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Numercial simulation of maintenance projects durations using the stochastic PERT method

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Dedication

To my beloved parents, for their unconditional love, sacrifices, and unwavering

support throughout my academic journey.

To my teachers, for their knowledge, guidance, and generosity.

To my brothers, for their comfort, kindness, and continuous encouragement.

To my friends and colleagues, for their support, encouragement, and shared moments.

And to everyone who helped me, even with a single word, during my entire learning path.

I dedicate this work to all of you, with deep gratitude.

Abstract

This thesis presents an in-depth study of a maintenance project involving a critical pump at a power generation plant located in the Wilaya of El Taref. The primary objective of this work is to analyze the project planning process while accounting for uncertainties associated with task durations.

Initially, a classical deterministic approach was applied to identify the critical path based on fixed task durations. This method allowed the determination of the sequence of activities that directly impact the overall project duration. However, this approach is limited by its assumption of deterministic time estimates, which often does not reflect the variability encountered in industrial contexts.

To address this limitation, a probabilistic loss method was employed. By incorporating uncertainties related to task durations, a simulation was conducted with one thousand iterations. The results revealed that several tasks have a significant probability of becoming critical, indicating that the critical path identified through the classical method may not be stable.

These findings highlight the relevance of a probabilistic approach for more robust and realistic management of industrial maintenance projects, especially in sensitive environments such as power generation facilities.

Résumé

Ce mémoire présente une étude approfondie d'un projet de maintenance d'une pompe essentielle au fonctionnement d'une usine de production d'électricité située dans la wilaya de El Taref. L'objectif principal de ce travail est d'analyser la planification du projet en tenant compte des incertitudes liées à la durée des différentes tâches.

Dans un premier temps, une méthode d'analyse classique a été appliquée, fondée sur l'identification du chemin critique à partir des durées déterministes des activités. Cette approche a permis de repérer la séquence de tâches dont la durée conditionne directement celle du projet. Toutefois, cette méthode reste limitée par l'hypothèse de durées fixes, souvent irréaliste dans un contexte industriel.

Afin de surmonter cette limite, une analyse probabiliste a été conduite. En intégrant les incertitudes inhérentes aux durées des tâches, une méthode de simulation a été mise en œuvre avec mille itérations. Cette approche a révélé que plusieurs tâches présentent une probabilité significative de devenir critiques selon les scénarios simulés, ce qui remet en question la stabilité du chemin critique initialement identifié.

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Les résultats obtenus mettent en évidence l'intérêt de l'approche probabiliste pour une gestion plus robuste et réaliste des projets de maintenance industrielle, notamment dans les environnements sensibles comme ceux liés à la production d'énergie.

التلخيص

يعرض هذا البحث دراسة معمقة لمشروع صيانة مضخة حيوية في محطة لإنتاج الكهرباء تقع في ولاية الطارف يهدف هذا العمل أساسًا إلى تحليل تخطيط المشروع مع أخذ الشكوك المرتبطة بمدة المهام بعين الاعتبار.

في البداية، تم تطبيق المنهج الكلاسيكي المعتمد على القيم الثابتة لتحديد المسار الحرج بناءً على مدد محددة للمهام. وقد مكّن هذا الأسلوب من تحديد تسلسل الأنشطة التي تؤثر مباشرة على مدة المشروع. غير أن هذه الطريقة تبقى محدودة بسبب افتراضها ثبات المدد، وهو ما لا يعكس بدقة الواقع الصناعي المتغير.

ولتجاوز هذا القيد، تم استخدام طريقة الخسارة الاحتمالية، حيث أُجريت محاكاة بألف تكرار، مع إدماج عدم اليقين المرتبط بمدة كل مهمة. وقد أظهرت النتائج أن عدة مهام لديها احتمال كبير لأن تكون حرجة، مما يشير إلى أن المسار الحرج المحدد بالطريقة الكلاسيكية قد لا يكون مستقراً.

تؤكد هذه النتائج أهمية استخدام المقاربة الاحتمالية لتحقيق إدارة أكثر واقعية وموثوقية لمشاريع الصيانة الصناعية، لا سيما في البيئات الحساسة مثل منشآت إنتاج الطاقة.

General Introduction

General Introduction:

In an industrial environment marked by increasing complexity and competition, and with the continuous objective of ensuring the longest possible operational continuity of machinery, time management has become a critical factor in improving performance—especially in maintenance projects, where delays can lead to significant financial losses and operational disruptions.

In this context, saving time inherently translates into saving money, which highlights the necessity of developing effective tools and strategies for planning and executing maintenance activities.

This work focuses on the numerical simulation of maintenance project durations using the probabilistic PERT method, applied to a real-world case study at KoudietEddraouche Company.

Today, maintenance engineering requires precise tools that allow for better anticipation of variability and enable efficient planning of various tasks. While tools such as PERT and GANTT charts are essential for visualizing task dependencies, they show limitations in managing uncertainty. This is where integrating probabilistic models becomes crucial, as it enables more accurate identification of critical paths and critical tasks, and more reliable estimation of activity durations, which supports informed decision-making in time and risk management.

To address this topic, the study is structured into four chapters:

- Chapter 1: Provides a general overview of KoudietEddraouche Company.
- Chapter 2: Introduces the theoretical background of the PERT and GANTT methods and their roles in project scheduling.
- Chapter 3: Explores the probabilistic PERT approach, focusing on its assumptions and mathematical properties.
- Chapter 4: Presents the simulation results performed in Excel, applied to a real maintenance project, followed by a thorough analysis.

This research aims to demonstrate the effectiveness of the probabilistic approach in enhancing maintenance planning within a real industrial setting, through a concrete and reproducible application. It particularly emphasizes the importance of identifying critical tasks and paths to improve scheduling accuracy and ensure project success.

Problem statement:

Integrating uncertainty modeling to accurately identify critical tasks.

Chapter I
Presentation of the company KoudietEddraouche

I.1 Introduction:

Energy production equipment plays an essential role in our modern society. It is used to convert different sources of energy into electricity, heat or mechanical power. The most common sources of energy used to power our equipment include Hydraulic energy generated by the force of moving water, harnessed by hydroelectric dams. These facilities use turbines to convert the kinetic energy of water into electricity; wind energy, which uses the kinetic energy of the wind and converts it into electricity using generators; and solar energy, which uses photovoltaic solar panels to convert sunlight into electricity. There is also thermal energy (thermal power stations), which comes from the heat generated by the combustion of fossil fuels (such as coal, natural gas or oil) or by nuclear reactions.

Combined-cycle power plants are one of the most common ways of producing electricity from this source. The thermal source varies, but the operating operating principle is the same: the heat generated by the combustion of fossil fuels (coal, oil fossil fuels (coal, oil, gas) is used to heat water and produce steam. The steam drives a turbine connected to an electrical generator, producing electricity.

In this chapter, we will look more specifically at the essential equipment used in the production of electrical energy in a combined-cycle power plant.

To illustrate these concepts, we will use the KoudietEddraouche power plant as a case study.

KoudietEddraouche power plant.

I.2 Presentation of the KoudietEddraouche company:

I.2.1 History and origin of the company:

The KoudietEddraouch power plant is an operational power station of at least 1,200 megawatts (MW) with three single-shaft technology units, each with a production capacity of 400MW.

The KoudietEddraouche power plant was built in 2007 by the American company General Electric and the Spanish company Eberdrola at an estimated cost of 2.7 billion dollars (179 billion dinars). It began production on the national grid on 07September 2013, and became a 100% SONELGAZ company.[1]

Fig I.1. General view of the KoudietEddraouche power plant.

I.2.2 Geographical location:

The site is located in the village of 'Sebâa' in the commune of Berrihane in the wilaya of El Taref. It is bounded to the north by the Mediterranean Sea (GPS: 36.885, 8.0778), to the south by a military detachment, to the west by vacant land and to the east by the vacancy centre FOSC Sonalgaz and the AEC desalination plant project - Algerian energy company. The site covers a total area of 42 ha (Figure I.1)[1].

I.2.3. Climatic conditions:

- Altitude: average + 40.00 mNGA.

- Ambient temperature: 35°C

- Sea water temperature: 23°C

- Average relative humidity: 73

- Maximum temperature: 45°C (for air-conditioning sizing and

refrigeration system to ambient air, electrical equipment and materials not

sheltered or located in non-air-conditioned premises.

Fig I.2. Satellite view of the KoudietEddraouche power plant[13] .

I.2.4. Social structure:

The KoudietEddraouche power plant has a number of employees qualified in several areas, which are divided into several departments, all of which are under the direction of the Managing Director.

- Studies and planning department:
- Electrical department;
- Mechanical department;
- Instrumentation and control department
- Operations Department;
- Human resources;
- Services common to all companies:
- Finance and Accounting Department: Responsible for the company's financial affairs.
- Legal Department: Responsible for the company's legal affairs (internal regulations and fraud);
- Procurement department [1].

I.3. Relevant processes and equipment of the power plant:

The KoudietEddraouche power plant is a combined cycle thermal power plant consisting mainly of three (03) single-shaft units with TG - Alternator - configuration. TV units with a generating capacity of 400 MW each, and a total generating capacity of 1,200 MW.

Each unit comprises:

- A General Electric PG9371FB type gas turbine;
- A recovery boiler;
- A steam turbine;
- An alternator;
- Transformers, their auxiliaries and annexes.

The total maximum net power of the power station (Plant Terminals) under the conditions of site is 1147 MW (natural gas fuel in normal state) and 1077 MW (diesel fuel in emergency state). The total maximum net capacity of each Combined Cycle unit is 381MW (gas fuel).

In general, the koudieteddraouche power plant consists of:

- Three single-shaft combined cycle units consisting of:
- The shaft line: TG, alternator and TV of STG109FB configuration.
- A gas heater
- An air filter
- An HRSG heat recovery boiler and its chimney
- A condenser
- A chemical conditioning station
- A sampling and analysis station.
- A main transformer and a withdrawal transformer.
- An excitation transformer and an excitation system.
- A starting transformer and a system for starting the alternator in engine mode ‘only on units 1 and 3’
- Distribution panel and supply of medium voltage auxiliaries ‘motors, transformers, etc’.
- Low voltage switchboards and auxiliary power supplies. "Motors, transformers, heaters, etc.
- Uninterruptible power supply distribution switchboards for control, measurement, supervision and protection substations.

- A 400V emergency diesel generator.
- A fire protection system.
- Shielded outpost for evacuating 400 KV electricity to the national grid.
- A control and command room via the MARK VIe system.
- Black Start station with 12 emergency 6.6Kv generators: production capacity: 12x2.6MW.
- Maintenance workshops
- Two heavy and linen spare parts shops.
- Chemicals shop.
- A natural gas supply system with an average pressure of 56 bars.
- 'ERM' gas regulating and metering station.
- Two diesel oil storage tanks with a capacity of 13,791 m3.
- Two untreated diesel oil storage tanks with a capacity of 600 m3.
- Diesel processing station.
- A fire protection station with a 2000 m3 water tank.
- A seawater circulation and pumping station
- An electro-chlorination station to generate chlorine using seawater.
- A desalination plant comprising two MFS-type desalination units with a capacity of 12m3/h.
- A desalination plant comprising two reverse osmosis desalination units with a capacity of 20m3/h.
- Two desalinated water storage tanks with a capacity of 2x2700 m3.
- A mixed-bed demineralisation station with a production capacity of 28 m3/h.
- Two demineralised water storage tanks with a capacity of 2x13022 m3
- An auxiliary boiler to provide sealing steam during start-ups.
- Hydrogen production station for cooling the machines.
- Compressed air production station for instrumentation and service.
- Effluent treatment station
- Administrative buildings and canteen.

