in common, and their strategic role in how organizations succeed, learn and change.

They are change agents, they commit to the project goals, and use their skills and expertise to promote a sense of share purpose for the entire project team. They work well under pressures and easily adapt with change and complexity in dynamic environments. They have good people skills and they possess abroad tools and techniques to resolve complex interdependent activities into tasks and sub-tasks that are documented, monitored and controlled.

In late 1980s, Microsoft encountered a problem of coordination amongst different teams. They came up with a solution to appoint an individual who has significant authority as a leader and a coordination for the project named Excel. They horizontally deployed project manager, processes ran more smoothly and team satisfaction with work dynamics. Later, Microsoft adopted Project Manager as a new role.

The Project manager has several key roles and responsibilities:

- **Activities and Resource Planning:** Planning is instrumental for completion of a project. The prime task of a project manager is to define the project‚Äôs scope and determine the availability of resources. They create a clear and concise document for guiding throughout the project execution and project control.
- **Organizing and motivating a project team:** They are in charge of developing a plan to support the team in order to achieve the project goals and control the performance.
- **Time Management:** Users evaluate the performance of the project depending on whether it has been delivered on time and on-time completion of the project is the pre-requisite for the success of the project.
- **Cost estimates and budget allocation:** A project manager ensures the completion of the project within defined and allocated budget. They frequently review the budget plans and forecasts to avoid cost overruns.
- **Ensure user satisfaction:** Users satisfaction is the most important key performance indicator to evaluate the project success. A project manager avoids uncertainty and keep user informed at every phase of the project.
- **Analyzing and managing project risks:** A project manager identifies and evaluates the potential risks and develop appropriate strategies to avoid and minimize the risks and their impact on the project.

- **Monitor progress:** A project manager need to control and analyze the key performance indicators related to the cost and time; take appropriate preventive and corrective measures.
- **Creating and managing reports and necessary documentation:** Creating and managing reports and necessary documentation: Finally, an experienced project manager provides relevant documentation with final reports and also identifies areas of development for future projects.

Project managers are integral part of all organization ranging from big ones to small ones, who are in-charge of complex and ambitious projects.

1.2 Planning & Scheduling in Project Management

Planning and scheduling are two distinct but inseparable aspect of Project management[2]. The process planning primarily medals with appropriate tools and techniques and methods to achieve the goals of the project. On the other hand, Scheduling deals with project baseline plan (Scope, cost and time) into an operational timetable. By merging together the project plan and the budget, schedule is the most important tool for project management. Further, integrated cost-time schedule serves as a fundamental basis for monitoring and controlling the project tasks thought out the project life cycle.

1.2.1 Relevance:

The Planning process is the one of the most important phase of the Project management. To develop project management plan is the process of defining, preparing, and coordinating all other planning activities.

The major benefit of the planning process is the creation of a comprehensive document which defines the entire project work and the how to perform the defined activities.

- Planning process is performed once in the beginning of the project or at predefined points of the project.
- Project management plan can be both as a summary version or a detailed one.
- Project management plan should have a baseline (Scope, Time and Cost)
- Project management plan can be updated as many times as deemed necessary. But, once it is baselines it can only be changed through internal control process.

Project Schedule as a Model of Control: The project planning [22] process leads to creation of a schedule as a model for project control which has its occurrences in certain situations of project initiation and implementation, for tracking progress and monitoring performance. It is very crucial for adapting to changes to avoid any project delays and clear communication amongst the project teams and an important process for project evaluation.

1.2.2 Criticality:

Project planning [7] process specifies the process to follow in future and assist with decision making in order to execute the entire project. The project manager are responsible for completion of the projects keeping in mind the interest of the stakeholders. They have to make sure that the plan is reliable and properly represents user's requirements. It is the most important and hence the critical process of the project management life cycle.

1.3 General Project Planning Methodologies

As project management began to be studied as a science and discovering various project archetypes, big corporations comes with different methodology and tools. As it spread over vast variety of industries, project managers tailored every approach and, methodology based on the industry requirements and different types of the projects.

For example, agile methodologies are effective on software development but it doesn‚Äôt work with infrastructure projects and vice-versa. Hence methods and techniques are bundled into methodologies to run a project consistently within time and within budget.

How to choose a right project management methodology? There are quite some good project planning methodologies available, so it can be difficult to choose the right one. **The focus of the thesis is primarily on project planning methodologies.**

A brief overview on different types of general project planning methodologies:

1.3.1 Traditional Project Management Planning

Traditional Project management is a universal practice which includes several techniques for planning, estimating and controlling activities. The aim of these techniques is to reach the desired project goals on time, within budget and in accordance to technical and managerial specifications. The ultimate goal is to make sure all the activities are carried out in a sequence.

In traditional planning, it is a sequence of steps taken to build the roadmap of the project and is one of the most fundamental step defining the performance of the project goals.

- To identify the project activities.
- To estimate the project duration.
- To determine the required resources.
- To develop a sequence of project activities network.

- To develop a documented project plan.

Traditional project management planning is the most common way to plan projects. It is not a methodology rather it is a collection of techniques, like WBS (Work Breakdown Structure), dividing into phases. The different tools used in traditional planning are:

1. WBS - Work Breakdown Structure
2. Project schedule and Plan - Gantt Chart

1.3.1.1 Work Breakdown Structure (WBS):

According to PMBOK [16], WBS is a deliverable-oriented hierarchical decomposition of work to be executed by the project team to accomplish the project objectives and create the required deliverables.

The purpose of WBS[19] is to define the project needs, to accomplish, and organize them into multiple levels, and displayed graphically in form of a chart.

The key terminologies used with WBS are work, deliverable and work packages. In the context to the project management, these terms have specific definitions:

- **Work:** According to PMBOK, work refers to "work products or deliverables that are the result of effort and not the effort itself". The work defines the end result of the activity. The work remains constant even though the amount of effort needed is variable.

- **Deliverable:** PMBOK says that deliverable is "any unique and verifiable product, result, or capability to perform service that is required to be produced to complete a process, phase, or project". Deliverables may vary within the project.

- **Work Package:** According to PERT, they developed WBS, a work package is "the work required to complete a specific job or process, such as a report, design , a documentation requirement or portion thereof, a piece of hardware , or a service. "PMBOK" provided a simpler definition; "a work package is the deliverable at the lowest level of the WBS."

1.3.1.2 Characteristics of a WBS

- **Hierarchy:** The WBS is a hierarchical nature divided into macro activity and micro activities and former is the sum of all the latter activities. 100%: Every level of decomposition should make up for 100% of the macro activity.

- **Mutually exclusive:** All elements of the WBS must be mutually exclusive. There must be no overlap in the deliverables as it avoid duplication of activities.

- **Outcome-focused:** The WBS focus on the deliverables not on the activities necessary to reach the goal.

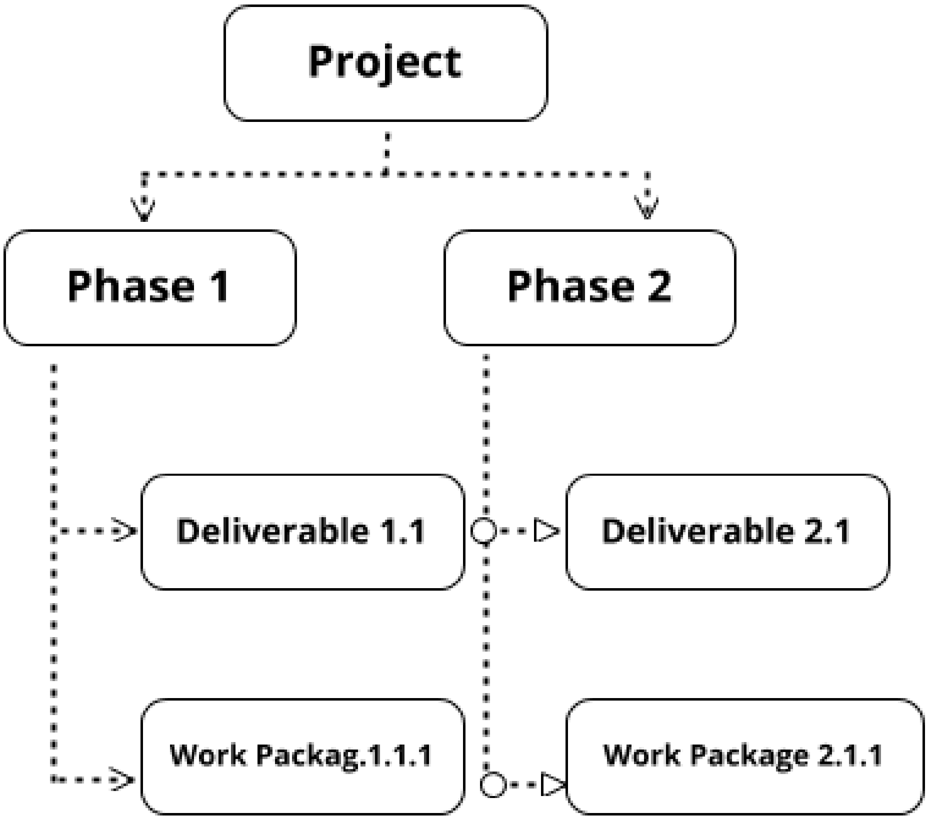

FIGURE 16. Work Breakdown Structure

Work Breakdown Structure data is the input to create a project schedule.

Gantt chart: Gantt chart is the most important technique in the traditional project management. It was created by Henry Gantt, which is who is considered as father of traditional project management.

It is an important tool for project planning, most useful ways of presenting tasks and activities of the project on a timeline. Currently, Gantt charts in excel. The Gantt chart is represented as -

By looking at the Gantt chart, it displays -

- What are the project tasks are
- Who is working on each task
- How long each task could take
- How tasks overlap and link with each other
- The start and finish the date of the project

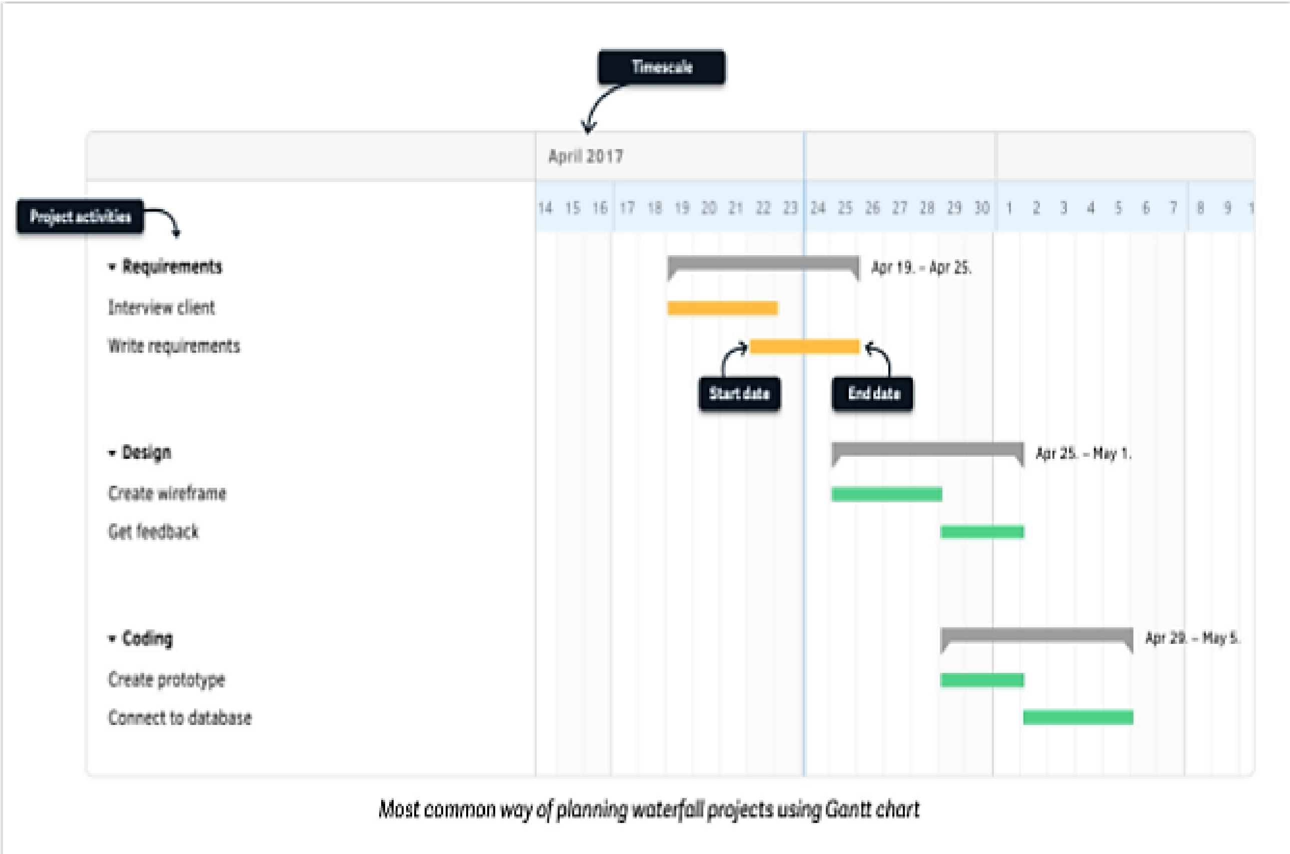

FIGURE 17. Gantt chart

Gantt chart is used to track the projects schedules and make project management less cumbersome. It helps to understand the relationship between tasks in a clear manner, keep all the team members well informed and successfully complete the project.

In today's scenario due to COVID - 19, Even if we are using traditional tools like Gantt chart to manage the projects, as long as project team embraces changes, provides frequent and valuable output to the users, reflecting and adjusting as needed, it is compatible to agile methodology to manage projects.

Traditional project planning tools in 21st century, as computer and internet became essentials parts of the business, processes became more complex and demanding, it no longer offers the best solutions for user's problems. The concept of traditional project planning tools has evolved and extended through different project management planning methodologies and frameworks.

Nevertheless, traditional management is still considered as foundation of all modern approaches and is still an inevitable methodology for big or complex infrastructure projects.

Gantt Chart: An Overview	
Advantages	Disadvantages
Easy to organize ideas	Increasingly complex with demanding projects
Clear layout of the activities	doesn't indicate actual quantity of work and resources
Helps to create realistic time schedules	constant updating due to changes in project planning
Highly visible	Difficult to see all activities and details in one chart

1.3.2 Deterministic Methodology - Critical Path method (CPM)

Critical Path Method (CPM) is the most important deterministic methodology for project planning and scheduling. It is a mathematical algorithm that helps to analyze, plan and schedule complex projects.

Each project consists of tasks and activities that are interconnected and essential for project's success. CPM comes into play when the project gets complex and demanding when traditional planning tools becomes ineffective. At its core, CPM is a powerful tool that allows to identify the longest path of the planned activities critical to meet the deadlines and also identify the early start and finish dates. By determining the critical path, we will know the activities are critical in completing the project, and which activities do not pose any serious impact on the project development.

How was CPM created?

In late 50's, El Du Pont de Nemours, an American chemical company, were seriously behind schedule, and they needed help with it to come back on the timeframe to complete the project. They came up with a solution to divide their project into thousands of tasks, measure the time to complete each activity, to assess which activities are critical to the entire project. They called this technique Critical Path Method or CPM.It was first tested for as chemical plant construction project, and since then it is used as one of the most frequently used techniques of the project scheduling and planning.

CPM is used to construct a model of the project that includes -

- A list of the activities to complete the project using WBS
- The time (duration) of the each activity to achieve completion
- The dependencies between the activities.

1.3.2.1 CPM Approach[14]

- CPM calculates :
  - The longest path of the planned activities to the end of the project.

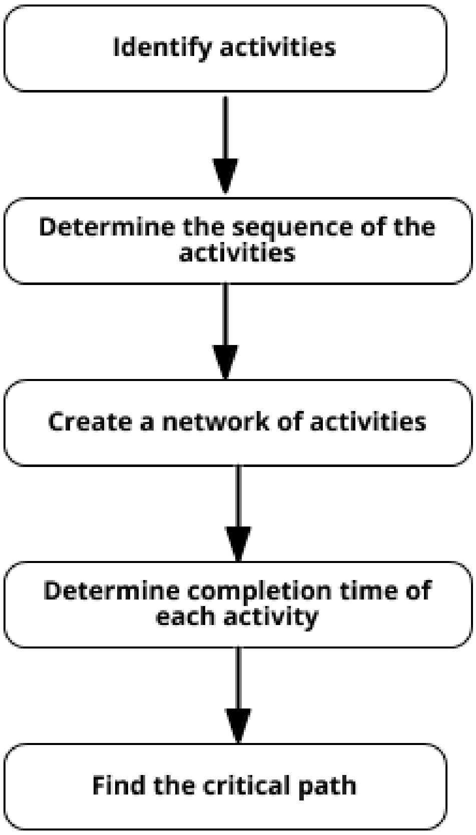

FIGURE 18. CPM workflow

    - The earliest and latest that each activity can begin and end without making the project longer.

- Determine the critical activities "the longest path".
- Prioritize the activities for the effective management and to shorten the planned critical of the project by -
    - Pruning the critical activities
    - Fast tracking i.e performing more activities in parallel
    - Crashing the critical path by shortening the durations of the critical path activities by adding resources.

1.3.2.2 Steps in Critical Path Method

A critical path method include the following methods:

1. **Identify activities:** By using the WBS, utilize the list if activities and identify them by name and a code, all activities must have a defined duration and end date.

2. **Determine the sequence of the activities:** It is the most important step as it provides a clear view of the relationship between the activities and helps to establish the dependencies as some activities occurrence will depend on the completion of others.

3. **Creating a network of activities:** After determining the interdependency amongst the activities, a network diagram is created, a critical path analysis chart; it allows you to use arrows to connect to the activities based on the dependency.

4. **Determine the completion time for each activity:** By estimating the time taken to complete each activity will help to determine the total time needed to complete the project.

5. **Finding the critical path:** A network of activities will help to create the longest sequence "the critical path" using these parameters

ES Early Start: the earliest time to start a certain activity provided that the preceding one is completed
EF Early Finish: the earliest time required to the finish the activity
LF Late Finish : the latest time required to finish the project without delays
LS Late Start: the latest start date when project can start without project delays.

If there is a delay in any task on the critical path, the entire project will be delayed. The critical path is the path where can be no delays. Not all of the project activities are equally important, while some of them have a huge impact on the critical path. The critical path method helps to determine which activities are ‚Äúcritical and which have ‚Äútotal float‚Äù. However, if any of the floating activities get seriously delayed, they become critical, and hence delays the entire project.

How resource limitations effect the CPM?

There are always certain limitations that affect our projects and create new dependencies. For example, resource limitations. In such scenario, the critical path changes into "critical resource path" where resources related to each activity become important part of the process.

As some of the tasks will have to be performed in a different order, which may cause delays and consequently, make the projects becomes longer than estimated.

Benefits of CPM are: Although new techniques have been there in fast-paced technological advances, CPM still offers a number of advantages. Prioritized tasks

1. Clarity on project's timeline for modifications

2. Risk assessment becomes easy

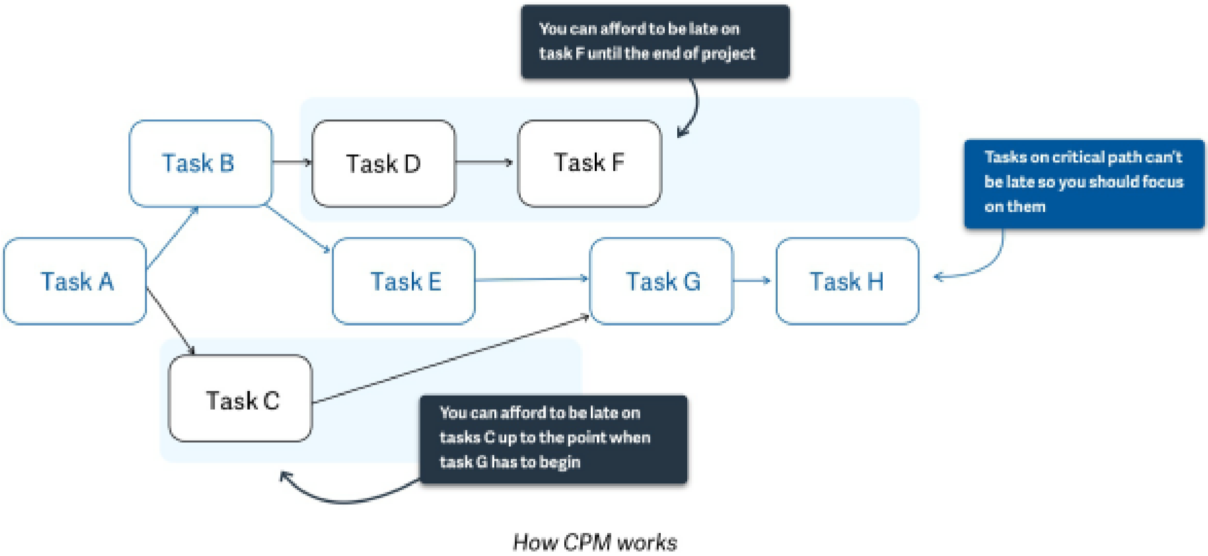

FIGURE 19. CPM Diagram

3. Redistribution of resources is efficient
4. Helps project panning team to stay focused

Hence, CPM allows tom reschedule less important tasks and focus all efforts on critical path to optimize work thereby avoiding delays.

1.3.3 Probabilistic Methodology - Program Evaluation and Review Technique (PERT)

The Program Evaluation and Review Technique PERT[4], is a probabilistic methodology in project planning that helps to analyze, represent, and evaluate and estimate the time required to complete the project within defined time duration. PERT allows project planners to identify start and end dates, and ultimately contributes to reducing time and cost required to complete the project.

PERT was developed in 1958 by the US Navy as a part of the Polaris project. Their aim was to manage the Polaris submarine missile program. CPM was also developed around the same time.

Unlike CPM, which determines the longest path needed to finish the project, PERT provides three different time estimates. While PERT deals with unpredictable activities, but CPM deals with predictable activities. Hence, PERT deals with non-repetitive activities and CPM involves activities of repetitive nature. Owing to these differences, PERT is widely used in research and development projects and CPM heavily used in construction projects.

Steps in PERT:

1. Identify specific activities and milestones: By listing out all the activities within a table, to get a clear overview of all the steps which can subsequently expand by adding information on sequence and time necessary to complete each activity.

2. Determining the sequence of the activities: It is easy to predict order for some activities while others might need in-depth analysis to determine their order.

3. Develop a network diagram: Once the sequence of the activities is defined, activities can be represented both series and parallel activities in the diagram.

4. Each activity should represent a node in the network, and arrows are used to show relationships between the activities.

5. Estimating the time required for each activity: What distinguishes PERT from the other techniques of project planning is its ability to deal with uncertainty in activity completion time. There are 3 time estimates PERT uses for each activity:

   - **Optimistic time:** the shortest time in which activity can complete
   - **Most likely time:**the completion time that has highest probability
   - **Pessimistic time:** the longest time in which the activity can complete

   Once these 3 time estimates are identified, expected time is calculated for each activity by using the following weighted average as:

   $$Expectedtime = \frac{(Optimistic + (4 * Mostlikely) + Pessimistic)}{6}$$

6. **Identifying the critical path:** By adding the times for the activities and determining the longest path, we can calculate the critical path. The critical path involves the total amount of time required for the project completion. The total project time is independent of the change in activities outside critical path.

1.3.4 Advantages

At its core, PERT helps to control complex and ambitious projects whose objectives are highly critical in nature. It helps to determine the fastest route possible to complete the projects. In-depth analysis of the project by viewing the activities both independently and in connection with each other. This provides clarity on time and budget required to complete the entire project. What-if analysis helps to identify all the possibilities and uncertainties related to the project. By

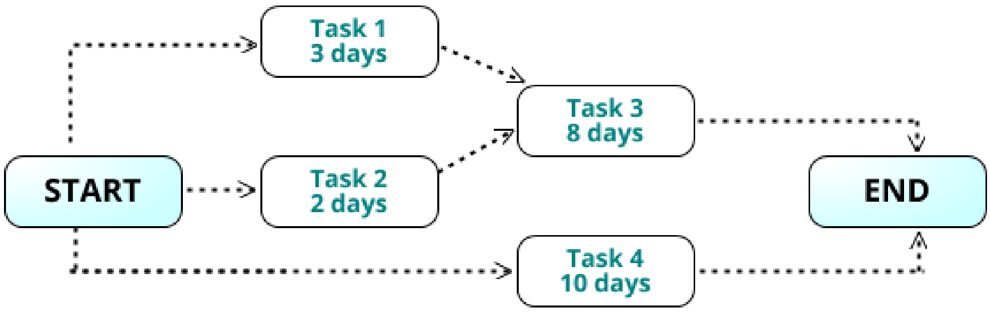

FIGURE 110. PERT Diagram

trying different combinations and choosing the most useful possibility, we can eliminate risks. It also highlights the activities that require careful monitoring.

1.3.5 Disadvantages

Even though PERT has proven to be an effective methodology for reducing the expected project completion time, there are still some limitations associated with it. Although PERT clearly defines all the activities on a project, it is sometime impossible to predict every step. As changes takes place within the project, it can seriously affect the initial PERT. While it is possible to make modifications but it leads to opportunity cost in terms of time. Project planning managers make time estimates and as they heavily depend on the estimates based on the experience of the project managers.

Overall, PERT allows to have an idea of possible time variation and helps to assess the importance of the uncertainties along the entire project duration. Unlike most methodologies, PERT provides the flexibility to identify the best-case and the worst-case scenarios and to develop a strategy on how to best coordinate large-scale projects.

1.3.6 Computational algorithm - Monte Carlo Simulations

The Monte Carlo Simulations is a computational algorithm used for simulations of various mathematical, statistical and scientific situation's during the project and is explained in several standards and PMI book[20].

The Monte Carlo method was first used in the Second World War during "Manhattan Project". Since then it is being utilized in vast number of fields. It utilizes the quantitative data and help in communicating and justifying the project variables in an explicit manner in comparison to forecast made on historical estimates.

It can be simply defined as statistical analysis optimized for approximation of quantitative problems on the basis of random sampling and probability. Based on the project completion variables, such as time and cost, they are represented through probability distributions. Monte-Carlo method can simulate the complete project for thousands of times depending on the nature of the project by selecting the random values each time from its probability distributions. After that, the process is repeated in order to calculate the overall completion variables of the project.

It will be discussed in great detail in subsequent chapters and its usage as an advanced planning methodology in project management for Nuclear infrastructure at CERN.

CHAPTER 2

MONTE CARLO SIMULATION

2.1 Introduction

Monte Carlo simulation is a computational technique for modeling and analyzing real-world systems and situations through projections of existing data for managing risks and uncertainties during project management. The results from these simulations allow project-managers to identify, analyze, and assess possible risks and develop risk mitigation and contingency plans during the execution of complex projects. We can therefore account for risk in quantitative analysis and decision making to handle difficult situations and by incorporating such interventions, we can equip and empower the project-manager to lead the project towards successful completion.

The technique (named after the Monaco town famous for its casinos) was initially developed by scientists working on the atom bomb during the second world war to game for possible scenarios

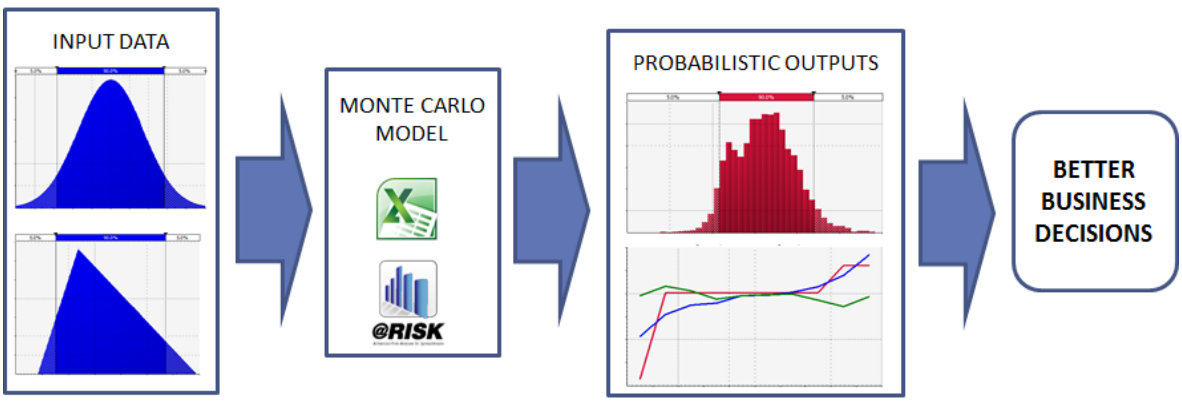

FIGURE 21. MC Simulation Workflow

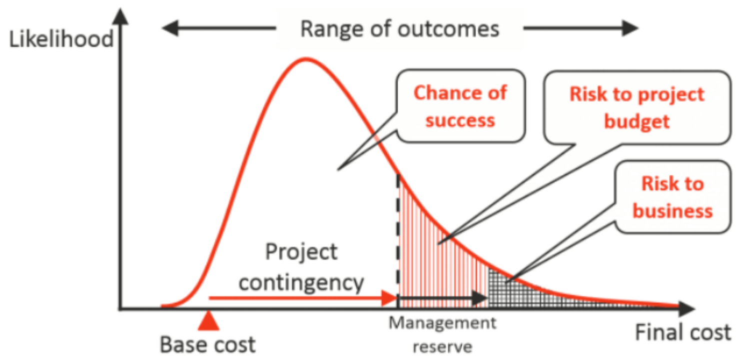

FIGURE 22. Range of Outcomes

in the outcome of the Manhattan project and the potential roadblocks that could arise during the execution of the secretive and high-stakes project. Monte Carlo simulation provides the decision-maker with a plethora of possible outcomes and their respective probabilities of occurrence for any given choice of action. These possibilities includes extremes - the outcomes of going for broke and the conservative option - along with all possible consequences for intermediary decisions. In the field of project management, Monte Carlo simulation can quantify the effects of risk and uncertainty in project schedules and budgets, giving the project manager a statistical indicator of project performance such as target completion date and budget.

Monte Carlo simulations are employed for effective risk management in wide-ranging fields such as manufacturing, engineering, finance, project management, energy, research and development, insurance, oil & gas, and transportation.

In this thesis, we have adapted the Monte Carlo simulation to be utilized as a forecasting tool for project scheduling and cost estimation, which is enunciated in detail in subsequent chapters. We have addressed uncertainties that poses potential risks to the project and quantifying useful likelihoods for meeting project milestones and immediate time and cost goals. It can also predict occurrence of scheduling and cost overruns. Hence, it enables to restructure the project as per updated requirements. Monte Carlo tools can also be further used for sensitivity and uncertainty analysis for risk variables of the project.

2.2 How MC Simulation Works

Monte Carlo simulation carries out risk analysis by building models of possible results by substituting a range of values - a probability distribution - for any factors that has inherent uncertainty. It then calculates results over many iterations, each time using a different set of random values from the probability functions.