I.3.1 Electricity production process: the combined cycle:

A combined-cycle power plant is a facility that produces electricity at using both a gas turbine (in the high-temperature range) and a steam turbine (in the medium and low-temperature range). The temperature at which stops extracting work from the gas turbine is close to the temperature at which the steam turbine starts working. It seems worthwhile to create a two-stage thermodynamic cascade, comprising a gas cycle followed by a steam cycle. Hence the

idea of the (see Figure below)[1].

Fig I.3. View of the layout of a combined cycle.

Today, the combined cycle is one of the most commonly used systems in power plants. It is a hybrid technology that combines a Brayton cycle for the production of electrical energy and a Rankine cycle for the production of thermal energy.

The excellent efficiencies now achieved by combined-cycle power plants (over 60% on a PCI basis) are the result of integrating two complementary technologies in terms of temperature level into a single production unit:

gas turbines, which operate at high temperatures (in an aeroderivative machine the gases typically enter the expansion turbine at 1,300°C and leave at around 500 °C), and steam power plants, which operate at lower temperatures (between 450°C and 30°C in this case).

In modern gas turbines, regeneration is rarely possible or economically attractive. Another way of exploiting the residual enthalpy of exhaust gases is to use them as a heat source for a second cycle of mechanical energy production. Combined cycles correspond to this new generation of thermal power plants.

In other words, the combined cycle is a combination of two thermodynamic processes

for the production of electrical energy. A first process consists of burning gas in a gas turbine, and a second process consists of

taking advantage of the exhaust gases from the gas turbine to produce steam in a heat recovery boiler to develop it in a steam turbine.

I.3.1.1. Genesis of the combined cycle:

The commercial development of combined cycle steam and gas turbines took place in parallel with the development of gas turbines. The first combined cycle gas turbine installed at a utility in the USA was a 3.5 MW gas turbine, the exhaust energy from which was used to heat the feedwater for a 35 MW conventional steam unit.

Most combined cycle systems for electricity generation installed in the 1950s and 1960s comprised fully-fired boilers (boilers). These systems were essentially adaptations of conventional steam power plants, using a fraction of the gas turbine exhaust as combustion air for the boiler. The efficiency of this type of combined cycle was around 5% to 6% higher than that of a similar conventional steam power plant.

These systems could economically use bare tubes in the boiler at due to the large average temperature difference between the combustion products and the water/steam.

I.3.1.2 Advantages of combined cycle:

The advantages of combined cycle include high energy efficiency, a reduction in pollutant gas emissions, greater operational flexibility, and continuous power generation regardless of weather conditions. These plants can harness more than 60% of the energy from burnt natural gas, emit less carbon dioxide and other greenhouse gases, and have a lower production cost per kilowatt. In addition, they offer greater reliability than solar thermal power plants, as they are not dependent on the availability of solar radiation.

I.3.1.3. Disadvantages of the combined cycle:

The disadvantages of the combined cycle lie in the emissions of pollutants and greenhouse gases associated with the combustion of natural gas or oil. These power stations can generate high emission compensation costs, depend on gas, coal or fuel oil producing countries, and often use non-renewable fossil fuel sources. In addition, they require a heat sink to remove residual heat, and gas supply can be tricky due to high and fluctuating demand.

The following is a general description of the main elements and how this technology works.

I.3.2. Main equipment of the combined cycle power plant:

A combined cycle power plant is made up of various components, of which each component plays a different role. Given the diversity of technologies relating to the manufacturer and the objectives of increasing production with optimum efficiency, there are many types of combined cycle power plant, such as the air-cooled and water-cooled techniques used in our case.

The main components of this type of power plant can be summarised as follows:

- Gas turbine.
- Steam turbine.
- Compressor.
- Combustion chamber.
- Heat recovery steam generator (HRSG).
- Condenser.
- Pump.
- Electricity generator.

The operating principles of this equipment are defined below.

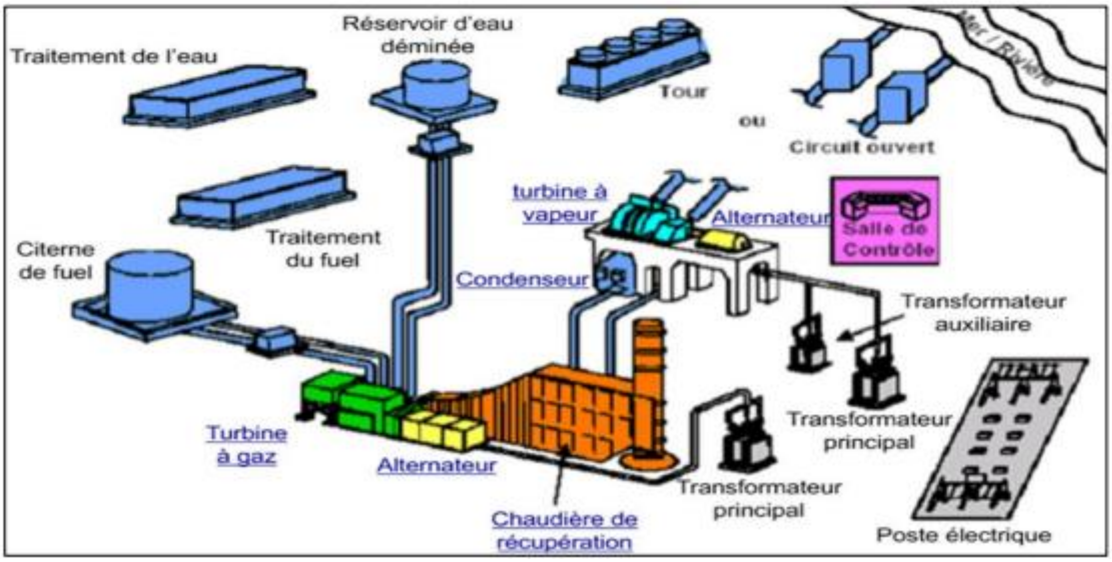


Fig I.4. Relevant equipment in the combined cycle power plant.

I.3.2.1. Gas turbine:

The gas turbine consists mainly of a combustion chamber, where the gases at its outlet are expanded in three stages, which occurs by passing through moving nozzles.

The gases enter through the blades at a very high temperature of 1,396 ºC, which is why the blades have to be cooled with compressor air (check stage 8 outlet).

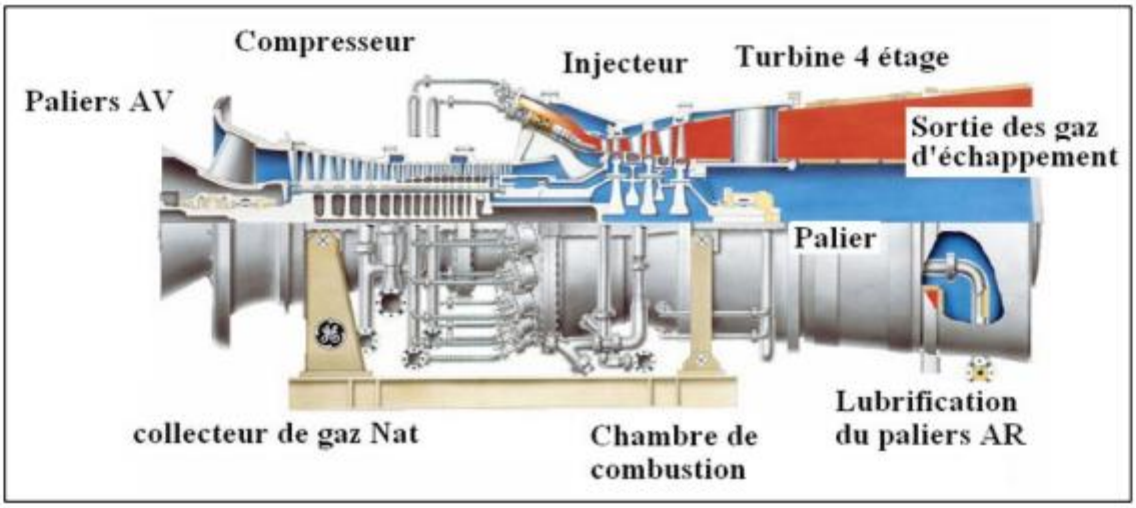
The air circulates through the inside of the blades and exits through orifices positioned so as not to impede the flow. The blades are also covered to protect them from corrosion, oxidation and deformation. The gases leave the gas turbine at a temperature of 623 ºC and 1 bar, and the

flue gas flow rate is approximately 2365 t/h (see Figure I.4).

Fig I.5. Front view of the gas turbine.

The turbine generates its rotational power by expanding the combustion gases, which possess a great deal of energy in fixed and moving blades, thus obtaining high circumferential velocities, these high velocity gases move the rotor blades. The number of stages in turbines is optimised in accordance with the capacity limitation and the pressure difference between stages.

In modern turbines, the fixed and moving blades of the first stages are cooled by the high temperatures of the exhaust gases, so that their service life is materially increased (Figure I.5).



FigI.6. Schematic diagram of a gas turbine.

A. Operating principle of the gas turbine

A gas turbine operates as follows:

- Draws in air from the environment.
- Compresses this air to a higher pressure using the compressor.
- Increases the energy of the compressed air by adding and burning fuel in a combustion chamber, producing hot gases.
- Directs these hot gases at high pressure and temperature to the turbine section.

This section converts the thermal energy into mechanical energy, causing the shaft to rotate. This rotation serves, on the one hand, to supply the energy required for the compression of the air in the compressor directly connected to the turbine and, on the other hand, to supply useful energy to the associated machine, such as an alternator or a centrifugal compressor, via a coupling.

- Finally, it exhausts the low-pressure, low-temperature gases resulting from these transformations into the atmosphere.

The figure below illustrates the variations in pressure and temperature in the various sections of the machine, corresponding to the operating phases mentioned above.

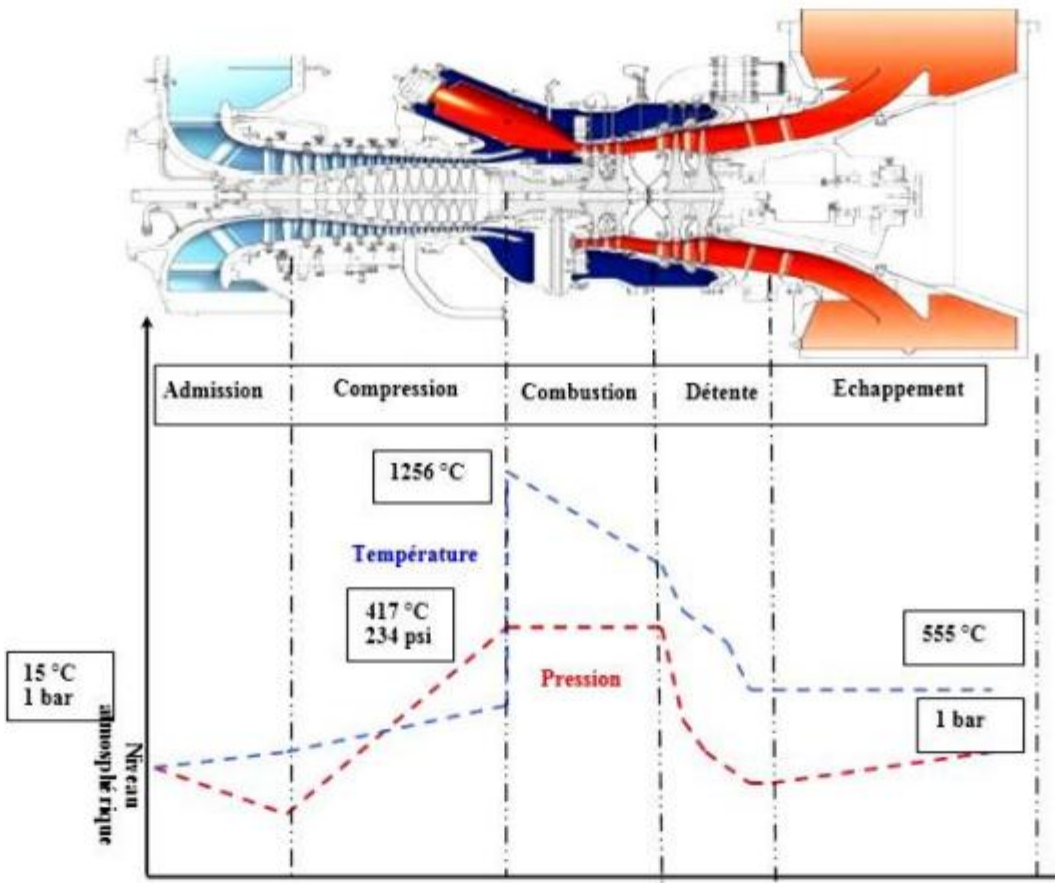


Fig I.7. Pressure and temperature variations in the different sections of the gas turbine.

B. Advantages and disadvantages of gas turbines

Advantages

- High power in a small space, where a diesel unit of the same power could not be accommodated.
- Continuous power production, except during start-up and shutdown.
- Easy starting even in extreme cold.
- Ability to run on a variety of fuels.
- Ability to operate at low loads.

Disadvantages

- For power levels below around 3 MW, installation costs are higher than for a diesel generator.
- The start-up time is much longer than that of a diesel generator; for example: 30 to 120 seconds for a turbine, compared with 8 to 20 seconds for a diesel generator.
- Lower efficiency than a diesel engine (simple cycle). For example: 28 to 33% for a 3 MW turbine, compared with 32 to 38% for a diesel unit.

I.3.2.2 Steam turbine:

The steam turbine is an external combustion heat engine, operating according to the Clausius-Rankine thermodynamic cycle. This cycle is characterised by the change of state of the driving fluid, which is generally water. The turbine converts the thermal energy of the steam, produced during expansion, into the mechanical energy of shaft rotation, which drives a rotating mechanical device.

The steam turbine in our power plant is an ‘A 15’ model manufactured by General Electric. It is made up of 2 bodies: a high and medium pressure body with opposing flows to balance the axial impulses and another low pressure body with double flow Power: 140 MW.

The Steam Turbine is responsible for transforming the thermal energy of the steam into mechanical rotational energy. It has fixed and moving blade rings and there are three pressure levels: HP, MP & BP.

The approximate efficiency of each section of the Steam Turbine is as follows:

HP 78 to 84%; MP 87 to 92%; BP 86 to 90%

The percentage of power produced in each section of the turbine is as follows:

HP 25 to 30%; MP 15 to 22%; BP 50 to 60%

Composition:

- HP section: 30 reaction stages
- MP section: 11 action stages
- BP section: 6 reaction and action stages

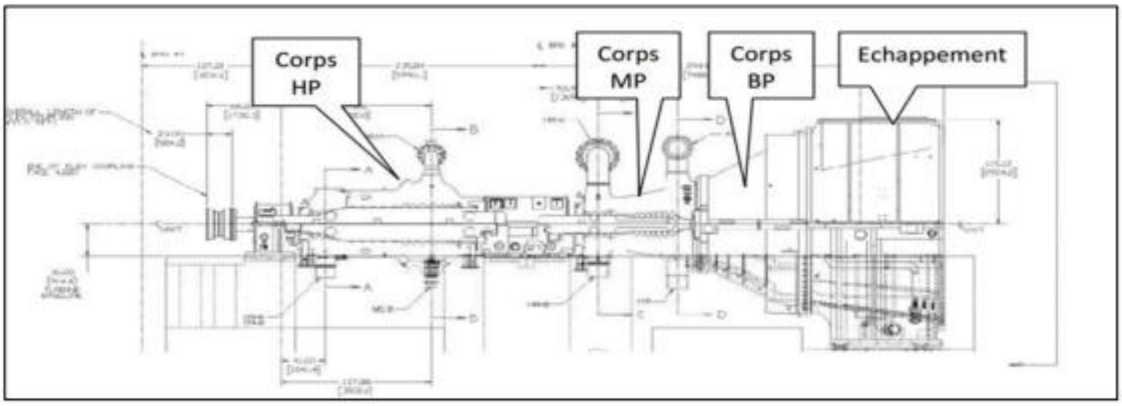
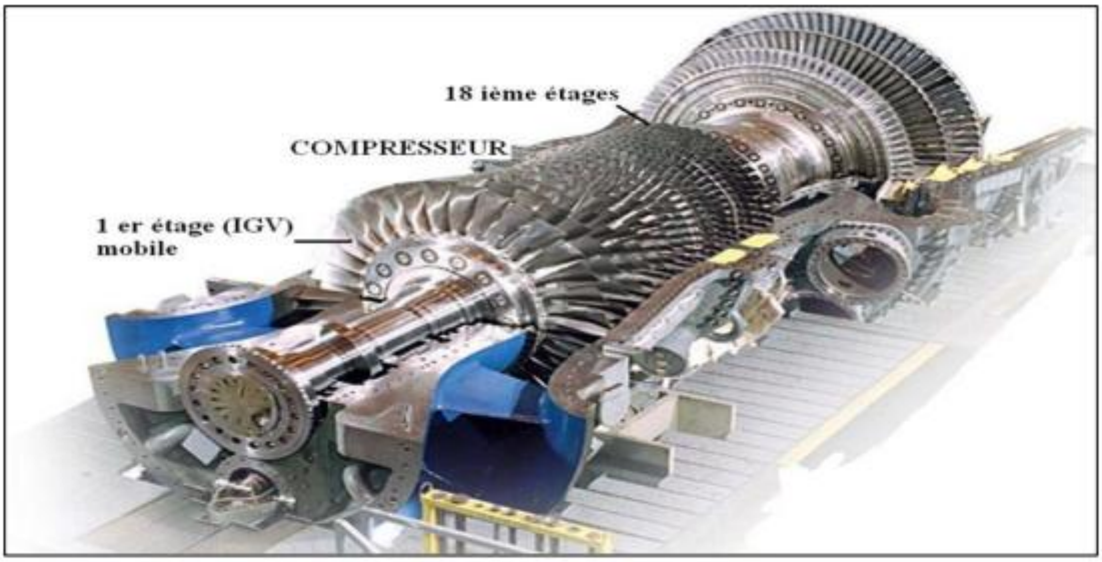


Fig I.8. Steam turbine components 16 A.

I.3.2.3. The compressor:

A compressor is a mechanical device used to increase the pressure of air, which increases its energy. In gas turbines used to generate electricity, we use axial-flow compressors. These



compressors generate a continuous flow of compressed air, as shown in the figure below.

Fig I.9. An axial-flow compressor of an electric gas turbine.

They consist of a set of fixed (stator) and moving (rotor) blades, and each rotor-stator assembly of the compressor constitutes a compression stage1. To obtain a high pressure, it is necessary to have several compressor stages (Figure I.9).

Fig I.10. View of the 18-stage compressor rotor.

The main purpose of the compressor is to supply pressurised air to the gas turbine combustion chamber to mix with the fuel.

The compressor is an 18-stage axial compressor with a compression ratio of 18.3 and an air flow rate of approximately 600 kg/s.

The compressor absorbs 2/3 of the work produced by the gas turbine (approximately 180 MW).

I.3.2.4. The combustion chamber:

The combustion chamber is the place where thermal energy is supplied to the air at carrying out a chemical reaction or combustion. In other words, a gaseous or liquid fuel is injected under pressure and then burnt with compressed air. The combustion chamber is designed to burn a mixture of fuel and air, in order to deliver the gases resulting from a high temperature to the turbine. It is crucial that this temperature does not exceed the permitted limit, otherwise there is a risk of damage to the combustion chamber and turbine.

I.3.2.5. Heat recovery steam generator (HRSG):

The HRSG is a horizontal type boiler, which operates in natural circulation mode, and uses the hot exhaust gas from the gas turbine to generate steam. The steam is directed to the Document steam turbine (Alstom,2009). It consists of three heat exchangers connected in series:

- **A.Economiser**

The economiser is the section of the boiler in which the feed water is first introduced into the boiler, and the combustion gases are used to raise the temperature of the water to saturation temperature.

- **B. Evaporator**

The section of the CVRC evaporator that is used to make the phase change, i.e. the water in the saturated liquid state is vaporised (the water becomes in the saturated vapour state).

- **C. Superheater**

The superheater section of the CVRC is used to dry the saturated steam. It superheats the water vapour leaving the evaporator at saturation temperature until it reaches a limit temperature that does not exceed the temperature resisted by the boiler materials.

1.3.2.6. Condenser:

The condenser is a surface heat exchanger located under the low-pressure turbine. The steam condenses on contact with the walls of the tubes, through which the cooling water passes. In this case, the exchanger used is of the countercurrent type, i.e. the water from the cooling tower circulates in the opposite direction to the steam.

The condensation of the steam discharged by the steam turbine is used to provide a storage chamber for the condensed water (hot well or condenser well);

The degassing of the water (subtraction of dissolved gases) is reheated the condensed steam which falls from the tubes and the fluids from the purges and the various drains to the saturation temperature.

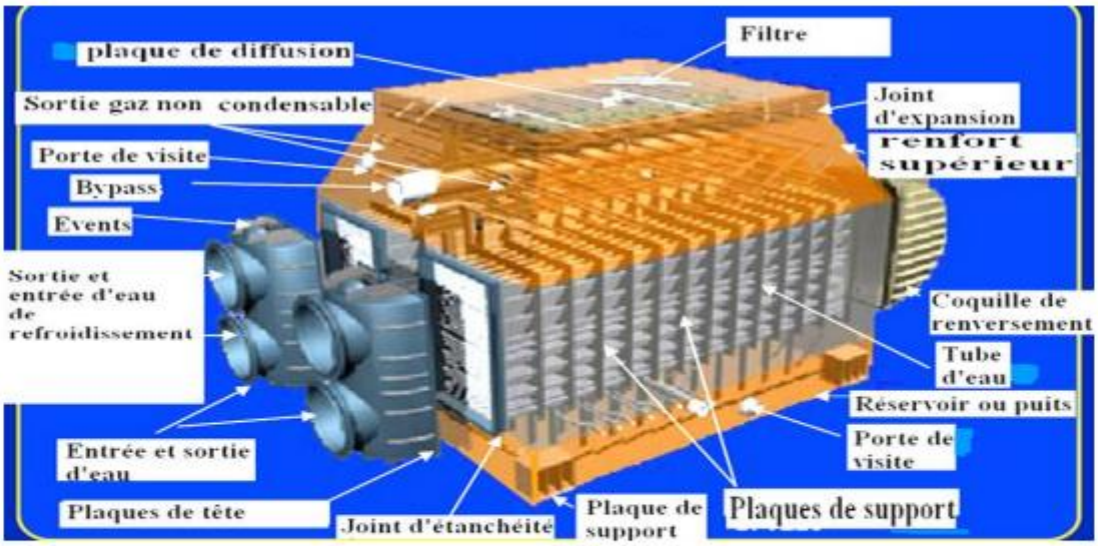


Fig I.11. Condenser components.