Based on the number of uncertainties and their ranges, a Monte Carlo simulation could involve thousands of iterations that produces distributions of possible outcome values. By using probability distributions, variables can have probabilities for occurrence of different outcomes. Probability distributions are a much more realistic way of describing uncertainty in variables of a risk analysis.

The standard deviation of that probability quantifies the likelihood that the actual outcome being estimated will be something other than the mean or most probable event. Assuming a probability distribution is normally distributed, approximately 68% of the values will lie within one standard deviation of the mean, about 95% of the values will lie within two standard deviations, and about 99.7% will fall within three standard deviations of the mean. This is known as the "68-95-99.7 rule" or the "empirical rule."

The most common probability distributions and certain important features related to them is described below.

1. **Normal/Bell Curve:** The user simply defines the mean or expected value and a standard deviation to describe the variation about the mean. It is a symmetric curve and values at the center of distribution (near mean value) are ones most likely to occur in this kind of distribution.

2. **Lognormal Curve:** Unlike the normal distribution, it is an asymmetric curve since the values in this distribution are positively skewed. It is used to represent values that don't go below zero but have unlimited positive potential.

3. **Uniform Curve:** All values have an equal chance of occurring, and the user simply defines the minimum and maximum.

4. **Triangular Curve:** The user defines the minimum, most likely, and maximum values. Values in the neighborhood of the most likely are more probable to occur.

5. **PERT Curve:** The user defines the minimum, most likely, and maximum values, just like the triangular distribution. Values around the most likely are more likely to occur. However values between the most likely and extremes are more likely to occur than the triangular; that is, the extremes are not as emphasized.

6. **Discrete Curve:** The user defines specific values that may occur and the likelihood of each

2.3 Advantages and Limitations of MC Simulation

Monte Carlo simulation provides a number of advantages over deterministic, or "single-point estimate" analysis like:

1. **Probabilistic Results:** The result indicates not just what could happen, but also how likely each outcome is.

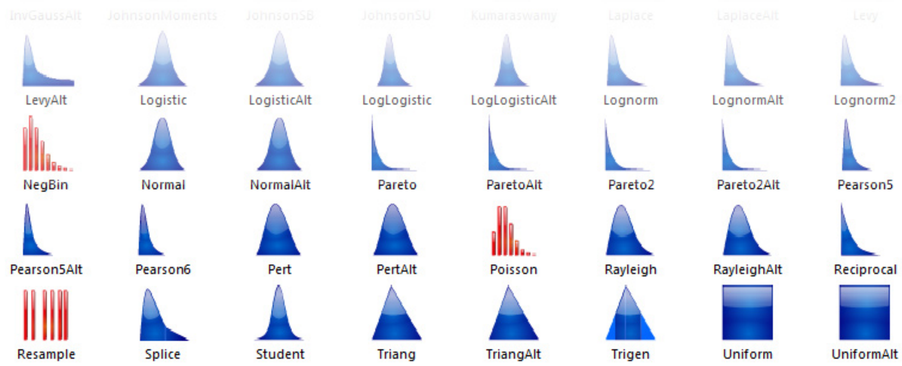

FIGURE 23. Distributions

2. **Graphical Results:** Monte Carlo simulation generates graphs of different outcomes and their chances of occurrence. This is important for communicating findings to other stakeholders.

3. **Scenario Analysis:** In deterministic models, it‚Äôs very difficult to model different combinations of values for various inputs to see the effects of truly different scenarios. Using Monte Carlo simulation, an analyst can quantitatively predict the inputs that had clustered values when certain outcomes occurred. This will be immensely valuable for pursuing further analysis.

4. **Sensitivity Analysis:** Deterministic analyses makes it difficult to predict the variables that have the maximum impact on the outcome. In Monte Carlo simulation, it‚Äôs easy to see which inputs had the biggest effect on bottom-line results.

5. **Correlation of Inputs:** In Monte Carlo simulation, it's possible to model interdependent relationships between input variables. It‚Äôs important for accuracy to represent how, in reality, when some factors goes up, others go up or down accordingly.

6. **Quantifiable Reasoning:** Monte Carlo simulation allows project-managers to better justify and communicate their arguments in the face of unrealistic project expectations.

On the other hand, this approach also involves certain limitations like:

1. The results are highly data-driven and data-dependent; therefore the quality of final estimates is directly impacted by quality and nature of input data.

2. The Monte Carlo Simulation shows the probability of completing the tasks, not the actual time to complete.

3. This technique will not applicable for a single activity along with completion of risk assessments completed as an pre-existing requirement.

Chapter 3

CERN and Project Planning

3.1 Introduction and Overview

The European Council for Nuclear Research is an International research organization that operates the largest particle physics laboratory in the world. The main function of CERN is to create particle accelerators and other infrastructure needed for state-of-the-art fundamental research in high-energy physics and as a result numerous experiments have been constructed at CERN through international collaborations. Founded in 1954, the CERN laboratory sits astride the French-Swiss border near Geneva. It was one of the Europe's first joint ventures and now has 23 member states. At an intergovernmental meeting of UNESCO in Paris in December 1951, the first resolution concerning the establishment of a European Council for Nuclear Research was adopted.

Today, the understanding of matter at it's most fundamental level due to the efforts by CERN goes much deeper than the nucleus, and CERN's main area of research is particle physics. Physicists and engineers at CERN uses the world's largest and most complex scientific instruments to study the basic constituents of matter the fundamental particles. Subatomic particles are made to collide together at close to the speed of light. The process gives us clues about how the particles interact, and provides insights into the fundamental laws of nature.

The instruments used by CERN are purpose-built particle accelerators and detectors. The Accelerators boosts beams of particles to high energies before the beams are made to collide with each other or with stationary targets. the Detectors observe and record the results of these collisions.

The hierarchical structure of CERN is divided into sectors, which are further divided into departments, group's ad sections. The relevance for the thesis is attached to the Accelerators and Technology ATS, Sector which is responsible for the operation and exploitation of the whole accelerator complex, in particular the Large Hadron Collider (LHC) and for the development of new projects and technologies. The ATS sector comprises of the Beams, Engineering and Technology departments respectively. The focus for this thesis is on project management for nuclear infrastructure in the Engineering department, which provides CERN with the engineering competences, infrastructure systems and technical coordination required for design, installation, operation, maintenance and dismantling phases of the CERN accelerator complex and its experimental facilities. The activity of project management is associated with Administration, Resources and Performance (ARP) group, which is the backbone of the Engineering department, facilitating administration and planning, coordination of CERN's technical infrastructure and management of non-beam facility development projects and quality management support.

The projects and quality management support section has expertise in several domains of technical management, including training on project management, systems engineering, requirements engineering and quality management. Project leadership and support for multidisciplinary non-beam facilities related project are also provided by the group.

Projects at CERN involves complex technical systems, while focusing on ORAMS/ RAMS, interoperability, reliability, availability, maintainability and safety in project management. CERN uses historical data, technical and professional expertise, MS-Project and standard classical tools such as WBS and Gantt chart for project planning and management.

It has also developed a dedicated framework called OpenSE - an open, lean, and participative approach to systems engineering. The development of this dedicated framework is motivated by the observation that project management and systems engineering methodologies by PMI's Project Management Body of Knowledge or more specialized ones such as the NASA's Systems Engineering Handbook, which are not very suited to development of complex scientific facilities. It should be noted that these scientific facilities and/or systems are complex one-of-a-kind projects and includes several safety and other potential risks owing to complex scientific environment.

3.2 Background and Research

Project planning at CERN [5] involves using traditional and effective methodologies for project planning using guidelines of an OpenSE tool [11] created by CERN for project management of large and complex scientific projects.They define the planning framework which involves a detailed description of the macro and micro-activities in order to ensure effective completion of the project. It comprises of the three components: the people who will do the planning, a process which specifies what the project team needed to do to manage time and resources, and the software tools and hardware that helps the project team to implement the process.

The project management approach taken at CERN for project planning and control in which two types of project schedules are prepared firstly, the Master schedule, which is a master plan

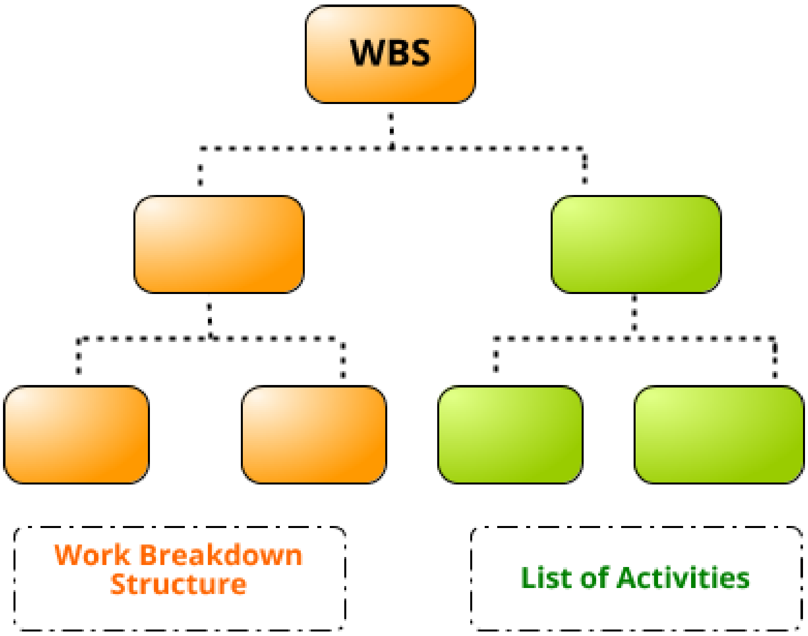

FIGURE 31. WBS

at a strategic level for the project and provides a project road-map with an intuitive approach. Secondly, the coordination schedule is created through a Gantt chart using Microsoft Project, displaying activity network at tactical level and more of an analytical approach.

In coordination Planning & Scheduling is a three step process which is followed:

1. Identifying the project activities using an analogical approach, Work breakdown Structure (WBS) based on PMBOK standards. It is a systematic approach based on the global lessons learned and collected by the Project Management Institute (PMI). Thereafter, the work packages are defined along with the activities and final deliverables of the project.

2. Identifying the resources available, estimating the resources required (based on historical data and technical and professional expertise) and these resources are assigned to the respective activities.

3. Scheduling the activities through the coordination schedule in a Gantt chart created in Microsoft software tool. It helps in estimating the duration of activities and also define the technical constraints between the activities. Furthermore, earliest/latest start/finish dates and the critical path are defined using Precedence Diagramming method and Gantt charts.

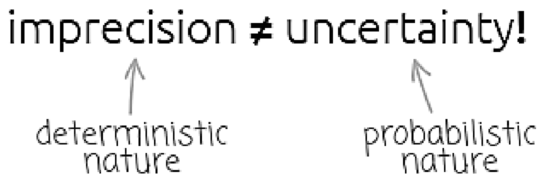

FIGURE 32. Imprecision-Uncertainty

The Project costing can be explained in a three step process -

1. Estimating the resources required to perform the project through various studies involved such as conceptual, feasibility and design etc. It answers to which costs to be taken into account and it is only the chargeable cost that is considered.

2. Budgeting the resources allocated to the project, and the cost estimates becomes the budget document created in a MS-Excel Spreadsheet. The budget document is authored and verified by a project manager and a few key study members, then validation is done by a project team at a work package level and by the study manager and a project manager at the cost center level.

The potential risks associated with the projects are related to quality, cost and schedule with an impact on use and coordination of activities and resources. The projects at CERN requires strong coordination among the technical groups and project management teams. To coordinate the project requires an overall view which can only be achieved by collecting and summarizing detailed information, which in turn is possible only if the historical data and information is coherent across the project.

The traditional project planning methodologies puts special emphasis on linear processes, upfront planning and prioritization. As per traditional classical methods like WBS, Gantt chart, time and budget are fixed, and requirements are variable due to which it often faces budget and timeline issues. The traditional classical methods are not able to interpret the uncertainty with the activities done in parallel by different cross functional teams in case of involving multiple stakeholders, hence any delay in work can lead to additional complexities and will have impact on both time and budget. All these risks cannot be reflected upon the Gantt chart which becomes difficult to monitor and control.

Use of advanced planning methodologies like Monte-Carlo can address these uncertainties that pose potential risks for the Nano-lab project. Monte-Carlo simulation model and a tool created in MS-excel are used for complex estimation of the scenario that involves a high degree of complexity and uncertainty to analyze the likelihood of meeting the objectives. The focus of the thesis is to use advanced project planning methodologies using a case study for a nuclear infrastructure project at CERN to mitigate shortfalls of traditional project planning methodologies heavily reliant on historical estimates and cannot take into consideration the uncertainty during the entire project life cycle. This main drawback is addressed by Monte-Carlo simulation model and an MS-Excel which is explained in subsequent chapters.

CHAPTER 4

RESEARCH METHODOLOGY

4.1 Monte-Carlo Simulation Model

Forecasting or estimation is the most important aspect of the Project planning activity. The most consequential estimates are related to schedule - time and budget - cost. As per the traditional classical project planning methodologies, they are calculated and presented as a single point estimate as in, an activity will take A days.Sometimes it is presented within a range, as in between A days to B days.But using a PERT like approach with three-point estimates for the variable with minimum A, most likely B and maximum C values are provided. Three point estimate provided the starting point for a two-fold approach to develop a Monte-Carlo simulation model and a tool in MS-Excel.

Since Project planning is based on the Work Breakdown Structure for complex projects and all activities are defined accordingly to create an overall estimate of the complete project. However, the problem arises when the project manager combines the estimates of the individual activities into an overall estimate of the complete project. This straightforward addition may lead to an incorrect estimation of overall activity variables such as time and cost. This happens as estimates are necessarily based on probabilities and probabilities do not combine in an additive manner. Monte-Carlo Simulations provides an intuitive way to obtain probabilistic estimates for the entire project based on the individual estimates of the activities comprising the entire project.

Use of advanced methodology such as Monte-Carlo which is a powerful statistical analysis tool also used to understand the impact of risk and uncertainty in prediction and forecasting models. In order to create a Monte-Carlo model, the beginning step is to develop an estimate and for that it is important to understand the shape of uncertainty as probability distributions.

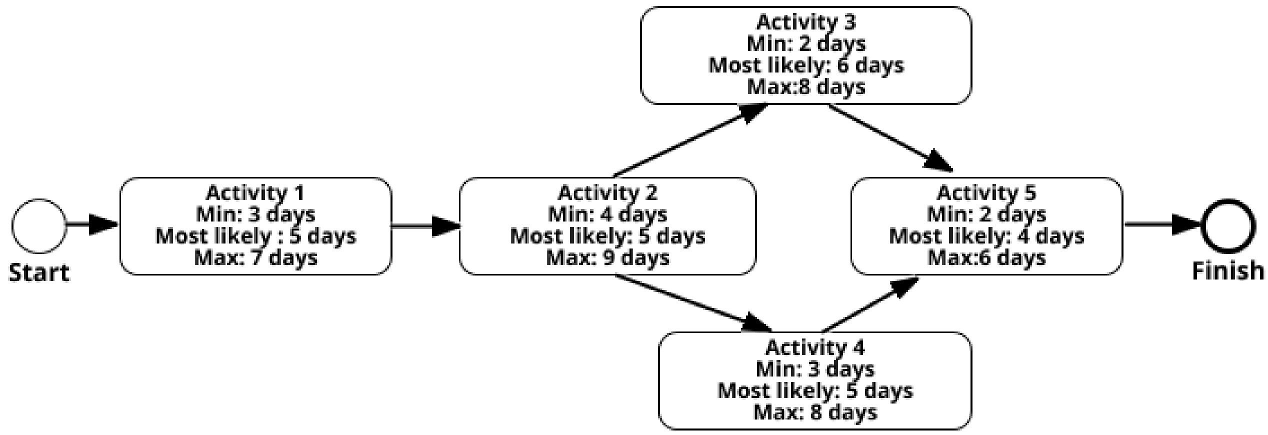

FIGURE 41. A project with 5 activities.