I.3.2.7. The pump:

Is a device whose role is to suck in and discharge a liquid, and therefore to ensure the movement of liquid in a system. In thermal power stations, there are three main types:

- **Feed pumps**

Their role is to draw water from the feed tank and deliver it to the boiler's tank.

- **Extraction pumps**

These draw water from the condenser and deliver it to the deaerator.

- **Circulation pumps**

Their role is to draw water from the source (river or ocean) to the condenser in order toabsorb the steam energy at the base pressure turbine outlet, to obtain a condensed liquid.

I.3.2.8. The alternator:

The alternator is an electrical generator. Inside the alternator, there is a rotor whichis driven by the steam turbine. The movement of the rotor creates an electric current throughinduction. Mechanical energy is thus converted into electrical energy.It is therefore the key component that transforms the mechanical energy generated by the turbinesinto electricity. Thanks to this process, a combined-cycle power plant can producemore electricity with the same volume of

fuel, whilereducing CO_2 emissions compared with coal-fired power plants.

Fig I.12. A smooth pole alternator.

In conventional power generation schemes, generators are synchronous.

The synchronous frequency in Algeria is 50 Hz.

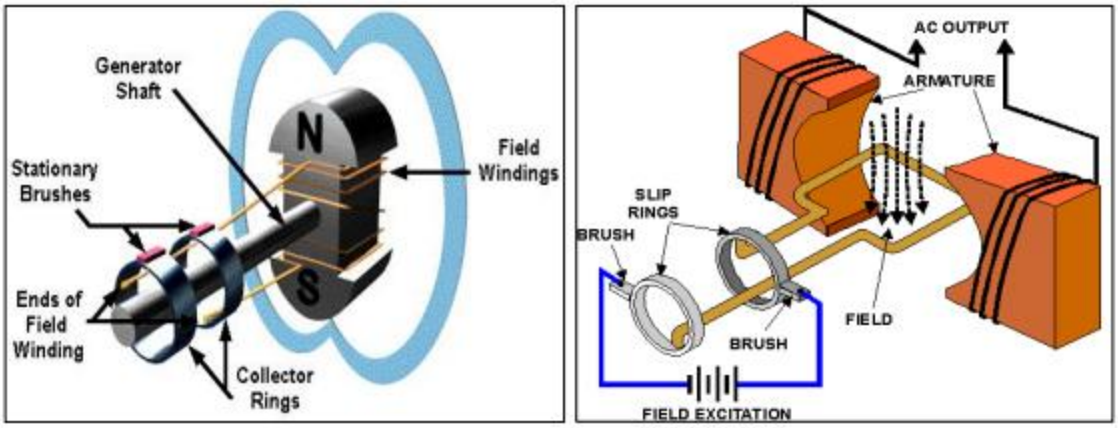


Fig I.13. Descriptive view of the alternator operating principle.

The alternator components are:

- Stator: core and spindles.
- Rotor: Body, spindles and retaining rings.
- Phase outputs
- Cooling
- Bearings
- Oil seals
- Excitation equipment
- Synchronisation

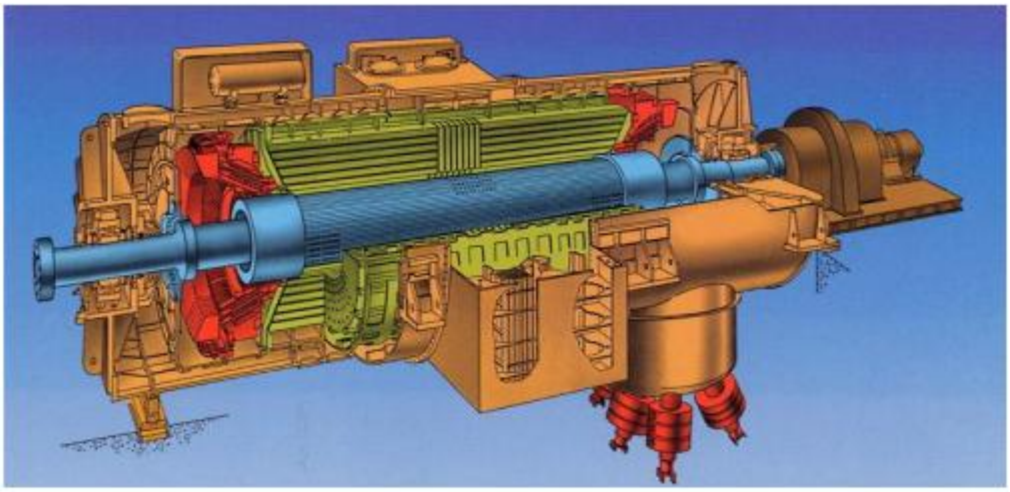


Fig I.14. View of the smooth pole alternator components.

I.3.2.9. Group transformer:

Each unit in the power plant is connected to the external network via amain link, known as the 'TP main transformer'.

The ‘TP’ main transformer is designed to evacuate the energy generatedby the generator to the 400Kv screened substation. The LV winding voltage will be that ofthe alternator. The connection between the generators and the group transformers (GSU)is made via the main busbar sector in an insulated sheath (IPB). Between thegroup circuit breaker (GCB) and the group transformer (TP), a T-branchconnects the extraction transformer (TS) via the secondary busbar section in an insulated casing (IPB).It will be fitted with a tap changer that can be operated in a de-energised state with five positions -5%; -2.5%, 0; + 2.5%; +5% on the high voltage side.0; 2.5%; 5% on the high voltage side.

Normal operating conditions

- Voltage variations: 0.925 to 1.075 Un
- Frequency variations: 48 to 52 Hz

Fig I.15. View of the group transformer.

I.3.2.10. Extraction transformer:

The ‘TS’ extraction transformer, placed downstream of the ‘TP’, is used to extractelectrical energy either from the alternator if the unit is coupled, or from the grid if theunit is decoupled, and to supply all the unit's auxiliaries in both normal and accidental operating situations (fig. I.15).

- The TS will be fitted with an on-load regulator. The adjustment range conforms to the voltage variation at the alternator terminals. Voltages, on-load adjustment. Thevoltages and the transformation ratio at the main tap should be chosen so that the TSsupplied by the alternator provides the nominal voltage chosen for the MV auxiliaries in normal operation and at full load, onthe secondary winding.

Fig I.16. View of the extraction transformer.

I.3.2.11. The recovery boiler:

The recovery boiler is simply an exchanger between the hot fumes from the gas turbine and the water or steam. The heat recovery boiler at the KoudietEddraouch power plant is of the ‘HRSG’ type. It is designed to use the energy available in the exhaust gases from a gas turbine, which will run on natural gas.

The exhaust gas conditions at the boiler inlet are defined at all ambient temperature and load ranges. At each operating point, the exhaust gas temperature and flow rate are calculated and

guarantees the boiler's performance. The boiler is designed for a possible variation of ± 14 °C from the expected value of the exhaust gases from the combustion turbine. This boiler includes the following systems.

- The HP steam system
- The resuperheater system
- The MP steam system
- The BP steam system
- The exhaust gas circuit

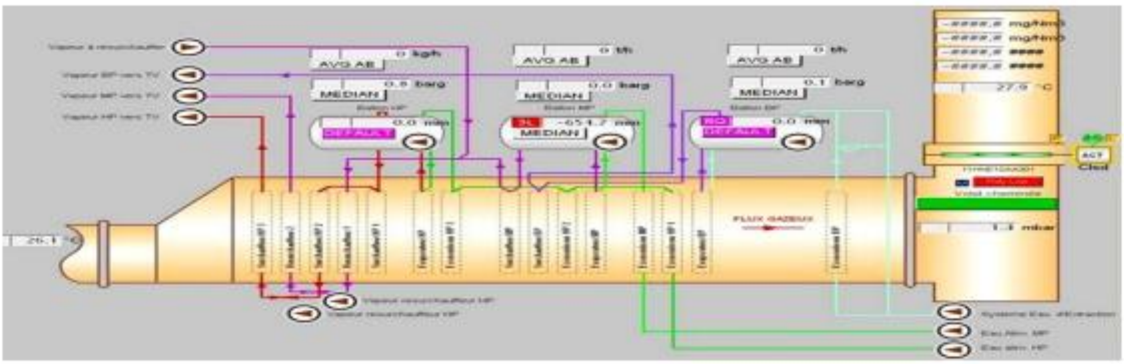
System composition:

a. HP3 Superheater, HP2 Superheater, HP1 Superheater, HP Balloon, HP Evaporator, HP3Economiser, HP2 Economiser, HP1 Economiser.
b. Resuperheater 2, Superheater1, MP Superheater, MP Boiler, MP Evaporator andMP Economiser.
c. BP Superheater, BP Boiler, BP Evaporator and BP Economiser with firstcirculation.
d. Stack damper, stack silencer

In addition to the above components, the boiler includes interconnecting pipework,valves including control valves, flow meters, drain andpurge valves and the necessary instrumentation.

The continuous blowdown system is designed to have a blowdown capacity of at least5% of the total HP flow and MP flow. The bleed valves are designed for highpressure drop and wide operating range.

The start-up bleed fromthe evaporator is sized for 15% of the maximum steam flow at a



minimum pressure of200 PSI.

Fig I.17. View of the 'CIMVIEW MARK VIe' recovery boiler.

Functions of these systems:

a. The HP system heats the feedwater and generates superheated steam forthe inlet into the steam turbine HP casing.

b. The MP system heats the feedwater and generates superheated steam which ismixed with the steam to be resuperheated at the outlet of the steam turbine HP casing.This mixture passes through the resuperheater and is then admitted to the MP section of thesteam turbine. The MP system also supplies hot water from the MP economiser tothe gas reheater.

c. The BP system heats the feedwater and generates superheated steam foradmission to the BP casing of the steam turbine.

d. The HP superheater desuperheater and the resuperheater desuperheater controlrespectively the temperature of the steam to the HP and MP casings of the steam turbine.

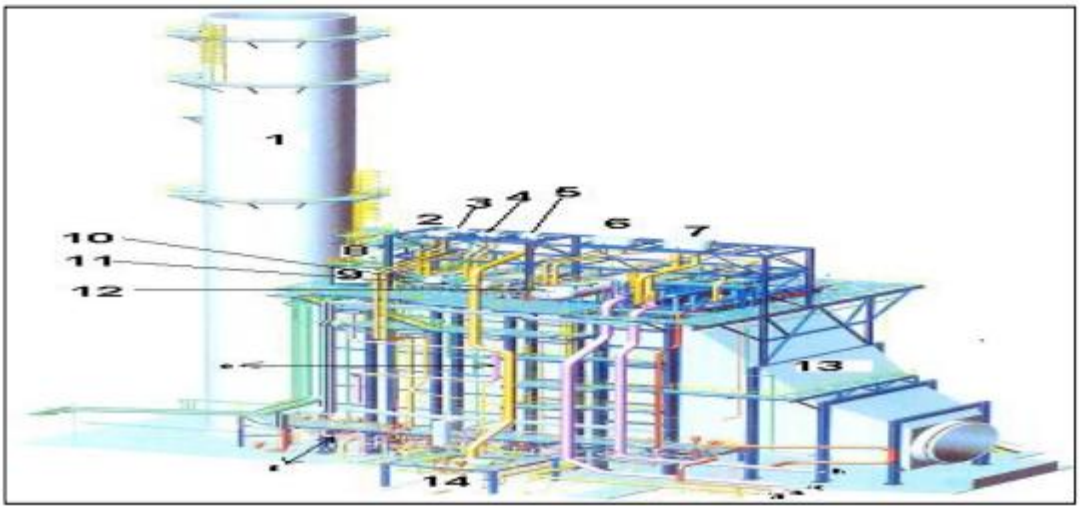


Fig I.18. Recovery boiler components.

1. The Chimney
2. Low pressure silencer
3. Deaerator silencer
4. Medium pressure silencer
5. Expansion tank silencer 6. High pressure silencer
7. Resuperheater muffler
8. Gas outlet
9. non-condensable gas manifold
10. Low pressure cylinder
11. medium pressure cylinder

I.4Medium-Pressure (MP) Feed Pumps:

The medium-pressure feed pumps are horizontal, centrifugal, and multistage.

The pump and motor are mounted on a common steel baseplate.

The motor has a power rating of 185 kW, two poles, 50 Hz, 400 V, squirrel-cage rotor, and IP55 protection rating.

The pump casing is made of ASTM A217 Grade WC6, while the shaft is ASTM A276 Type 410.

The impeller is of the closed type, with a joint-plane casing, vertical upward suction, and vertical upward discharge, both flanged.

The seals are cooled with water from the auxiliary cooling system via a heat exchanger, while the bearings are cooled directly with auxiliary cooling water.

Each pump has a capacity of 100%, with a flow rate under design conditions of 96.53 m^3/h.

Fig I.19.(MP) Feed Pumps.

Chapter II

Presentation PERT method and GANTT chart

II.1 Introduction:

Project management is a key area in many industries, ranging from construction and IT to research and innovation. A project, whether simple or complex, involves a number of challenges that the project manager must resolve to ensure success. The main challenges include managing time, costs and resources, and the uncertainty that can affect the progress of the project. In this context, effective tools are needed to plan, monitor and adjust project activities throughout its lifecycle.

The **PERT** network and the **Gantt** chart are among the most widely used project management tools, as they enable tasks to be organized and monitored while taking into account time and resource constraints. These tools are essential for optimum project management, while minimising the risks of delays, cost overruns or poor resource management.

A. PERT method:

II.A.2. General presentation of the PERT method:

The PERT method is a project management method designed to predict the properties of a project in terms of time, deadlines and costs. PERT (Program Evaluation and Review Technique (Eng) Technique d'Évaluation et d'Examen de Programme (Fr)) originated in the US Navy and dates from the late 50s. Its principle is to divide a project into a set of actions called tasks and to represent them graphically using a dependency graph.

Thanks to the chronology and interdependence of each task, the project as a whole can be structured and each task can be planned in relation to the others, in order to minimise deadlines and reduce the impact of delays in carrying out the various tasks. To finalise the implementation of the PERT method, a number of activities need to be carried out:

- Define the project precisely;
- Define a project manager to whom you will report and who will take the important decisions;
- Analyse the project in terms of large groups of tasks, and then break down certain tasks if necessary;

- Define the tasks very precisely and determine their duration;
- Researching the corresponding costs, which may call certain tasks into question;
- Implement the tasks according to the agreed schedule;
- Carry out periodic checks to ensure that the system is not drifting; if it is, take the necessary steps - even if it means revising the planning using the PERT method - to minimise the consequences.

II.A.3. General concepts:

II.A.3.1 Representation:

The PERT method is used to represent the planning of a project using a dependency graph [2].

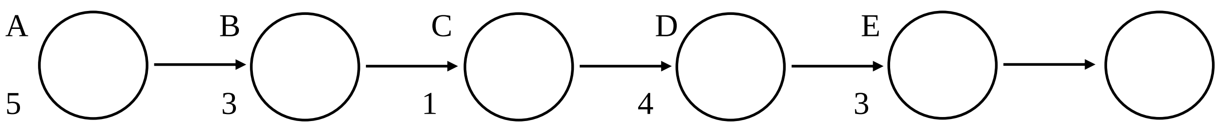


Fig II.1. PERT representation of a project.

II.A.3.2 Definitions

II.A.3.2.1. Task:

A task moves the work toward its final state; it therefore consumes time, energy, and materials, and thus incurs a cost.

Each task is represented by an arrow (a directed segment in the direction of the time flow), the length of which is independent of the task's duration [3].

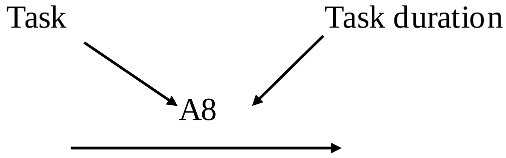


Fig II.2. Representation of a task.

II.A.3.2.1.1.Dummy task:

A dummy task represents a constraint between dependent tasks.ach dummy task is represented by a dotted arrow; it has zero duration, consumes no resources, and therefore incurs no cost [3].

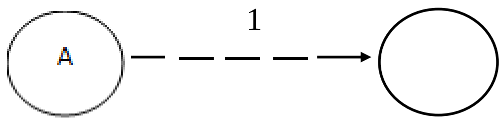


Fig II.3. Dummy task representation.

II.A.3.2.2. Step:

A step refers to the start or end of a task. A step is represented by a circle or another geometric shape. A step has zero duration and therefore incurs no [3].

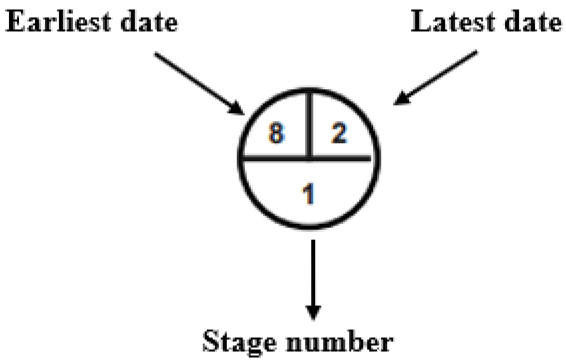


Fig II.4. Representation of a step.

II.A.3.2.3. Network:

It is the set of tasks and steps that represents the work as a whole. The network highlights the relationships between tasks and steps [3].

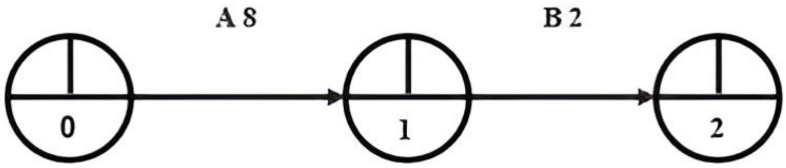


Fig II.5. Representation of a PERT network.

II.A.3.3. Rules for graphical representation:

The network always contains a single start step and a single end step. Each task has at least one start step and one end step, and a task cannot start until the previous task has finished.

Two different tasks cannot have the same start and end steps. Two tasks that start at the same time and are executed simultaneously are each represented by its own arrow, and the starting point of the two arrows is the starting point of the two arrows is the start of the same step.

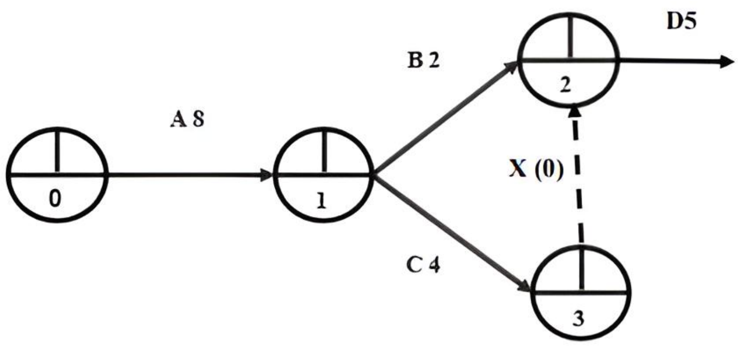


Fig II.6. Representation of simultaneous tasks.

Tasks B and C are synchronised, i.e. they start at the same time, but neither task B nor task C can start until task A is completely finished (Figure II-6). If you want D to start only when B and C have finished:

Because of the construction rule which prohibits the two tasks B and C from running simultaneously, we use a task x (0) called <<fictitious task >> which is used to represent this type of linking constraint (precedence constraints). This is a task whose duration and cost are zero. It is represented by dotted lines. [3]

If two tasks start simultaneously or are close in time, each is represented by its own symbol, and the arrow linking them represents a single step

As tasks A and B start together before task C can start, task C can only start once tasks A and B have been fully completed. (Figure II-7).

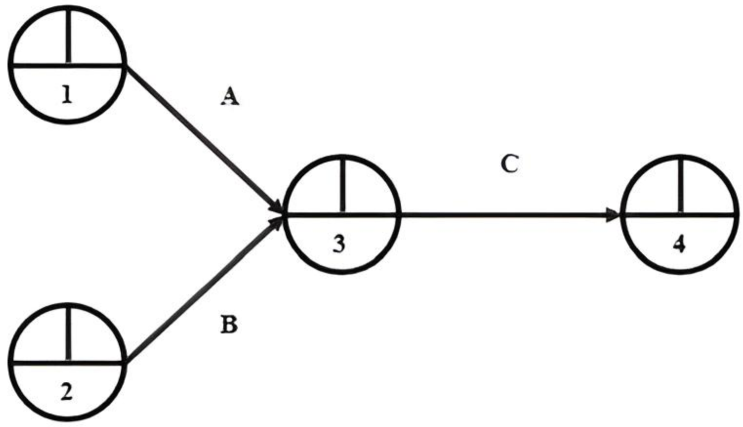


Fig II.7. Convergent task representation.

II.A.4. Construction of a PERT Network:

The construction and analysis of a PERT network involve performing the following operations [4]:

- Establishing a detailed list of tasks;
- Identifying predecessor tasks (as well as successor tasks, where applicable).
- Constructing partial graphs.
- Combining the partial graphs.
- Building the complete network.

II.A.4.1.1. Establishing a Detailed Task List:

We consider the following list of 12 tasks, labeled from A to L. The estimated duration of each task is provided [4].

Table II.1. List of Tasks and Their Respective Durations.

Task	Duration
A	3

B	1
C	5
D	6
E	4
F	2
G	9
H	5
I	8
J	2
K	3
L	7

II.A.4.1.2. Identifying Predecessor Tasks:

The analysis of the project and its constituent tasks makes it possible to define the chronological precedence relationships between tasks, and by simple deduction, to infer the values in the "Successor Task(s)" column,these results are summarized in the following table.