4.2 Background Definition

Problem: Imagine an example, let's consider a 4 activities project in IMAGE 1. The second activity is dependent on the first activity as they are in series, and the third and the fourth activity are dependent on the second activity but not on each other and in series with the fifth activity. The first two activities are in series and last two are in parallel but can only be started if the second activity is completed and then in series with the fifth activity.

The image 41 also shows the three-point estimates for each activity i.e the minimum, most likely and the maximum completion times.

4.3 Shape of an Uncertainty

In order to understand, lets consider data for an Activity 1, it finishes in 3 days and the range possible to complete the activity lies between 3 days and 7 days. It is clear that each of the outcomes are not equal likewise. The most likely outcome provided is 5 days. Moreover the likelihood of completing in less than 3 days or more than 7 days is zero. if we plot the likelihood of completion against completion time, the figure would look like image 42.

Image 42 poses several questions:

1. What are the relative likelihoods of completion for all intermediate times i.e. those between 3 to 5 Days and 5 to 7 days?

2. How can we quantify the likelihood of intermediate times? How can one get a numerical value of the likelihood for all times between 3 to 7 days?

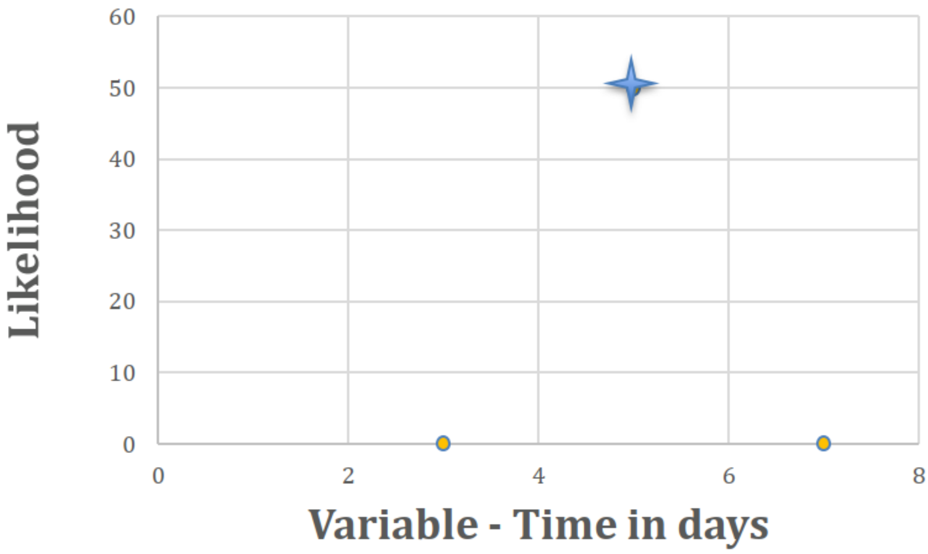

FIGURE 42. Likelihood of finishing in 3 days, 5 days or 7 days.

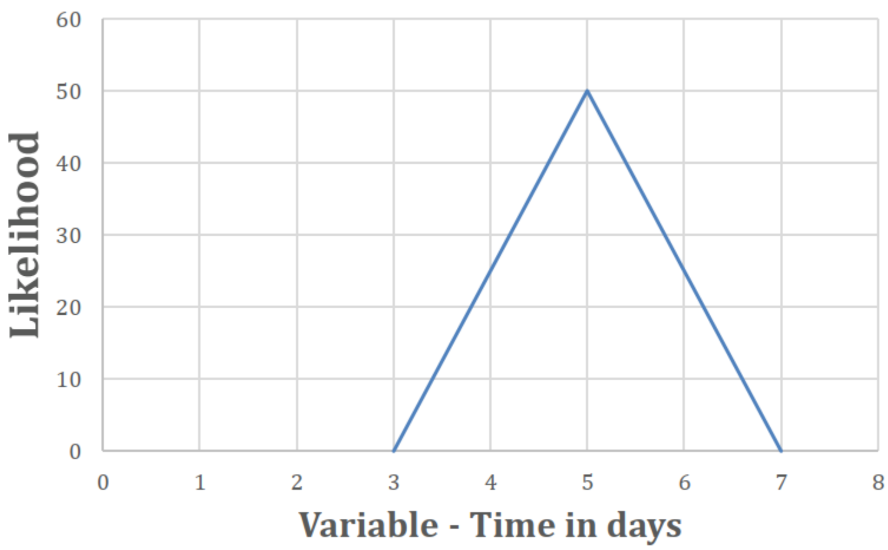

FIGURE 43. Triangular distribution fitted to points in Image 41

Note: The likelihood of completion must be zero for nay time less than 3 days or greater than 7 days. To answer the above-mentioned questions, when we know the relative likelihood of completion of all times, then it is easy to calculate the numerical value. As there is no information regarding intermediate times,it is assumed that likelihood increases linearly from 3 days to 5 days and decreases in the same way from 5 days to 7 days as shown in the IMAGE 3, it provides a triangular distribution.

As there could be infinite number of possibilities.It can happen that the maximum duration

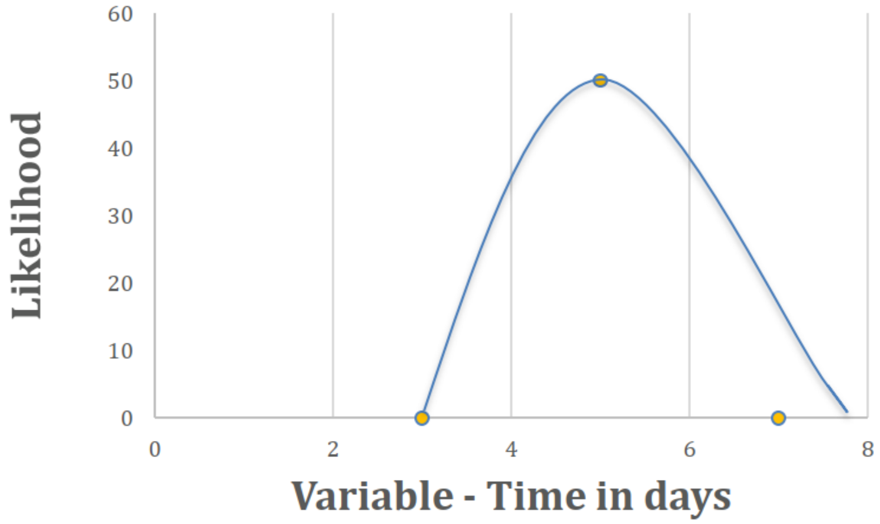

FIGURE 44. A distribution with potentially infinite completion time

7 days can extend due to exceptional reasons and the activity gets delayed.In this case the likelihood will look like image 44.

The important take away for the above-mentioned uncertainties should be expressed in shapes rather than numerical values as mentioned in a book by Sam Savage, "The flaw of Averages"

As it can be seen, most of the distributions are skewed to the right with a long-tail and it resembles the most general feature of distributions which describes variables such as time and cost for project activities in infrastructure projects.

4.4 Research Approach

4.4.1 Likelihood to Probability

Now lets define the quantitative measure of the likelihood.

Consider the following: 1. If an event is impossible, its likelihood should be zero. 2. The sum of likelihoods of all possible events should equal complete certainty which should be a constant value. Since constant can be anything, in this case it is equal to 1.

We denote a generic variable "v" and calculate its likelihood by $P(t)$. These quantities can be extended to calculation of time and cost estimations for execution of the project. In this problem we are doing calculations for time.

For a, b being the range of the activity duration, such that $v < a$ and $v > b$,

$$p(v) = 0 \tag{4.1}$$

and for a $\leqslant$ v $\leqslant$ b,

$$\sum_{v} p(v) = 1 \tag{4.2}$$

where $\sum v$ denotes sum of all non-zero likelihoods i.e. which lies between a and b variable values. $P(t)$ is called probability by mathematicians instead of the likelihood. With all the assumptions beforehand, we can calculate numerical values for the probability of completion for all variables between a and b and lets focus on the shape of the distribution. With this problem beforehand let's assume all four tasks can be fitted to triangular distributions.

4.4.2 Triangular Distribution

Let's focus on the estimates for activity 1, these three-point estimates are associated to each variable, minimum v_{min}, most likely v_{ml} and maximum v_{max}.

To calculate the probability associated to each variables. Since the variable v_{min}, and v_{max} corresponds to the minimum and maximum times, the probability associated with it both of them is zero.

Why? If it wasn't zero, then there would be a non-zero probabilities of completion for time less than v_{min}, or greater than v_{max} which isn't possible. Here an assumption has been taken into account that probability varies continuously so for if it is a non-zero value , p_0 at v_{min} then it must take a value lightly less than p_0, but greater than zero at v slightly smaller than v_{min}.

Now, for the most likely v_{ml}, by definition the probability attains its highest value at the v_{ml}. Assuming, probability can be described by triangular function, the distribution is shown in image 45.

For carrying out the simulation, it is needed to deduce the equation describing the above distribution.

4.4.3 Area under Triangle

Firstly, the area under the triangle must be equal to 1, as the time taken to complete the task between v_{min} and v_{max} and hence

$$\frac{1}{2} * base * altitude = \frac{1}{2} * (v_{max} - v_{min}) * p(v_{ml}) = 1 \tag{4.3}$$

where $p(v_{ml}$ is the probability of the variable ml.

Furthermore, by rearranging we get,

$$p(v_{ml}) = \frac{2}{(v_{max} - v_{min})} \tag{4.4}$$

To derive probability for any quantity (v) lying between v_{min} and v_{ml},

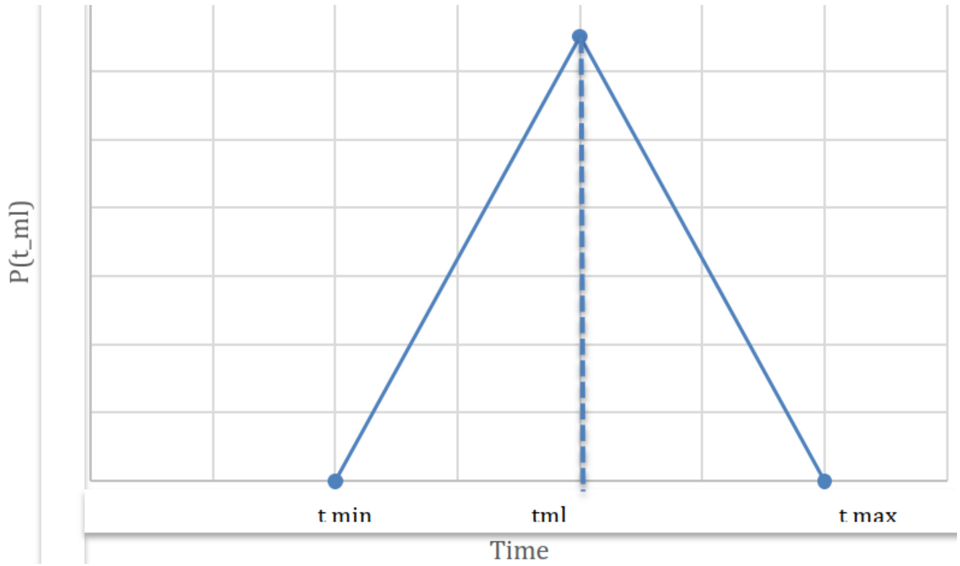

FIGURE 45. Triangular distribution redux

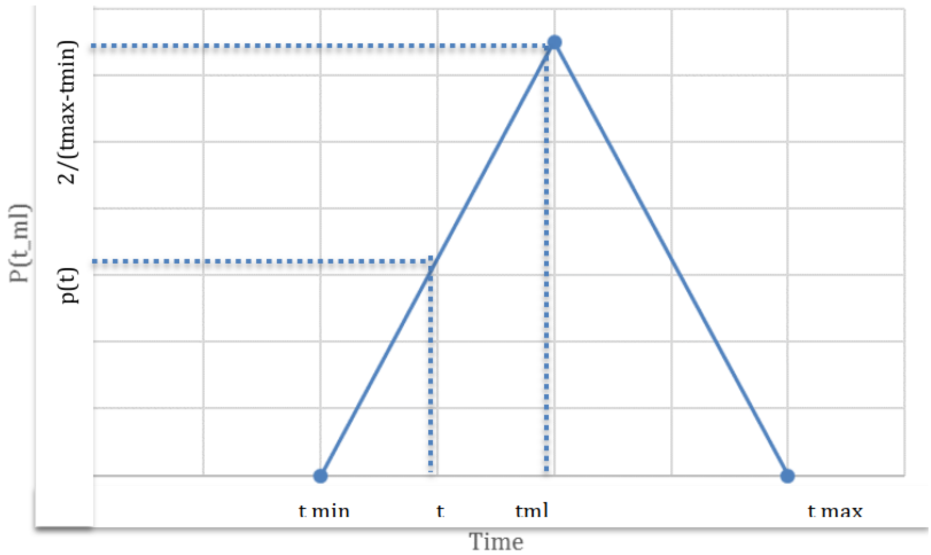

FIGURE 46.

$$\frac{(v - v_{min})}{p(t)} = \frac{(v_{ml} - v_{min})}{p(ml)} \tag{4.5}$$

Consequence of ratios on either side of 4.5 is equal to slope of line joining points $(v_{min}, 0)$ and $(v_{ml}, p(ml))$.

Substituting 4.3 in 4.4 and simplifying,

$$p(t) = \frac{2*(v - v_{min})}{(v_{ml} - v_{min})(v_{max} - v_{min})} \tag{4.6}$$

for $v_{min} \leqslant v \leqslant v_{ml}$.

Similarly, probability for time between (v_{ml} and v_{max}),

$$p(t) = \frac{2*(v_{min} - v)}{(v_{max} - v_{ml})(v_{max} - v_{min})} \tag{4.7}$$

for $v_{ml} \leqslant v \leqslant v_{max}$.

Equations 4.6 and 4.7 provides Probability distribution Functions (PDF) for times existing between v_{min} and v_{max}.

In Monte Carlo simulations, the PDF's are not used rather Cumulative Distribution Functions (CDF) is used, with probability (p(t)) that is computed as a function of time (t).

To reiterate, the PDF quantifies the completion probability $p(t)_{PDF}$ of a task at time (t), whereas $p(t)_{CDF}$ indicates the probability of task completion by time (t).

The CDF and $p(t)_{CDF}$ is essentially sum of all probabilities between v_{min} and v.

For $v < v_{min}$, area under triangle with vertices at $(v_{min}, 0)$, $(v, 0)$ and $(v, v(t))$ indicates probability.

Using triangle formula and Equation 4.6,

$$p(t) = \frac{2*(v - v_{min})^2}{(v_{ml} - v_{min})(v_{max} - v_{min})} \tag{4.8}$$

for $v_{min} \leqslant v \leqslant v_{ml}$.

For the case of $v \geqslant v_{ml}$, the area under curve equals the total area subtracted by the area enclosed by triangle between v and v_{max},

$$p(t) = 1 - \frac{(v_{max} - v)^2}{(v_{ml} - v_{min})(v_{max} - v_{min})} \tag{4.9}$$

For $v_{ml} \leqslant v \leqslant v_{max}$, $p(t)$ ranges between 0 and v_{min} and increases monotonically, attaining a value of 1 at v_{max}.