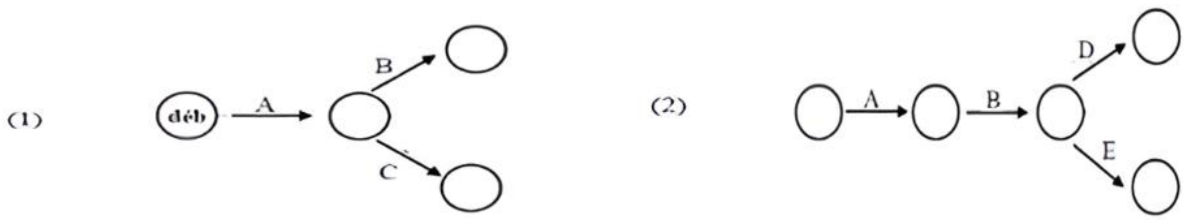
Table II.2. List of Tasks, Predecessor Tasks, and Successor Tasks.

Task	Duration	Predecessor Task(s)	Successor Task(s)
A	3	None	B, C
B	1	A	D, E
C	5	A	F
D	6	B	F
E	4	B	G
F	2	C, I, D	G
G	9	E, F	None
H	5	None	I, J
I	8	H	K
J	2	H	L
K	3	I	L
L	7	J, K	None

II.A.4.1.3. Constructing Partial Graphs:

A partial graph represents a segment of the final PERT network. Two distinct levels of partial graphs can be defined:

The level of predecessor task(s) / current task.



The level of predecessor task(s) / current task / successor task(s).

Fig II.8. An Example of the Set of Partial Graphs at the Level of Predecessor Task(s) / Current Task / Successor Task(s).

II.A.4.1.4. Combining Partial Graphs:

Next, the partial graphs are progressively combined as the construction of the PERT network advances.

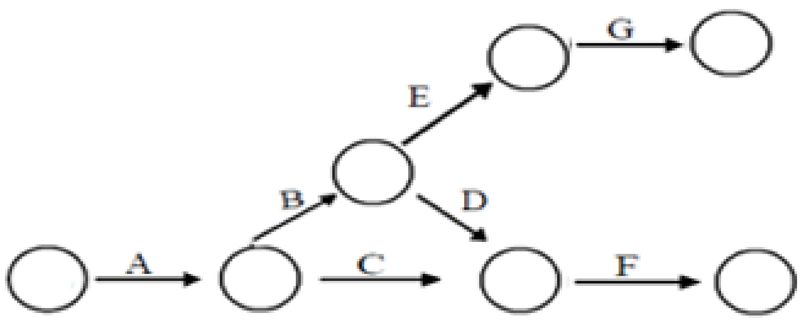


Fig II.9. Example of Combining Partial Graphs from (1) to (5).

II.A.4.1.5. Building the complete network:

The aggregation of all partial graphs enables us to obtain the complete PERT network [4].

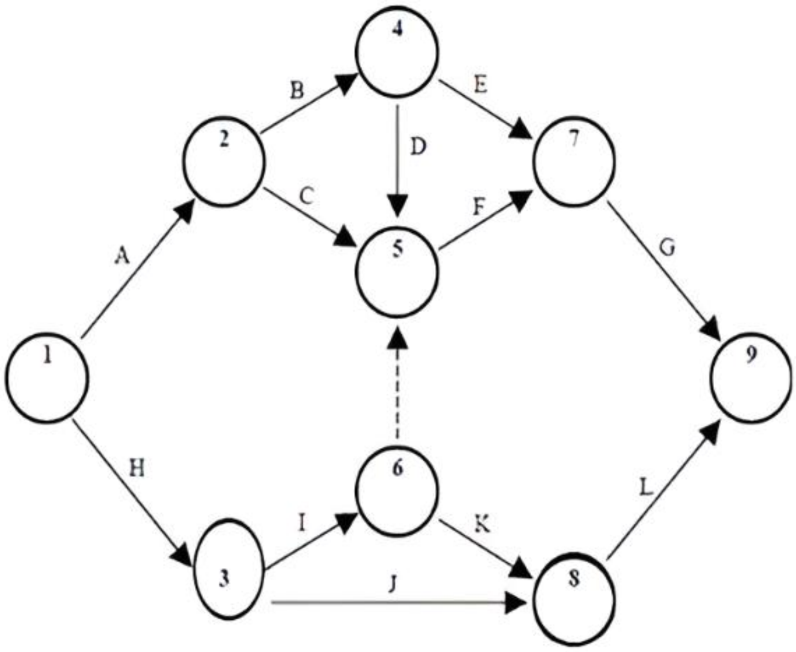


Fig II.10. PERT Network.

II.A.5. Calculation of Temporal Parameters in the PERT Network:

II.A.5.1. Earliest Start Time Calculation:

This step involves determining the earliest possible time at which each task in the project can begin, based on the completion of all its preceding tasks. It establishes a forward timeline and sets reference points that structure the overall project schedule.

II.A.5.2. Latest Finish Time Calculation:

This calculation identifies the latest possible time by which a task can be completed without delaying the overall project. It is obtained by working backward from the project deadline and considering the durations of subsequent dependent tasks.

II.A.5.3. Free Float Calculation:

The free float represents the amount of time a task can be delayed without affecting the start of any succeeding tasks. It is computed as the difference between the latest finish time and the earliest start time. Tasks with zero float are considered critical, as any delay would directly impact the project timeline.

II.A.5.4. Critical Path Identification:

The critical path corresponds to the sequence of dependent tasks that determines the shortest possible duration for the project. It includes all tasks with zero float. Any delay in one of these tasks will result in a delay of the entire project, making this path essential to monitor and control.

II.A. .6PERT Cost:

In some cases, a project may take too long to complete. In such cases, the project manager is obliged to reduce the duration in order to meet contractual deadlines or strategic constraints.

This reduction can be achieved by accelerating critical tasks (a method known as crashing), which involves adding extra resources such as technicians, operators, machines or specialised equipment. However, this decision leads to an increase in the overall cost of the project, which must be analysed [5].

II.A.6.1 .Cost definitions:

Project costs can be classified into two broad categories:

- ✓ Direct costs
- ✓ Indirect Costs

II.A.6.1.1. Direct costs:

Direct costs are those that can be attributed directly to a specific project task or activity.

They include in particular:

- Materials used for production;
- Direct labour (salaries of workers, technicians, etc.);
- Tools and equipment used exclusively for a given task.
- These costs generally increase when a task is accelerated (e.g. overtime, hire of additional equipment) [6].

II.A.6.1.2 Indirect Costs:

Indirect costs are overheads that cannot be directly associated with a specific project task or product.However, they are essential to the overall smooth running of the organisation or project.

- ✓ These costs generally include

- ✓ Salaries for support functions (management, accounting, supervision not directly assigned to a task),
- ✓ Rent or charges for facilities,
- ✓ Administrative costs,
- ✓ Communication, marketing and security costs.

Although they do not vary as much as direct costs when the project is accelerated, they can increase if the project lasts longer, which makes their management essential in a PERT cost analysis [5].

II.A.7. Project acceleration method:

To accelerate a project, certain conditions must be met:

1. Obtain the critical path.
2. Reduce the duration of critical path tasks.

B. GANTT method:

II.B.8.1 General information:

This is a diagram-type method, created around 1918, which is still very widely used. The technique can be used without actually presenting the diagram. It involves determining the best possible way of position the different tasks of a project to be carried out over a given period based on:

- ✓ the duration of each task;
- ✓ precedence constraints between the various tasks,
- ✓ deadlines to be met,
- ✓ processing capacity (which may change as a result of overtime investments made)[8].

II.B.8.2. Definition:

The Gantt chart, commonly used in project management, is one of the most effective tools for visually representing the progress of the various activities (tasks) that make up a project. The left-hand column of the diagram lists all the tasks to be carried out, while the header line represents the most appropriate time units for the project (days, weeks, months, etc.). Each task is represented by a horizontal bar, whose position and length represent the start date, duration and end date. This diagram shows at a glance:

- The different tasks to be considered
- The start date and end date of each task
- The expected duration of each task
- Any overlap between tasks, and the duration of this overlap
- The start date and end date of the project as a whole

In short, a Gantt chart lists all the tasks that need to be completed in order to bring the project to a successful conclusion, and indicates the date by which these tasks must be carried out (the schedule).

In a nutshell, a Gantt chart lists all the tasks that need to be completed to bring the project to a successful conclusion, and indicates the date by which these tasks must be carried out (the schedule)[9].

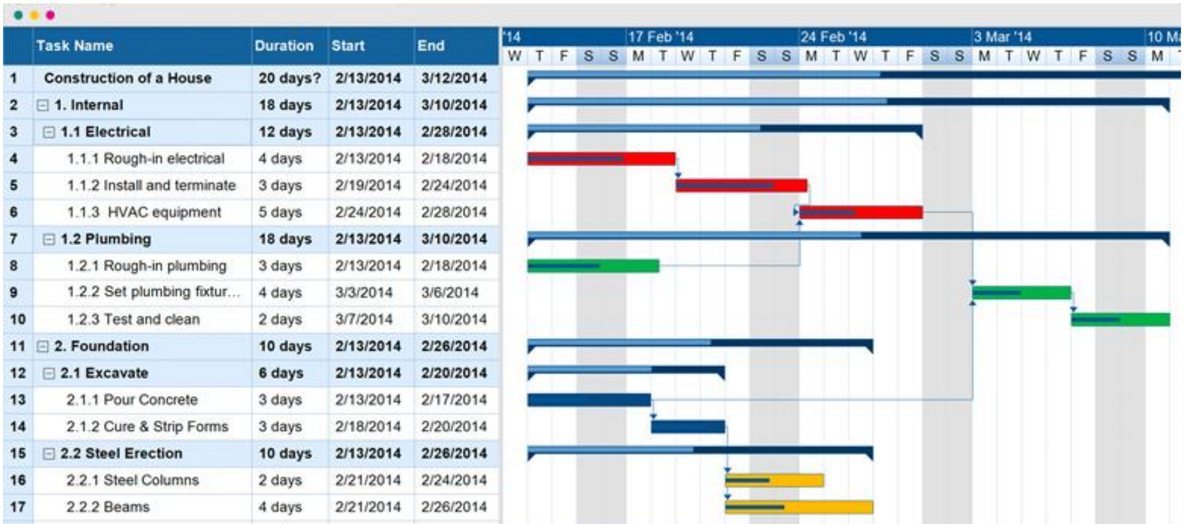


Fig II.11. GANTT chart[15].

II.B.8.3. Field of Application of the GANTT Method:

It is developed in the same fields as the PERT chart [3].

II.B.8.4. Conditions for Implementing the GANTT Method:

Its application is essential after the PERT chart if the project is complex, or on its own if the project is simple [3].

II.B.8.5. Components of a Gantt Chart:

The Gantt chart is presented as a bar chart, where each row represents a task and each bar indicates its duration on a time scale. Here are the main components of a Gantt chart [10]:

- Task: A specific action or activity within the project.
- Duration: The estimated time required to complete the task.
- Start/EndDate: The scheduled period during which the task is to be performed.
- Task Bar: A visual representation of the task's duration on the timeline.
- Dependencies: Logical relationships between tasks that determine the sequence of execution.
- Critical Path: The sequence of tasks that directly affects the total duration of the project.
- Progress**: The percentage of completion for each task.**
- Resources: Individuals, teams, or tools assigned to execute the tasks.