Put the ranges and $a = v_{min}, b = v_{ml}, c = v_{max}$, the resulting PDF and CDF are shown in images 47 and 48.

4.5 Monte Carlo Simulation Technique in Excel

The basic concept is to use Monte-Carlo simulations is to simulate the entire project for a large number of iterations N (let's say for 10000) and thus obtain N overall completion variables (both

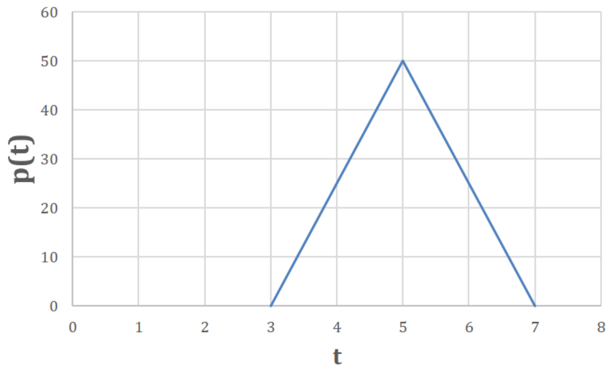

FIGURE 47. PDF for triangular distribution ($v_{min} = a, v_{ml} = b, v_{max} = c$)

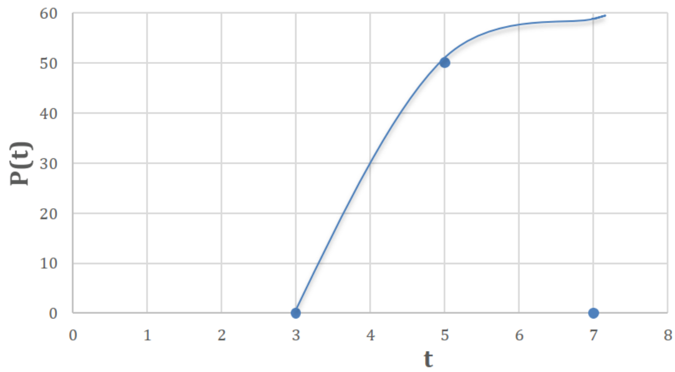

FIGURE 48. CDF for triangular distribution ($v_{min} = a, v_{ml} = b, v_{max} = c$)

time and cost in this case). In each of the N iterations, simulation is done for all the activities in the project and then added appropriately to give an overall project completion variable for the iteration. The resulting overall N completion variables will be different ranging from the sum of minimum completion variables to the sum of maximum completion variable. In other words, it will help to obtain PDF and CDF for the overall completion variables.

4.5.1 Simulating Single Activity using CDF

From image 48, the CDF for the triangular distribution has a S shape and ranges from 0 and 1 inn value. All the CDFs has S shape regardless of the details underlying PDF.

Reason: The cumulative probability must lie between 0 and 1 as it can never be negative or greater than 1.

For Monte-Carlo Simulation:

1. To generate a random number between 0 and 1, it corresponds to the probability that the task will finish at variable v.

2. Find the variable v, which corresponds to value of probability, this is the completion time for this simulation Iteration. Incidentally, this method is called *Increased Transform Sampling*.

3. For N iterations, a programmable mathematical algebra expression can provide variable corresponding to the probability directly. This is obtained by solving the equations 4.8 and 4.9.

   Solving equations 4.8 and 4.9 yields the following expression for time (t):

$$v = v_{min} + \sqrt{p(v)(v_{ml} - v_{min}) * (v_{max} - v_{min})} \tag{4.10}$$

   for $v_{min} \leqslant v \leqslant v_{ml}$ and

$$v = v_{max} - \sqrt{1 - (p(v)(v_{max} - v_{ml}) * (v_{max} - v_{min}))} \tag{4.11}$$

   for $v_{ml} \leqslant v \leqslant v_{max}$.

4. Combine it with an Excel formula using IF function.

4.5.2 Simulation

Steps for simulation in Excel for N = 10000 iterations:

1. Create a series of activities within the Excel workbook defining the variables as $v_{min}, v_{ml} and v_{max}$ needed for the completion of entire project.

2. Considering activity 1, Rows 3 to 5 in columns A and B shows the minimum, most likely and maximum completion variables and the same rows in Column C lists the probabilities for each variable.

   The probability for v_{min} is 0 and for v_{max} is 1.

   The $P(v_{ml})$ can be calculated by using equation 4.8 wherein $v = v_{max}$ reduces the probability to :

$$p(v)_{ml} = \frac{(v_{ml} - v_{min})}{(v_{max} - v_{min})} \tag{4.12}$$

3. From Row 7 to 10006 in column A are simulated probabilities form activity 1. They are obtained by using MS-Excel RAND() function, which generates uniformly distributed random numbers between 0 and 1. This gives us a list of probabilities corresponding to 10000 independent iterations for an activity.

4. The 10000 probabilities are to be translated into completion variable for the activity. It is done by using 4.8 and 4.9. depending on whether the simulated probability is less than or greater than $P(v_{ml})$, which is in cell C4 and given by 4.11. This conditional function is done in Excel by using IF () function.

5. Following all activities are simulated in a similar manner. Now let‚Äôs combine them:

   - For activities in series, sum of all completion variables for each task are added to get overall completion variables, which is shown in Rows 7 to 10006 of Column N and Column R.

   - For activities in parallel, the overall completion variables is the maximum of the completion variables of the number of tasks in parallel. It is computed in Rows 7 to 10006 of Column N.

6. Finally, the overall project completion variable for each iteration is the sum of columns G, R and N and is shown in Column S.

7. Sheets 2 and 3 shows the plots of the probability and cumulative probability distributions for complete project completion variables.

4.5.3 Explanation - Probabilities (PDF and CDF) and Estimates

The image 49 on sheet named PDF of the MS-Excel is the probability distribution function (PDF) of the completion variables. The x- axis shows the elapsed variable and the y-axis shows the number of Monte-Carlo iterations that have a completion variable which lies in the relevant bin (of width 0.5 variable).

As an example, for the simulation in image 49, considering variable as time in days, there were 1192 trials (out of 10000) that had completion time lying between 16.5 days and 17.5 days. Though, each times numbers can vary in Monte-Carlo, of course the maximum will lie between 16-18 days range and iterations close to as mentioned earlier.

As discussed earlier the, CDF is considered rather than PDF, the above image11 shows the probability of completion by a particular day as in, 90% likely that the project will finish in 19 days. Uncertainty can be seen from 14 days till 19 days so it is the region where the probability changes most rapidly as function of elapsed time.

Using Monte-Carlo, through CDF, which tells the greatest uncertainty in the estimates because that region in which probability change most rapidly as a function of elapsed variable. Of course, the exact results of the variable are dependent on assumptions of the distribution. In the end, as discussed earlier, that 'uncertainty is a shape, not a number'[18].

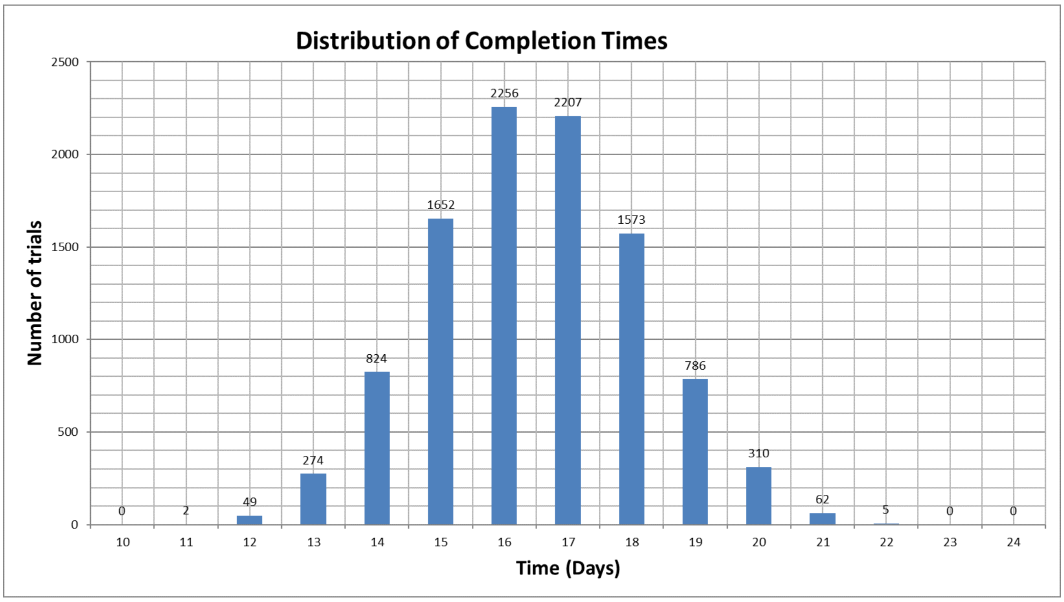

FIGURE 49. PDF, Probability distribution of completion times (N = 10000)

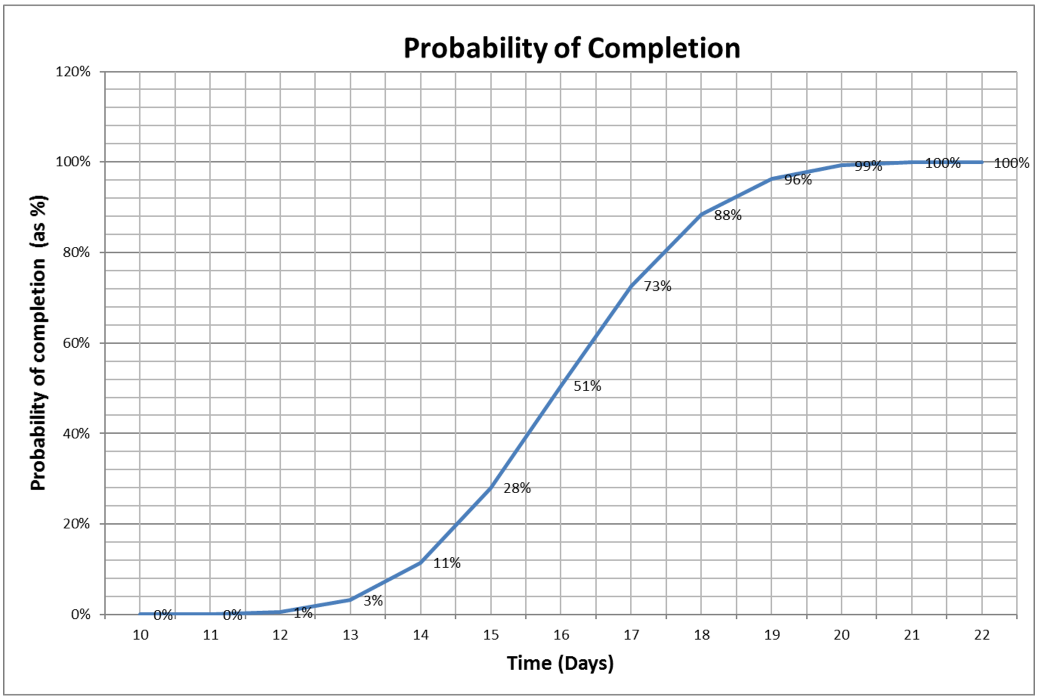

FIGURE 410. CDF, Probability of completion by a particular day (N=10000)

Chapter 5

Case Study of Nuclear Infrastructure

The Isotope mass Separator On-Line facility (ISOLDE)[10] at CERN is a "unique source of low-energy beams of radioactive nuclides, those with too many or too few neutrons to be stable". The facility fulfills in fact the old alchemical dream of changing one element into another. It enables a wide ranging study of atomic nuclei, including the most exotic species.

Owing to the volatility and pyrophoric properties of the radioactive particles, it is required to have dedicated laboratories to ensure safe handling of the radioactive particles. It is proposed to have an extension to existing "Class A laboratory"[13] in order to provide safe space for handling and production of radioactive targets by building a dedicated space for carrying out the activities.

This decision for construction of Nano-Lab was taken by keeping in mind the benefits that can be availed from the already available infrastructure of the existing building. A nuclear infrastructure project, the Nano-Lab, is studied during its design phase and currently in its execution phase. It is an extension of the existing building and will be comprised of a radioactive material storage area and two laboratories for manipulating uranium nano particles. The Nano-Lab project planning is the most critical step of the project management life cycle owing to the complex scientific environment at CERN and the potential risks associated to it.

5.1 Description of the project

Nano-Lab : A Nuclear infrastructure with a $22m * 7m$ building and a floor area of approximately $140m^2$ and is fully reinforced concrete, partially composed of high density concrete walls ($> 3.9tons/m^3$). It is an extension of existing building and the upcoming building will be composed of three sections:

1. **Production Laboratory:** A dedicated laboratory for the production of radioactive nano-

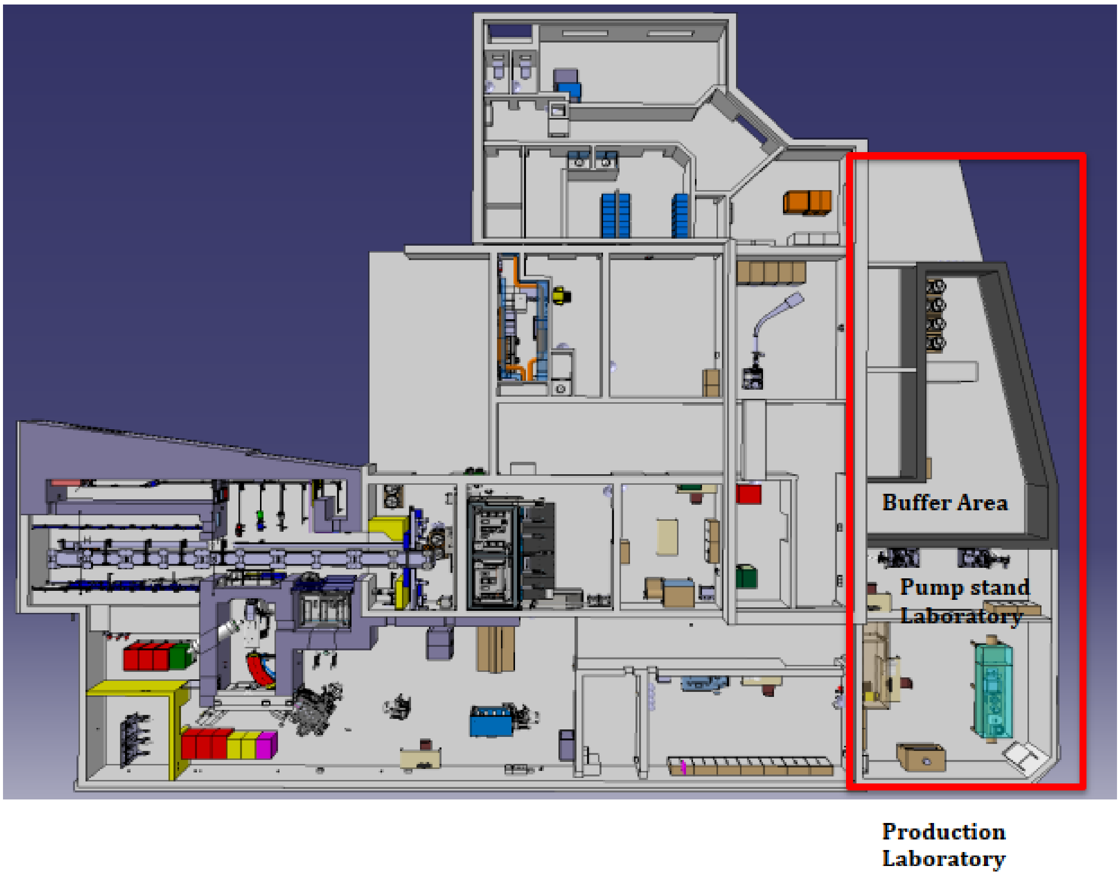

FIGURE 51. Proposed layout of the Nano-Lab

particles used as targets for ISOLDE facility.

2. **Pump stand Laboratory:** is used for manipulation and calibration of the radioactive nano-particles.

3. **Buffer Area:** A temporary storage area for radioactive waste and will be built with concrete possessing reinforced shielding properties. It will be used as an immediate repository for radioactive waste and also as a storage place for accommodating contaminated equipment from the ISOLDE experiment.

In the design phase of the project areas, the approximate areas calculated for the Nano-Lab layout are:

1. Buffer area: $49m^2$

2. Pump stand Laboratory: $23m^2$

3. Production Laboratory: $44m^2$

5.2 Forecasted Planning and Scheduling Phase

Forecasting and planning phase is carried out by the project manager assigned by the project management team. The project manager assigned to the Nano-Lab project is responsible for initiating, planning, executing, controlling and closing projects. This thesis aims to analyze the classical planning tools employed for this project, review their limitations and drawbacks, and study and implement alternative advanced planning methodologies.

Project management is the application of knowledge, skills, tools, and techniques to the project activities in order to meet requirements. The focus of this thesis is on initiating and planning methodologies used for Nano-Lab project at CERN.

Project management processes [16] fall into five groups:

- **Initiating**
- **Planning**
- Executing
- Monitoring and Controlling
- Closing

Project management knowledge [16] draws on ten areas:

- Scope
- **Time**
- **Cost**
- Quality
- Human resources
- Communications
- Risk management
- Stakeholder management
- Integration

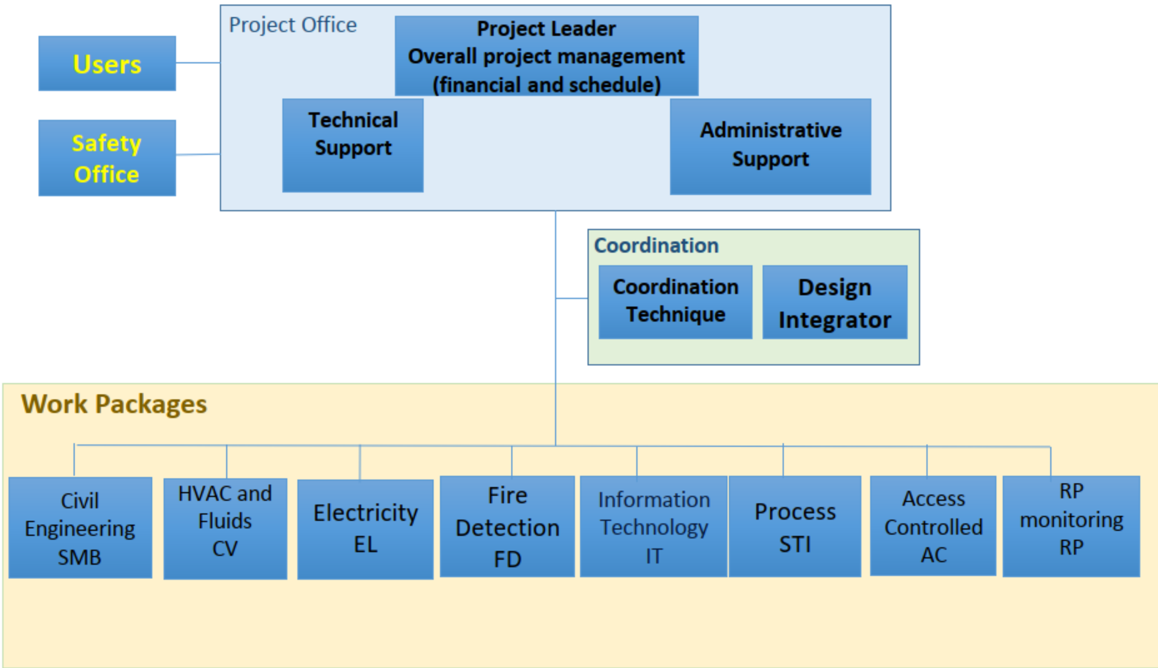

FIGURE 52. Proposed lay-out of the Nano-Lab

A Work Breakdown Structure (WBS) in project management and systems engineering is a deliverable-oriented breakdown of a project into smaller components. In the Nano-Lab project, the key project deliverables were divided into ten work packages. The WBS for the Nano-Lab displays the work packages involved and then the respective activities are defined accordingly.

A brief outline of work packages [9], [12] are:

1. **Work Package_1_SMB:** Site Management and Building department (SMB) carry out the civil engineering activities, strategy, design and studies and further also carry out on-site execution works and integrate it with services provided by other work packages. The major activities they carry out are:

    - Conduct studies - Preliminary geo-technical study, design and technical studies.
    - Procurement activities.
    - Preliminary works on-site.
    - Execute activities like earthwork, concrete and finishing's.
    - Non-IT works in the Nano-Lab site.
    - Support safety coordinator activities.

2. **Work Package_2_CV:** Cooling and Ventilation work packages is responsible for the design, construction, commissioning, maintenance and operations of the technical installations in Nano-Lab. The major activities they will carry out are:
   - Design documentation as-built and marking.
   - Modifications in CV system in existing building.
   - Ventilation supply and extraction.
   - Execute activities such as earthwork and concrete, finishing,Äôs.
   - Electrical works, instrumentation and control.
   - Compression air works.
   - Pump stand, water cooling, raw water and leak detection.
   - Test and commissioning.
   - Process extraction and fans consolidation.
3. **Work Package_3_Process Equipment:** will be the users of the Nano-Lab who carry out the activities for particles production and carry out responsibilities of target stations for"'Class A" type laboratories. The major activities they will carry out are:
   - Moving Pump stands.
   - Delivery and installation of equipment in production laboratory.
   - Conduct equipment testing.
4. **Work Package_4_RP:** Radiation Protection work package carries out activities and services aimed at personnel protection, waste processing, radiation and stray monitoring and also establishes the rules and procedure with respect to the radiation protection. The major activities of this work package are:
   - Supply of monitors for RP.
   - Installation of Monitors.
   - Conducting Tests.
5. **Work Package_5_EL:** Electrical group provides all electrical supplies, routings and installation, commissioning, and integration activities for electrical services. The major activities are:
   - Installation support.
   - Cable pulling,Äôs for pump stand and fire detection.
   - Installation of luminaires.

- Chute and catch chute installations.
- fire cable tests.
- Excavation of soil for Earthing services.

6. **Work Package_6_IT:** Information Technology group provides all IT related services including supplies, installation and integration support to other work packages. The major activities they will carry out are:

   - Moving GSM cable.
   - IT cable pulling.
   - Works related to ducts and plug boxes.
   - Conduct Tests.

7. **Work Package_7_FD:** Fire Detection provides the services for fire detection points, routings and procedures and safety aspects for the Nano lab protection for both personnel and equipment. The major activities they will carry out are:

   - Installation of equipment and sniffers.
   - Conduct Tests.

8. **Work Package_8_GAS:** Gas work package handles associated technical services for projects by providing gas supply and installation services. The major activities they will carry out are:

   - Installation of gas pipelines for Argon.
   - External work + tests.

9. **Work Package_9_AC:** Access Control package provides the access control services for the Nano-Lab to assist the users to ensure access to work in a controlled radioactive environment. The major activities they will carry out are:

   - Cable pull to door entry.
   - Installation equipment and door connection.
   - Conduct Tests.

10. **Work Package_10_PPM:** Project management team provides coordination, integration and monitoring activities apart from technical and administration support.

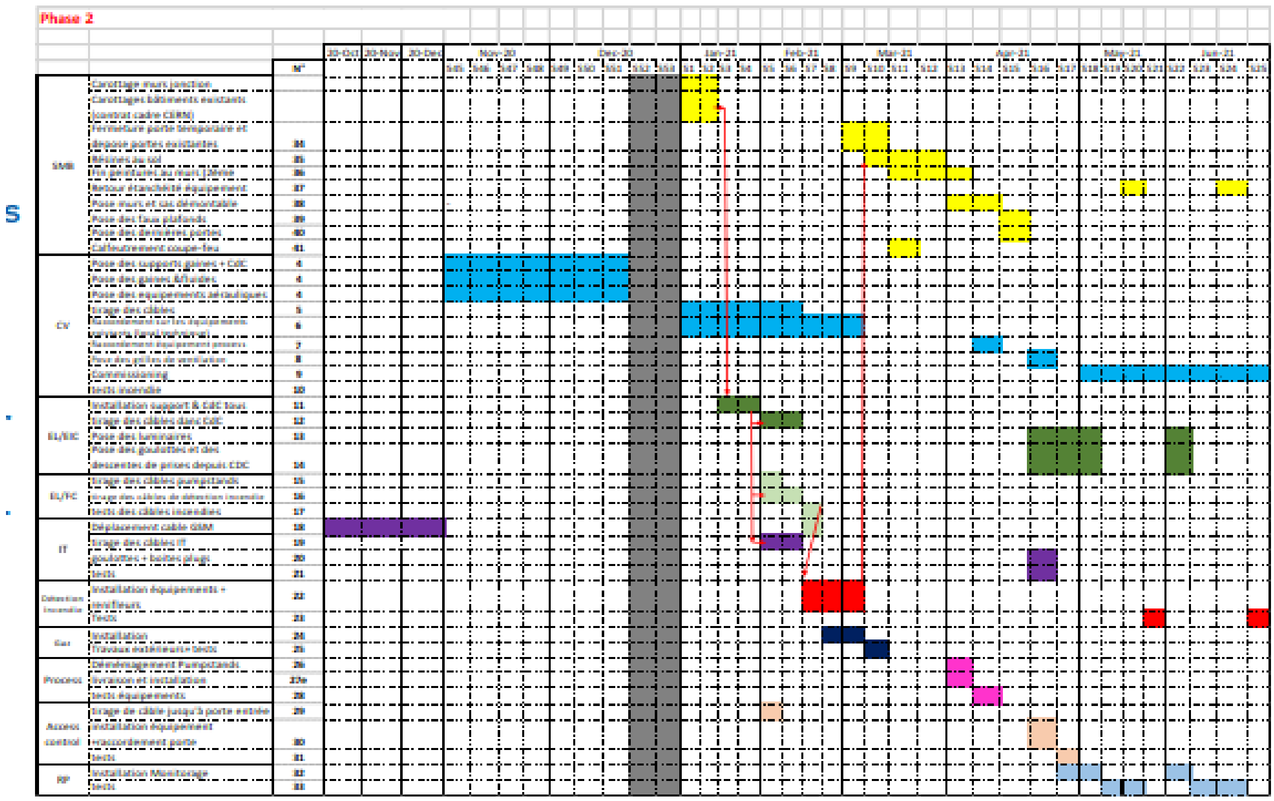

FIGURE 53. Gantt chart Schedule

5.3 KPI for the project - Time and Cost

Using WBS, the project planning is done for both time and cost KPIs. Historical data, technical and professional expertise are the foundations for forecasts related to time and costs. Project is divided into activities which are both in series and parallel. Planning is depicted via Gantt chart, a classical traditional project management tool for project planning & scheduling. The Duration of the project will be Oct 2019 -June 2021 approximately 615 days. However, uncertainty comes into play, so rigorous governance of processes and control over data is needed to enhance reliability. Use of techniques like Monte-Carlo which is a powerful statistical analysis tool is used to understand the impact of risk and uncertainty in prediction and forecasting models.

5.3.1 Use of Monte-Carlo Simulation Model

Use PERT like approach wherein estimates for an activity are based on 3 points in variables like time and cost for Nano-Lab project. Monte- Carlo simulation provides a principled and intuitive way to obtain probabilistic estimates at the level of an entire project based on estimates

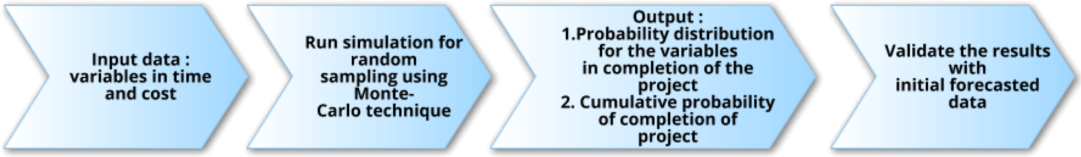

FIGURE 54. Monte Carlo Simulation Model

of the individual activities that comprise it. This three-point estimate will be the input for the Monte-Carlo simulation model.

Activity	Minimum	Most Likely	Maximum
1			
2			
3			

5.3.2 Input data for the model

The inputs are:

- Variables (v): Time in days & Cost in kCHF for minimum, most likely and maximum points.
- v_min - minimum time/cost needed to complete the activity,
- v_ml - most likely time/cost needed to complete the activity,
- v_max - maximum time/cost needed to complete the activity,
- $P(V)$ - occurrence/probability
- In Monte Carlo function we work with Cumulative Distribution Function (CFD) which is the probability of the task completing by time T
- $P(V)$ is the Sum of all probabilities between v_min and v
- $P(V)_{CFD}$ should lie between 0 to 1.

Also, for methodology and simulation, refer to sections 4.5.1 and 4.5.2 in chapter 4.

5.3.3 Run Simulation for Variable - Time

Using input data from table 52, the simulation was iterated for N = 10000 iterations and steps for undertaking the simulation in MS-Excel are as follows:

1. Create a series of activities within the Excel workbook [15] using the table in MS-Excel defining the time as v_min, v_ml and v_max needed for the completion of entire project.

2. Considering activity 1, Rows 2 to 5 in columns A and B shows the minimum, most likely and maximum completion variables and the same rows in Column C lists the probabilities for each variable, with time being considered as the variable in this case. For v_{min} the probability is 0 and for v_{max} is 1. The probability at $P(v_{ml})$ can be calculated by using equation 4.8 wherein $v = v_{max}$ reduces the probability to

$$p(v)_{ml} = \frac{(v_{ml} - v_{min})}{(v_{max} - v_{min})} \tag{5.1}$$

3. From Row 6 to 10005 in column A are simulated probabilities form activity 1. They are obtained by using MS-Excel RAND() function, which generates uniformly distributed random numbers between 0 and 1. This gives us a list of probabilities corresponding to 10000 independent iterations for an activity.

4. The 10000 probabilities are to be translated into completion times for the activity. It is done by using equations 4.10 and 4.11 depending on whether the simulated probability is less than or greater than $P(v)_{ml}$, which is in cell C3 and given by equation 4.12. This conditional function is done in Excel by using IF () function.

5. Following all activities are simulated in a similar manner. Now let's combine them: Project has 41 broad activities with tasks being both in series and parallel as shown in the Gantt chart. After simulating time for all the tasks individually and also for all the tasks happening in parallel, only the maximum time is considered for the calculating total time. Network diagram is shown in image 55 below, considering the overlaps in table 51 due to parallel activities where maximum duration is considered.

6. For activities in the series and the maximum duration of the parallel activities are added to get overall completion variables, which is shown in Rows 6 to 10005 of Columns from (H+K+Q+Z+AC+AL+AO+CB+CH+CK+DL+DR+DU+DX).

   Finally, the overall project completion variable for each iteration is the sum of columns (H+K+Q+Z+AC+AL+AO+CB+CH+CK+DL+DR+DU+DX) and is shown in Column EF.

7. The minimum, average, median and maximum values of the completion times both in days and weeks are calculated in the entire iterations from Rows 6 to 10005 in column EH.