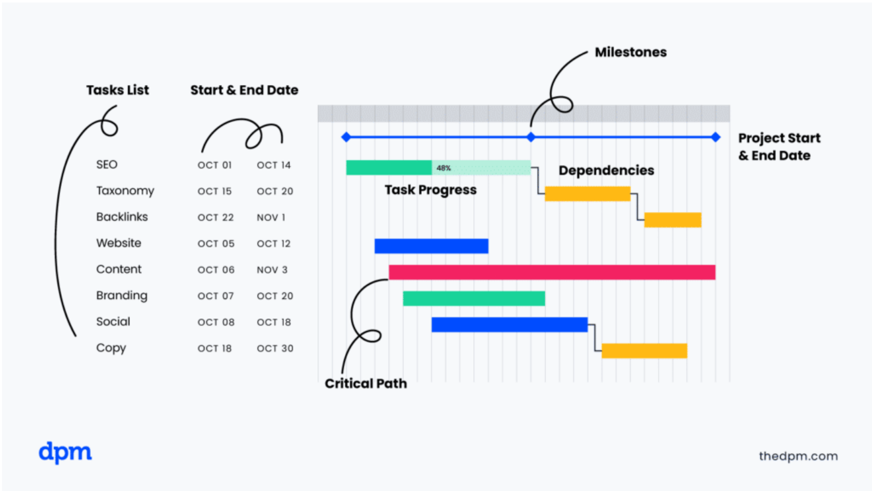


Fig II.12. Components of a Gantt Chart.

II.B.8.6. Gantt Chart Construction (Steps):

In other words, these are the steps or phases that must be followed to construct a Gantt chart[5]:

- List the Tasks: Break down the entire project into individual tasks.
- Decompose the Project into Subtasks (WBS – Work Breakdown Structure): Use WBS to organize the project into manageable components.
- Determine the Duration of Each Task: Estimate the time required for each task (in days, weeks, etc.).
- Identify Dependencies: Define which tasks depend on the completion of others.
- Set the Project Start Date: Typically determined by the earliest task in the sequence.

- Draw the Time Scale:Use a horizontal axis representing time units (days, weeks, or months).
- Draw Task Bars: For each task, draw a horizontal bar proportional to its duration.
- Add Relationships (Links): Use arrows to represent dependencies between tasks.
- Update with Progress: Track the progress of each task during project execution.

II.B.8.7. GANTT chart software tools:

Several software tools are widely used for creating GANTT charts, including:

Microsoft Project, GanttProject, ProjectLibre, and cloud-based platforms such as Asana, ClickUp, and Monday.com.

The most widely used application :Ms Project.

Fig II.13. Microsoft Project[14] .

Conclusion:

To successfully carry out a project, the project manager must establish a comprehensive plan. This involves defining the activities, organizing them over time, identifying task dependencies, estimating the required effort for each task, and allocating appropriate resources.Among the most effective planning tools are the PERT and GANTT methods. The PERT method enables visualization of task dependencies, calculation of the earliest and latest start and finish dates, and identification of the critical path, which determines the project's minimum completion time. Although PERT does not initially account for cost estimation, it can be complemented by cost analysis techniques to define the overall project budget.The GANTT chart complements PERT by clearly displaying the timeline of tasks and resource allocation. It also defines milestones that represent key phases of the project and help monitor progress.In summary, effective project planning requires scheduling techniques like PERT and GANTT, combined with the experience and intuition of the project manager to ensure timely and successful project completion.

Chapter III

Probabilistic PERT

III. Probabilistic PERT

III.1. Introduction:

The network method discussed so far can be described as deterministic, since the estimated estimated activity times are assumed to be known with certainty. However, in the design of a gearbox or a new machine, various activities are based on judgement. are based on judgement. It is difficult to obtain a reliable estimate of time due to technology. Time values are subject to change variations. For cases where activities are non-deterministic in nature, PERT has been developed. By consequently, there is a new probabilistic Pert version which takes into account the hazards on dates and durations and relies on estimating three durations to determine the expected durations of each of each activity and the total expected duration of the project as well as the delay variance.

III.2. Definition:

PERT probabilistic method is where activity time is represented by a distribution of probability distribution. This probability distribution of activity time is based on the time estimates of three different three different time estimates made for each activity. These are shown below:

- Optimistic time estimate: very unlikely that the task will take less time than.
- Most likely time estimate:this is what we really think will happen
- Time estimates Pessimistic [11].

III.3. Principles of Probabilistic PERT:

The duration of each task *i* is uncertain.

The duration, denoted as *Di* is a random variable, meaning that *Di* can take multiple values according to a probability distribution.

Based on this distribution, we can compute:

- The expected duration (mean),
- The variance,
- And the standard deviation of the task duration [12].

III.4. Definition – Beta Distribution:

The duration of each project task is considered random, and the Beta distribution is systematically used to calculate a probable duration based on three parameters.This approach is based on the evaluation of three key parameters:

- Optimistic duration (t_o□ □ or a): The minimum estimated duration, assuming everything goes better than expected.
- Pessimistic duration (t□ $_e$□ or b): The maximum estimated duration, assuming everything goes as poorly as possible.
- Most likely duration (t□ □or m): The most realistic estimate, the one that would be chosen if only a single value were to be provided.

To obtain the parameters a, b, and m — which are used to calculate the mean and variance — the following formulas are applied:

For task Ti:

- **Probable Duration** ("Estimated Mean Time")

$$\mathrm{t_{pro}}\ (\mathrm{Ti}) = \frac{\mathrm{t_{opt}}\ (\mathrm{Ti}) + 4\mathrm{t_{real}}\ (\mathrm{Ti}) + \mathrm{t_{pess}}\ (\mathrm{Ti})}{6}$$

- **Standard Deviation**

$$\sigma(\mathrm{Ti}) = \frac{\mathrm{t_{pes}}\ (\mathrm{Ti}) - \mathrm{t_{opt}}\ (\mathrm{Ti})}{6}$$

- **Variance**

$$\text{Var (Ti)}= \sigma^2\text{(Ti)}$$

III.5. Probabilistic PERT Calculation:

There exists a version of PERT that accounts for uncertainties in both start dates and activity durations.
Its application is carried out in multiple steps.

Step 1:

This step involves determining the probability distribution of the duration of each task Ti using a Beta distribution based on three-time estimates: a, b and m.

Table III.1. Optimistic, Most Likely, and Pessimistic Time Estimates with Task Dependencies.

Task	**Predecessor task**	**a(day)**	**m(day)**	**b(day)**
A	-	4	5	12
B	A	1	1.5	5
C	A	2	3	4
D	B	3	4	11
E	D-C	2	3	4

Step 2:

Based on the three-time estimates defined in Step 1, we calculate the expected value and the variance of the task duration, which serve as parameters for the Beta distribution.

$$\mathrm{t_{pro}}\ (\mathrm{Ti}) = \frac{\mathrm{t_{opt}}\ (\mathrm{Ti}) + 4\mathrm{t_{real}}\ (\mathrm{Ti}) + \mathrm{t_{pess}}\ (\mathrm{Ti})}{6}$$

Table III.2. Estimated Task Durations (t_pro) Using the PERT Formula.

Task	$\mathbf{t_{pro}}$
A	$t_{pro}\,(Ti) = \frac{4+4*5+12}{6}$=6
B	2
C	3
D	5
E	3

Step 3:

Critical path duration: The duration of a path is the sum of the durations of the tasks along that path.The sum of random durations, Sd, is itself a random variable, for which we calculate the expected value (mean) and the variance.

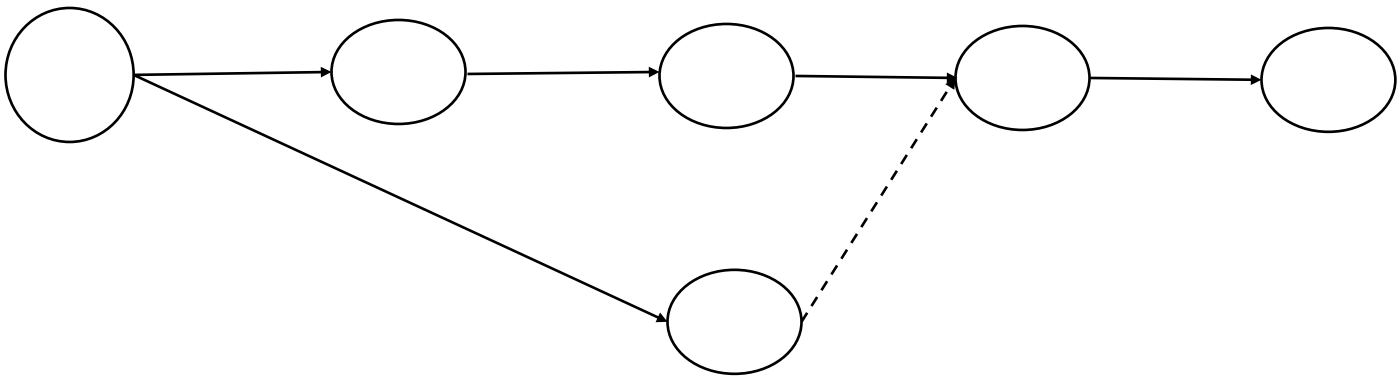


Fig III.1.PERT network.

The total duration of the project is 16 days.

The critical path is A-B-D-E

For each path, we can then calculate:

- The estimated duration for all tasks Ti on the path
- The estimated variance for all tasks Ti on the path
- The estimated standard deviation (i.e., the square root of the total variance)

$$\sigma(\mathrm{Ti}) = \frac{t_{pes}\ (\mathrm{Ti}) - t_{opt}\ (\mathrm{Ti})}{6}$$

$$\mathrm{Var}\ (\mathrm{Ti}) = \sigma^2(\mathrm{Ti})$$

Table III.3. PERT-Based Estimates: Mean Durations (Tm), Standard Deviations (σ), and Variances (Var) for Each Task.

Task	Tm	$\sigma(Ti)$	Var (Ti)
A	6	1.33	1.76
B	2	0.66	0.43
D	5	1.33	1.76
E	3	0.33	0.10

$$Var\ (Sd) = 3.65 \sigma\ (Sd) = 1.91$$

The time required to complete the project follows a normal distribution with a mean of 16 and a standard deviation of 1.91.

Step 4:

To analyze the probability of completing a project by a specific date using a normal distribution, we use the variable transformation formula, also known as a change of variable.

$$Z = \frac{T - T_m}{\sigma}$$

where:

T = project duration,

Tm = estimated average project duration

Let the estimated duration of the project be T = 20 days.