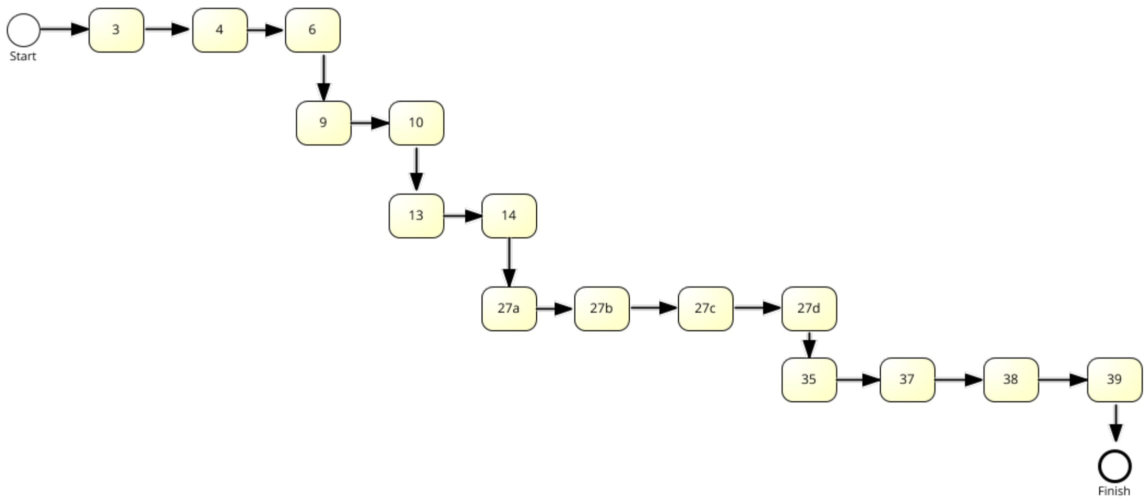

FIGURE 55. Network Diagram

8. Sheets 2 and 3 in [15] shows the plots of probability and cumulative probability distributions for project completion time and the results are explained in Chapter 6.

List of Overlap Activities	Maximum Time (days)
5,6	45
5,6,11	45
5,6,12,15,16,19,29	45
5,6,12,16,19	45
6,17,18,22	45
6,22,24	45
25,34,35	15
35,36,41	15
26,27e,36,38	15
7,28,38	10
39,40	10
8,13,14,20,21,30	15
13,14,31,32	15
9,13,14,32	20
9,33	20
9,23	20

Table 51: List of Overlap Activities

The cost and schedule activities are calculated separately. Similarly, simulation is run for the forecasted estimates for the cost of the project. Input data used in terms of cost in the Monte-Carlo simulation model is carried out analogously as in section 5.3.2.

5.3.4 Run simulation for Variable - Cost

Input data: Cost in kCHF

Steps for simulation in Excel for N = 10000 iterations using data as input from table 53:

1. Create a series of activities within the Excel workbook [15] using Table 1 defining the time as v_min, v_ml and v_max needed for the completion of the entire project.

2. Considering activity 1, Rows 2 to 5 in columns A and B shows the minimum, most likely and maximum completion variables and the same rows in Column C lists the probabilities for each variable.

   For v_{min} the probability is 0 and for v_{max} is 1.

   The probability at $P(v_{ml})$ can be calculated by using equation 4.8 wherein $v = v_{max}$ reduces the probability to

$$p(v)_{ml} = \frac{(v_{ml} - v_{min})}{(v_{max} - v_{min})} \tag{5.2}$$

3. From Row 6 to 10005 in column A are simulated probabilities form activity 1. They are obtained by using MS-Excel RAND() function, which generates uniformly distributed random numbers between 0 and 1. This gives us a list of probabilities corresponding to 10000 independent iterations for an activity.

4. The 10000 probabilities are to be translated into completion variable for the activity. It is done by using equations 4.10 and 4.11 depending on whether the simulated probability is less than or greater than $P(v)_{ml}$, which is in cell C3 and given by equation 4.12. This conditional function is done in Excel by using IF () function.

5. Following all activities are simulated in a similar manner. Now let's combine them: Different work packages have several activates and all are simulated together for 10000 iterations in Row 6 to Row 10005.

6. For activities in the series and the maximum duration of the parallel activities are added to get overall completion variables, which is shown in Rows 6 to 10005 of Columns from (AJ+CY+DA+DD+DG+DJ+DM+DP+DX+DZ).

7. Finally, the overall project completion variable for each iteration is the sum of columns (AJ+CY+DA+DD+DG+DJ+DM+DP+DX+DZ) and is shown in Column EC.

8. The minimum, average, median and maximum values of the completion times both in CHF and kCHF are calculated in the entire iterations from Rows 6 to 10005 in column ED.

9. Sheets 2 and 3 shows the plots of the probability and cumulative probability distributions for complete project completion cost and the results will be explained in Chapter 6.

After running the Monte-Carlo simulations, using the range from step 8, histogram is plotted for both time and cost with a defined bin width and then subsequently probability and cumulative probability distributions for complete project completion time and cost are evaluated with forecasted estimates most likely and then uncertainty is explained in an explicit manner.

Forecasted Estimates of Time for all Work Package Activities				
N	Activity	Minimum	Most Likely	Maximum
1	SMB Strategy	10	15	20
2	SMB Procurement Phase	5	15	20
3	SMB Phase 1 works	132	176	220
4	HVAC Pipes support and equipment	25	35	45
5	HVAC electrical cable	25	30	40
6	HVAC existing connections	40	45	50
7	HVAC new process equipment connections	1	3	5
8	HVAC Ventilation grills	1	3	5
9	Commissioning	15	20	30
10	Fire Alarm Tests	1	1	5
11	EL Installation Support	5	10	20
12	EL Electrical Cable Installation	5	10	20
13	EL Lighting	10	15	20
14	EL Cables on Walls	10	15	20
15	EL/FC Pump Stand Cables	1	5	10
16	EL/FC Fire Electrical Cable	5	10	20
17	Fire Electrical Cable	1	5	5
18	IT GSM Cable	5	5	10
19	IT Electrical Cables	5	10	15
20	IT Electrical Work on Walls	1	3	5
21	IT Electrical Cable Tests	1	1	3
22	Fire Detection Equipment	10	15	20
23	Fire Detection Tests	1	1	5
24	Gas Installation	5	10	15
25	Gas External Works	3	5	10
26	Moving Pump Stands	3	5	10
27a	Glove Box Spec Tech	20	34	40
27b	Glove Box Procurement Phase	45	45	60
27c	Glove Box Design	30	30	50
27d	Glove Box Making	70	70	100
27e	Process Equipment Installation	1	3	5
28	Test Equipment	1	1	3
29	AC Electrical Cables	5	5	15
30	AC Door Connections	1	3	5
31	AC Tests	1	2	5
32	RP Monitor Installation	10	12	15
33	RP Tests	10	12	15
N	Activity	Minimum	Most Likely	Maximum
34	Demolish Existing & Temporary Doors	5	10	20
35	Resin	10	15	25
36	Painting	10	15	25
37	Resin on Equipment	1	3	5
38	Light, Walls and Doors	5	10	20
39	False Ceiling	5	10	15
40	Last Doors	3	5	10
41	Fire Stop Fillers	3	5	10

Table 52: Forecasted Estimates of Time for all Work Package Activities

Forecasted Cost Estimates for all Work Package Activities			
Work Units	min	Most Likely	Max
Total Civil Engineering	979	1060	1140
Studies	120	120	120
Preliminary Works	100	110	120
Earth Works and Concrete	535	589	642
Finishing	150	165	180
Services for IT	24	26	28
Draftsman/Work Supervisor	50	50	50
HVAC	552	575	600
Replacement of Process Extractor	1 13.25	13.78	14.31
Duct Work and Diffusers	62	64.48	66.96
Pipe Work Process	41	42.64	44.28
Cooling Pump Stand	18.2	18.92	19.65
Compressed Air	5.5	5.72	5.94
Instrumentation	24	24.96	25.92
Accessories	109	113.36	117.72
Filters	72	74.48	77.76
Modification existing Power Cubicle	5	5.2	5.4
Control Cubicle	15	15.6	16.2
Electric Cabling- Earthing & Carriers	20	21.8	21.6
Design. Documentation as built and Marking	47	48.88	50.76
FAT, Testing and Commissioning	20	20.8	21.6
Transport, Manual Handling	10	10.4	10.8
Others	6	6.2 4	6.48
Scaffolding	3	3.12	3.24
FSU Control Software	15	15.6	16.2
FSU Supervision During Work	18.75	19.5	20.25
FSU Draftsman	16.5	17.16	17.82
FSU Documentation and Inventory	10.4	10.4	10.8
BAG Oxidation	0	0	0
Modification Existing Rooms	21.18	23.29	25.41
Electricity	20	22	24
IT	14	15	16
RP Monitoring	110	121	132
Fire Detection	37	41	44
Gas	35.18	39	42
Access Control	13.42	15	16
Laboratory equipment	202	222.2	242.4
Total Project Cost	2177	2325	2472

Table 53: Forecasted Cost Estimates for all Work Package Activities

CHAPTER 6

FINDINGS AND DISCUSSION

Following to chapter 5, after conducting Monte-Carlo Simulations the output provided is the likelihood of completion of objectives of the project in terms of time and cost and which is expressed through probability.

6.1 Results: Monte-Carlo simulation for total time

The image 61 on sheet PDF of the MS-Excel is the probability distribution function of the completion time. The x-axis shows elapsed time and the y-axis displays number of Monte-Carlo iterations that have a completion time which lies in the relevant bin (of width 6 days).

The results are plotted as a histogram displaying the distribution of completion times over 10000 random sampling processes. The basis of the histogram is the time in days calculated using MS-Excel functions (minimum, average , median and maximum) in the table below. The minimum and the maximum time defines the range of the histogram plot.

Total Statistical Time for completion in Days	
Min	466.8
Avg	526.2
Median	526.3
Max	589.4

As a result of the nuclear infrastructure case study after simulating in image 61, considering time in days, there were 1130 trials (out of 10000) that had completion time lying between 513 days and 519 days. Even though each instance, the numbers may vary in Monte-Carlo, the maximum time will lie between 579 days range and iterations close to the previous calculation.

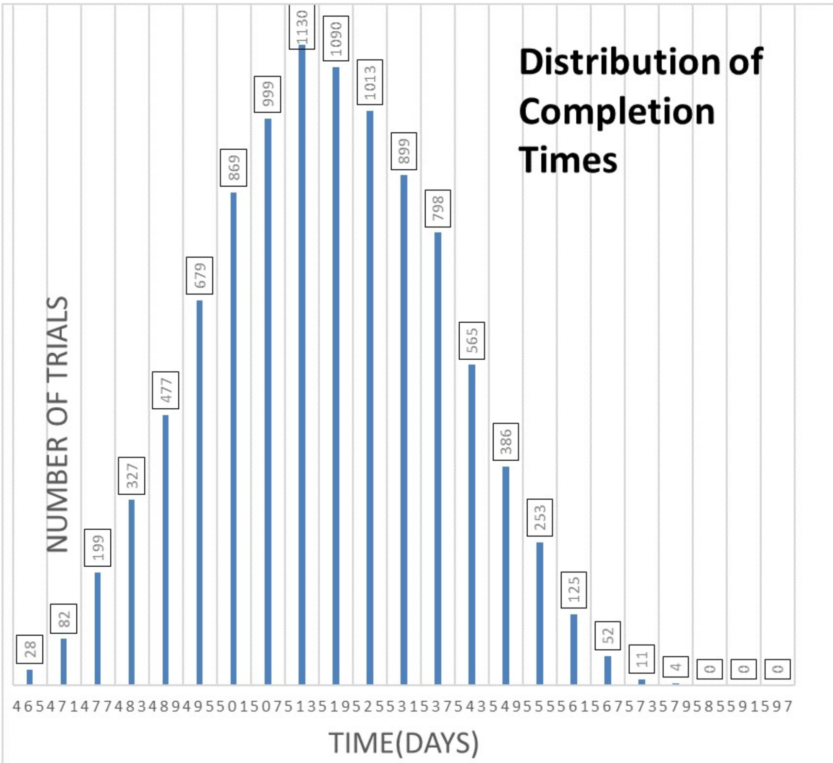

FIGURE 61. Number of trials v/s Total time in days

The image 62 shows the cumulative probability function (CDF), which is the sum of all the completion times from the earliest possible finish day until the actual day of completion. The findings are that the probability of completion is above 90% for total time of approximately 545 days. This is quite close to the forecast of total project duration of 615 days from October 2019 - June 2021. Uncertainty can be seen from 501 days till 549 days so it is the region where the probability changes most rapidly as function of elapsed time.

6.2 Results: Monte-Carlo Simulation for Total Cost

The basis of the histogram is the cost in kCHF calculated using MS-Excel functions (minimum, average , median and maximum) in the table below. The minimum and the maximum cost defines the range of the histogram plot.

Statistical total cost for completion in kCHF	
Min	2251.7
Avg	2324.1
Median	2323.6
Max	2405.6

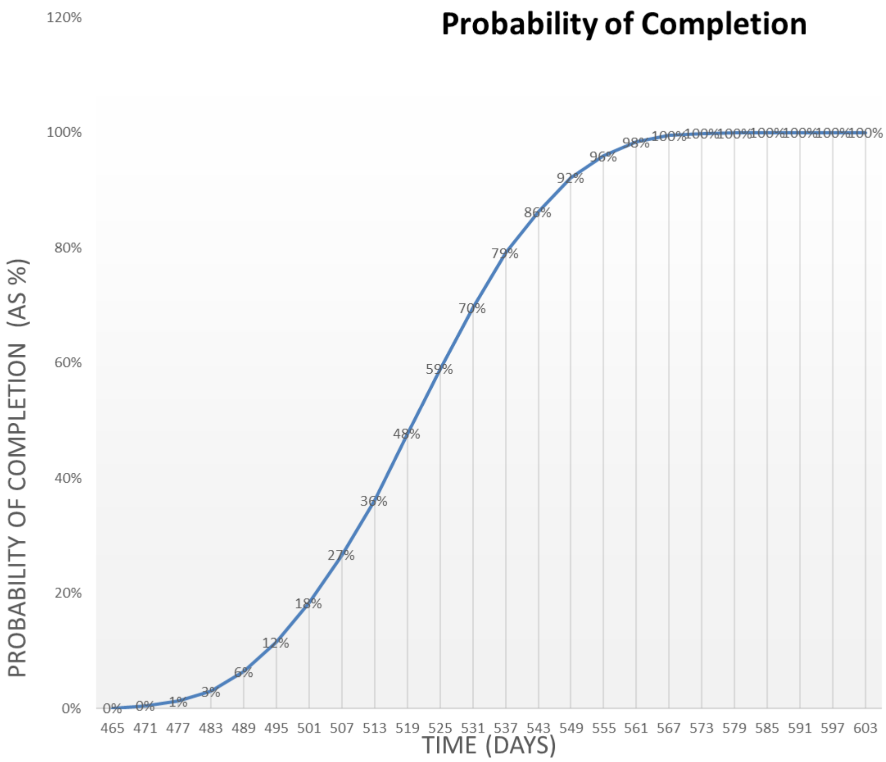

FIGURE 62. Probability distribution of completion times (N = 10000)

The image 63 on sheet PDF of the MS-Excel is the probability distribution function of the completion cost. The x-axis shows the incurred cost and the y-axis shows the number of Monte-Carlo iterations that has a completion cost, which lies in the relevant bin (of width 6 kCHF). The results are plotted as a histogram displaying the distribution of completion costs over the 10000 random sampling processes.

As an example, for the simulation in image 63, considering variable as cost in kCHF, there were 897 trials (out of 10000) that had completion time lying between 2300 kCHF and 2312 kCHF. Even though in each instance, the numbers can vary in Monte-Carlo, the maximum cost will lie close to 2400 kCHF and iterations close to the previous calculations.

The image 64 shows the cumulative probability function (CDF), the sum of all the completion costs from the earliest possible finish day till the actual day of completion. The findings are that the probability of completion is above 90% for a total cost of 2350 kCHF. This is quite close to the forecast of total project duration of 2326 kCHF. Uncertainty can be seen from 2294 kCHF till 2354 kCHF so it is the region where the probability changes most rapidly as a function of cost add critical activities can be planned to ensure project budget containment.

Monte-Carlo simulations make the uncertainty in forecasts explicit and can help to forecast in terms of probability and use it on a universal tool MS-Excel which is very handy and self-explanatory can be used by technical and non-technical individuals within an organization

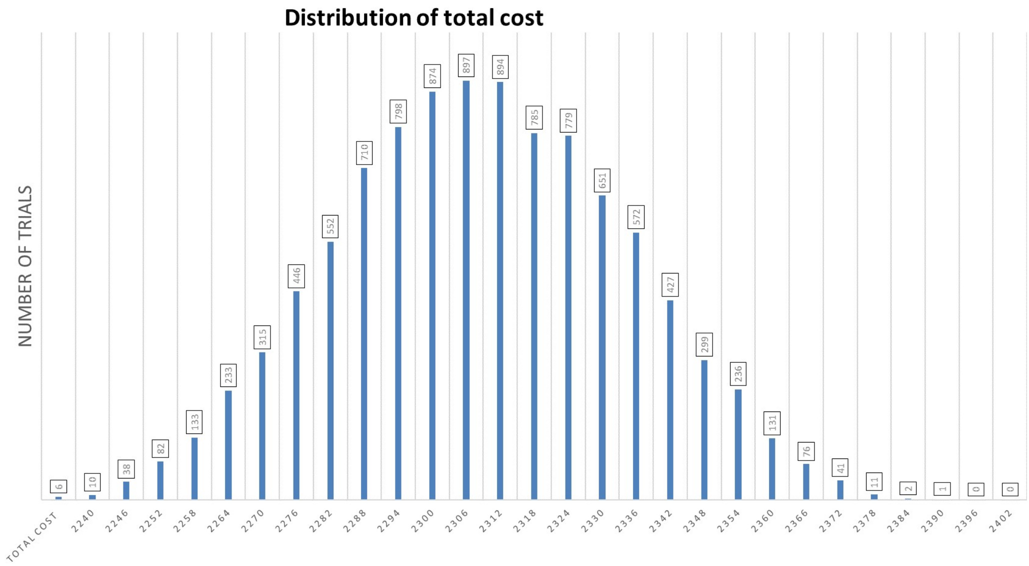

FIGURE 63. Number of trials v/s Total cost in kCHF.

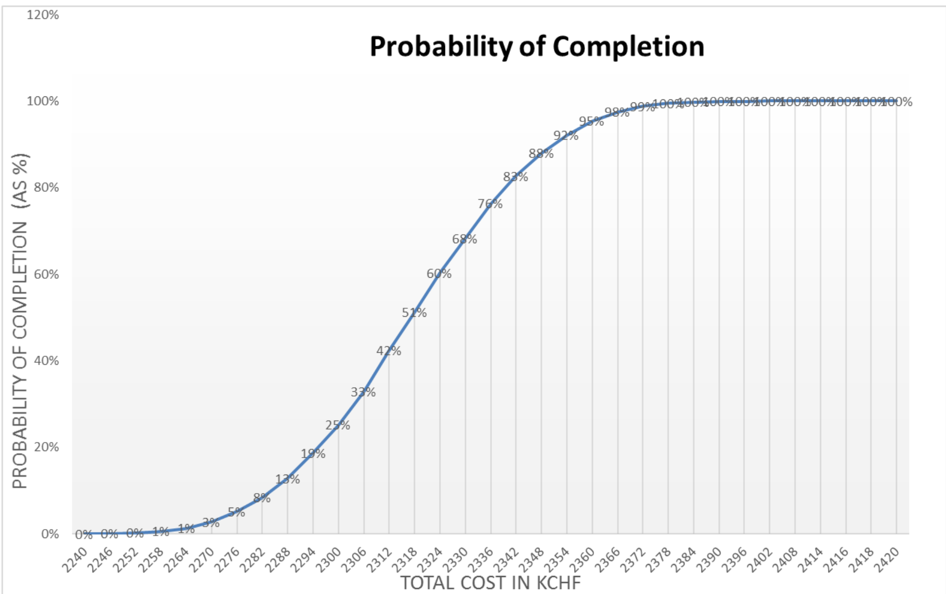

FIGURE 64. Probability distribution of completion costs (N = 10000)

handling the project. It is essential that "new structure for guiding project control decisions to ensure that a project is completed on schedule when activity durations are uncertain and modeled by random variables. This structure consists of specifying a specification limit for each activity duration. During the project, if the time to complete an activity is going to exceed its specification limit, actions are taken, at some cost, to bring the time down to that limit"[8].

Monte Carlo simulation based models and tools explores alternative resource-allocation strategies for infrastructure projects that have uncertain activity duration and costs. It extends resource allocation beyond current models that assume activities' duration are deterministic. It supports efficient project planning and scheduling along with traditional project planning methodologies based on historical estimates. A combination of both will likely address project planning and scheduling risks like the Nano-Lab project, CERN and other complex projects in scientific environments.v

CHAPTER 7

Proposals and Recommendations

7.1 Proposals

As discussed in the chapter 1 and in chapter 6, one of the risks associated with usage of traditional classical project planning methodologies is the project delays and cost overruns. As a further step or an extension to the work carried out in this thesis, Monte-Carlo Simulation technique can be further utilized to analyze the risk associated with different aspects of the project.

Uncertainty is always associated with estimates for the total time and the overall cost of the project as discussed as the main focus if this thesis. Currently, there are several different methodologies available to conduct risk analysis, the most common amongst them are Sensitivity Analysis using Monte-Carlo and Earned Value Management, EVM. Sensitivity Analysis is based on the dynamic aspects including risks associated to the project and EVM is primarily focused on the historical data. The two methodologies are explained in brief below.

7.1.1 Sensitivity Analysis

It is the Quantitative risk assessment[21] which evaluates how changes in a specific model variable impacts the output of the model. For example in project management it allows to identify which tasks duration with uncertainty has most impact or a stronger correlation with the end date of the project.

As functions of time and cost activities contributes to the total risk, using Monte-Carlo, sensitivity analysis can be done through Tornado diagram which shows how sensitive is the project to the each decision variable as they change over allowed ranges, how they contribute towards final risk associated to total project completion time and cost. It acts as powerful tool for decision makers as it not only focuses on the most important activities but also guide them to

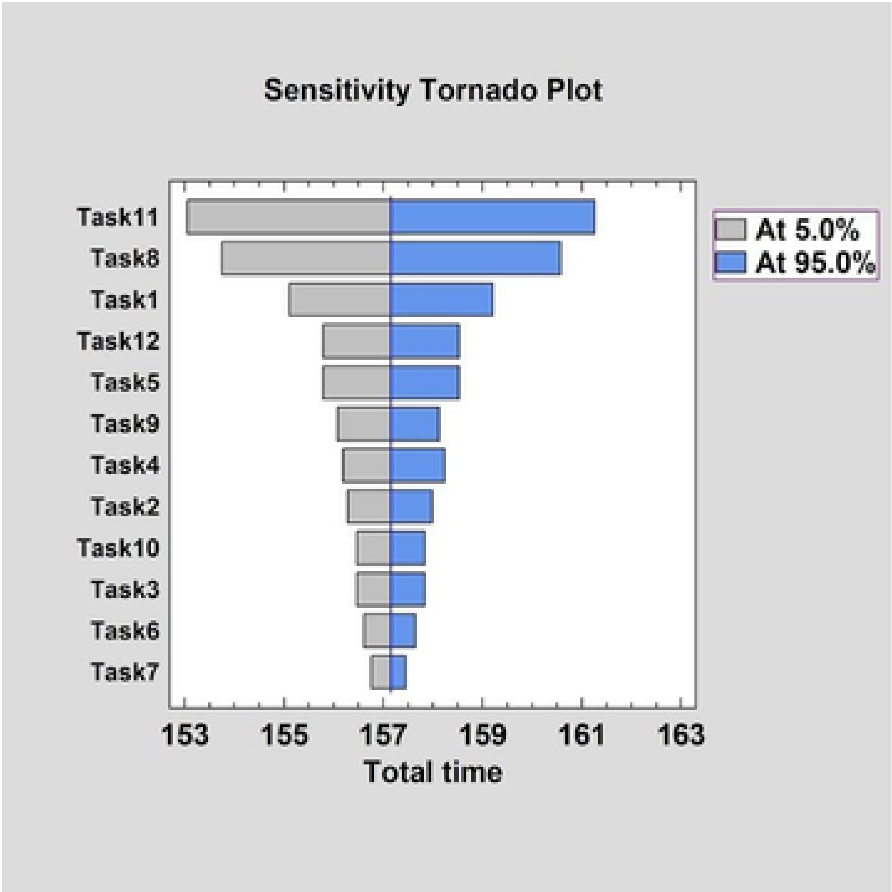

FIGURE 71. Tornado Diagram for Sensitivity Analysis

take necessary action based on the probabilities calculated through Monte-Carlo method. It is highly beneficial as it provides a dynamic analysis which is easily understood and efficient in explaining uncertainty and give results which are easily intercepted by project team in order to take necessary actions.

7.1.2 Earned Value Management (EVM)

EVM is the assessment of actual successful completion of the project and its translation into a metric called earned value, which provide project manager a greater insight into both project performance and potential risk areas.

The key to the early visibility and the resultant management opportunities is the existence of an integrated baseline. Such a baseline results from a four-step process. First the work of the project is comprehensively defined and subdivided into commonly understood tasks. These tasks are phased consistent with the performance sequence logic and the schedule objectives of the project. Resource estimates are then established for the performance of the tasks and are designated as the budgets or targets for the work; these are time phased consistent with management

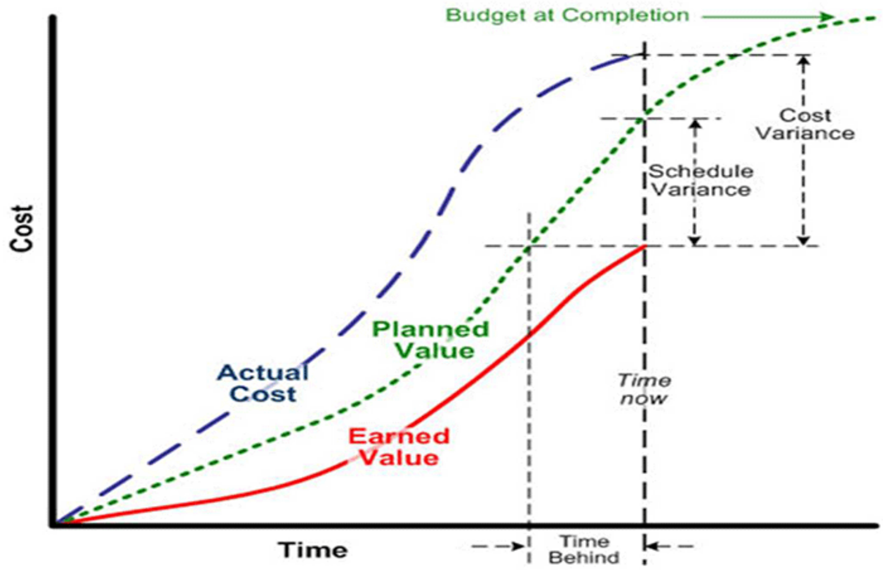

FIGURE 72. Probability distribution of completion times (N = 10000)

visibility needs of the project. Finally, this is integrated with the risk assessment/management process.

7.1.2.1 How to Calculate Earned Value [3]

Earned value calculations require the following:

Planned Value (PV) = the budgeted amount through the current reporting period Actual Cost (AC) = actual costs to date Earned Value (EV) = total project budget multiplied by the

With these readily available information, can do more calculations.

Schedule Performance Index (SPI)

SPI = $\frac{EV}{PV}$

SPI measures progress achieved against progress planned. An SPI value <1.0 indicates less work was completed than was planned. SPI >1.0 indicates more work was completed than was planned.

Cost Performance Index (CPI)

CPI = $\frac{EV}{AC}$

CPI measures the value of work completed against the actual cost. A CPI value <1.0 indicates costs were higher than budgeted. CPI >1.0 indicates costs were less than budgeted.

For both SPI and CPI, >1 is good, and <1 is bad.

Estimated at Completion (EAC)

EAC = $\frac{(TotalProjectBudget)}{CPI}$

EAC is a forecast of how much the total project will cost.

7.1.3 Limitations

One of the main limitations of EVM in comparison to Monte-Carlo tools for Risk analysis, are EVM may fail to consider the dynamic changes happening. Using EVM for project planning and monitoring tool, if there are projects delays or project run beyond the budget, it may lead to misleading figures for Project KPIs when it comes to forecasts and estimates. Another issue is that EVM is significantly based on the assumption that future performance of the different aspects of the project can be estimated on the basis of the past performance. The different performance indicators of EVM such as CPI, SPI etc. are optimized not only to predict the future [parameters, but also to make optimal decisions. Further, there is a greater possibility that the actual values of different variables in future may deviate from the estimated values as forecasts are based on historical performance.

7.2 Recommendations

Hence a combination of the Monte-carlo for project planning, risk analysis and project performance monitoring can be efficiently dine by using EVM. It may prove to be an effective project management methodology to handle complex projects based strongly on historical estimates and ensure the project meets both schedule and budget deadlines and can adapt to the uncertainties.

Chapter 8

Conclusions

Monte-Carlo analysis is a powerful tool that can give project controls professionals and project managers valuable information that can be used to improve project execution by identifying risks and the most important activities within a schedule that may not be on the critical path, ensuring a realistic execution plan, aligning the stakeholders involved in a project, and avoiding claims and potential liquidated damages in complex projects. Historical estimates and human judgement with technical and professional expertise and classical project planning tools are an important tool for project planning of complex and scientific projects.

It helps to understand the uncertainty which is deciphered from the region in the plot for CDF, where probability changes most rapidly with time. As I have presumed the assumptions made for 3-point estimates by the project manager or team are valid in case of complex scientific projects where not much of the relevant data is available from outside of the organization. Hence the exact results of the simulations are dependent on these human-made assumptions.

Furthermore, Monte-Carlo Technique simplified MS-Excel tools helps in optimization of the planning & scheduling and provide results that are easy to analyses and understand (schedule for start-finish of the project). This in turn helps to validate the results with the manual forecasts for project based on human skills. Further as recommended, the sensitivity of the activities involved can also be analyzed through Monte-Carlo analysis by understanding what a schedule is sensitive to, it can allow changes to execution to improve the end date. It will contribute to development of realistic or achievable payment milestones within a schedule. As in recent challenging times of COVID-19, the projects are delayed due to unplanned suspension of activities which would have significantly affected the Projects schedule and end-dates. So Monte-Carlo as an advanced planning methodology can help to evaluate the present completion percentage and progress of the projects in terms of time or cost as during estimates we already consider a range and it makes it easy to update the project planning and schedule accordingly and monitor the work packages deadlines and payment milestones.

Monte-Carlo analysis will never replace good judgment and the human ability to make decisions based on experience but a combination of two is an incredible method to govern processes and control variables for project management.

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