The probability that the project completion will be achieved by 20 days is as follows:

$$P\ (T \leq 20) \Rightarrow P((T - 16)/1.91 \leq (20 - 16)/1.91)\ = P(Z \leq 2.09)$$

It is usually assumed that path durations follow a normal (Gaussian) distribution. Using a Gaussian table, one can then determine either a duration corresponding to a fixed probability, or the probability of completing the project within a given timeframe.

$$P(Z \leq 2.09)$$

We decompose Z=2.09 into 2.0+0.09

Using the standard normal cumulative distribution table, it can be observed that P(Z≤2.09) =0,9817

t	0	1	2	3	4	5	6	7	8	9
0,0	0,5000	0,5040	0,5080	0,5120	0,5160	0,5199	0,5239	0,5279	0,5319	0,5359
0,1	0,5398	0,5438	0,5478	0,5517	0,5557	0,5596	0,5636	0,5675	0,5714	0,5753
0,2	0,5793	0,5832	0,5871	0,5910	0,5948	0,5987	0,6026	0,6064	0,6103	0,6141
0,3	0,6179	0,6217	0,6255	0,6293	0,6331	0,6368	0,6406	0,6443	0,6480	0,6517
0,4	0,6554	0,6591	0,6628	0,6664	0,6700	0,6736	0,6772	0,6808	0,6844	0,6879
0,5	0,6915	0,6950	0,6985	0,7019	0,7054	0,7088	0,7123	0,7157	0,7190	0,7224
0,6	0,7257	0,7291	0,7324	0,7357	0,7389	0,7422	0,7454	0,7486	0,7517	0,7549
0,7	0,7580	0,7611	0,7642	0,7673	0,7704	0,7734	0,7764	0,7794	0,7823	0,7852
0,8	0,7881	0,7910	0,7939	0,7967	0,7995	0,8023	0,8051	0,8078	0,8106	0,8133
0,9	0,8159	0,8186	0,8212	0,8238	0,8264	0,8289	0,8315	0,8340	0,8365	0,8389
1,0	0,8413	0,8438	0,8461	0,8485	0,8508	0,8531	0,8554	0,8577	0,8599	0,8621
1,1	0,8643	0,8665	0,8686	0,8708	0,8729	0,8749	0,8770	0,8790	0,8810	0,8830
1,2	0,8849	0,8869	0,8888	0,8907	0,8925	0,8944	0,8962	0,8980	0,8997	0,9015
1,3	0,9032	0,9049	0,9066	0,9082	0,9099	0,9115	0,9131	0,9147	0,9162	0,9177
1,4	0,9192	0,9207	0,9222	0,9236	0,9251	0,9265	0,9279	0,9292	0,9306	0,9319
1,5	0,9332	0,9345	0,9357	0,9370	0,9382	0,9394	0,9406	0,9418	0,9429	0,9441
1,6	0,9452	0,9463	0,9474	0,9484	0,9495	0,9505	0,9515	0,9525	0,9535	0,9545
1,7	0,9554	0,9564	0,9573	0,9582	0,9591	0,9599	0,9608	0,9616	0,9625	0,9633
1,8	0,9641	0,9649	0,9656	0,9664	0,9671	0,9678	0,9686	0,9693	0,9699	0,9706
1,9	0,9713	0,9719	0,9726	0,9732	0,9738	0,9744	0,9750	0,9756	0,9761	0,9767
2,0	0,9772	0,9778	0,9783	0,9788	0,9793	0,9798	0,9803	0,9808	0,9812	0,9817
2,1	0,9821	0,9826	0,9830	0,9834	0,9838	0,9842	0,9846	0,9850	0,9854	0,9857
2,2	0,9861	0,9864	0,9868	0,9871	0,9875	0,9878	0,9881	0,9884	0,9887	0,9890
2,3	0,9893	0,9896	0,9898	0,9901	0,9904	0,9906	0,9909	0,9911	0,9913	0,9916
2,4	0,9918	0,9920	0,9922	0,9925	0,9927	0,9929	0,9931	0,9932	0,9934	0,9936
2,5	0,9938	0,9940	0,9941	0,9943	0,9945	0,9946	0,9948	0,9949	0,9951	0,9952
2,6	0,9953	0,9955	0,9956	0,9957	0,9959	0,9960	0,9961	0,9962	0,9963	0,9964
2,7	0,9965	0,9966	0,9967	0,9968	0,9969	0,9970	0,9971	0,9972	0,9973	0,9974
2,8	0,9974	0,9975	0,9976	0,9977	0,9977	0,9978	0,9979	0,9979	0,9980	0,9981
2,9	0,9981	0,9982	0,9982	0,9983	0,9984	0,9984	0,9985	0,9985	0,9986	0,9986
3,0	0,9987	0,9987	0,9987	0,9988	0,9988	0,9989	0,9989	0,9989	0,9990	0,9990
3,1	0,9990	0,9991	0,9991	0,9991	0,9992	0,9992	0,9992	0,9992	0,9993	0,9993
3,2	0,9993	0,9993	0,9994	0,9994	0,9994	0,9994	0,9994	0,9995	0,9995	0,9995
3,3	0,9995	0,9995	0,9995	0,9996	0,9996	0,9996	0,9996	0,9996	0,9996	0,9997
3,4	0,9997	0,9997	0,9997	0,9997	0,9997	0,9997	0,9997	0,9997	0,9997	0,9998
3,5	0,9998	0,9998	0,9998	0,9998	0,9998	0,9998	0,9998	0,9998	0,9998	0,9998
3,6	0,9998	0,9998	0,9999	0,9999	0,9999	0,9999	0,9999	0,9999	0,9999	0,9999
3,7	0,9999	0,9999	0,9999	0,9999	0,9999	0,9999	0,9999	0,9999	0,9999	0,9999
3,8	0,9999	0,9999	0,9999	0,9999	0,9999	0,9999	0,9999	0,9999	0,9999	0,9999
3,9	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000

Fig III.2. The standard normal distribution table.

The probability that the project will be completed within 20 days is 98.17%, with an industrial risk of 1.83%.

Conclusion:

Applying the probabilistic PERT method to a real project (one of KoudietEddraouche's projects) requires a thorough understanding of the method, which is why we have devoted a whole chapter to explaining it and better understanding its stages.

As in reality a project is never totally predefined at the outset and there are always modifications, risks and changes in the initial plan, projects are considered as stochastic systems, it is more realistic to apply the Probabilistic PERT method where we can always prepare for uncertainty in a more exact way and with mathematical calculations.

The KoudietEddraouche company and the project on which we are going to apply the method will be presented in detail in the next chapter of this work.

Chapter IV

Results and Discussions

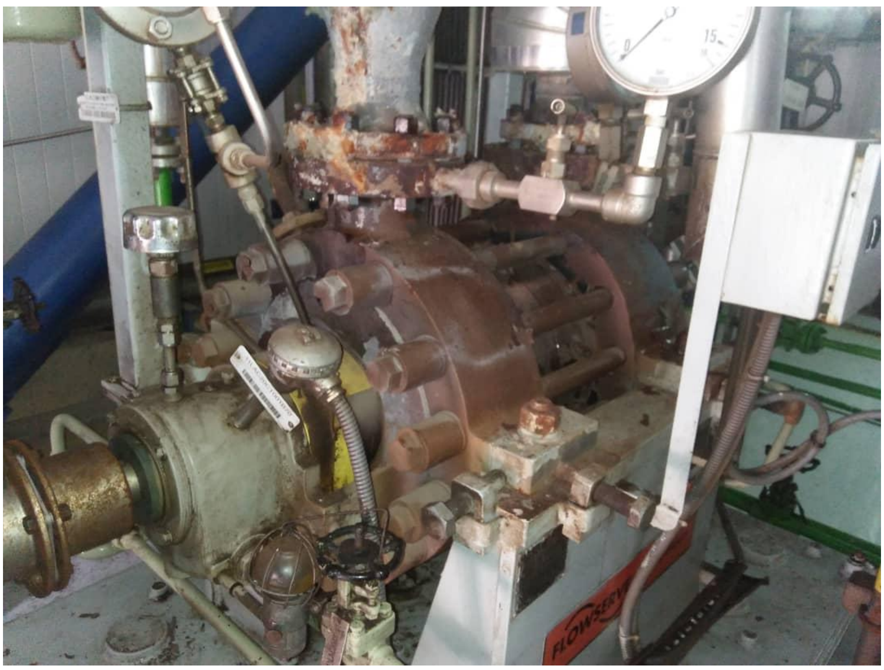
IV. Results and Discussions:

IV.1. Introduction.

A major overhaul was conducted on the Medium Pressure (MP) feedwater pump, a key component within the Heat Recovery Steam Generator (HRSG). This pump is responsible for supplying preheated water to the MP steam drum and plays a critical role in the desuperheating of the MP reheater and the HP bypass. Additionally, it provides feedwater to the gas preheater, ensuring appropriate natural gas temperature prior to combustion in the gas turbine.

The overhaul included a comprehensive inspection of the pump's mechanical condition, evaluation of its hydraulic performance, and verification of auxiliary protection systems—particularly the minimum flow recirculation line equipped with a flow control valve. The operational behavior of the pump was analyzed under various conditions, including normal operation, startup, shutdown, and fault scenarios.

The objective of this analysis is to identify all individual tasks involved in the major overhaul process and estimate their respective durations in order to construct a detailed PERT diagram. A novel optimization method was implemented using Excel and the probabilistic PERT technique to reduce the total overhaul time and enhance future maintenance planning and



scheduling efficiency.

Fig IV.1.MP Pump 11LAC20AP001.

IV.2. Functional Specification of the MP Pump 11LAC20AP001:

IV.2. 1. Functional Role:

The MP pump 11LAC20AP001 is a medium-pressure (MP) feedwater pump used totransfer treated water from the storage tank (feedwater tank or reservoir) to the boiler inlet, while ensuring the flow rate and pressure conditions required for the boiler's normal operation are met.

IV.2. 2. Location within the Installation: Pump Installation Overview:

- Unit: Thermal Power Plant / Industrial Boiler.
- Area: MP Pumping Zone (Medium-Pressure Pump Room).
- Building: Technical Room for Feedwater Supply.
- Control Hierarchy Level: Local supervision and integrated into the central control-command system.
- Proximity: Located in immediate proximity to the feedwater tank (treated water reservoir), Downstream of the water treatment system (reverse osmosis or demineralization), Upstream of the high-pressure (HP) pumps.

IV.2. 3. General Characteristics: Technical specification of the pump.

Pump Type: Horizontal multistage centrifugal pump

Equipment Number: 11LAC20AP001

Nominal Discharge Pressure: ~30 to 45 bar (typical for a medium-pressure pump)

Nominal Flow Rate: Between 20 to 60 m^3/h (depending on boiler demand)

Pumped Fluid: Treated (demineralized) water

Fluid Temperature: ~60–90 °C

Drive System: Variable-speed electric motor (via VFD – Variable Frequency Drive)

Discharge To: Common header supplying the boiler or the high-pressure (HP) pump.

IV.2. 4. Control and Automation:

The pump operation is managed through an automated system ensuring optimal performance and safety.

- Main Control Mode: Automatic via the control-command system.
- Local Manual Mode: Available for maintenance or testing outside supervisory control
- Flow Regulation: Ensured by a Variable Frequency Drive (VFD) to adjust motor speed according to flow or pressure setpoints.
- Redundancy: One or two twin pumps (e.g., 11LAC20AP002 and 003) can provide backup or operate in alternation.

IV.2. 5. Protections and Safeguards:

Safety mechanisms built into the pump operation.

Discharge pressure switch: Alerts for overpressure or underpressure

Motor thermistor: Thermal protection for the motor

Vibration sensor (if installed): Mechanical condition monitoring

Leakage monitoring: Via internal relief valve or automatic recirculation to the tank

Electrical protection: Motor circuit breaker or thermal relay

Supervision alarms: Low discharge pressure, motor fault, leakage, cavitation, etc.

IV.2. 6. Operation Under Special Conditions:

Behavior during start-up, shutdown, or failure.

Normal start-up: Automated sequence with suction pressure check and valve opening.

Normal shutdown: Commanded by PLC, discharge valve closes, motor stops gradually via VFD.

In case of failure: Automatic switch to standby pump (002 or 003); alarm is logged and displayed.

Table IV.1. Tasks of a Major Overhaul of the MP Pump.

N	Task
A1	- Work Permit Preparation.
A2	- Motor iockout.
A3	- Motor decabling.
A4	- Instrumentation Isolation.
A5	- Instrument decabling.
A6	-Dismantling the instrumentation and storage
A7	-Draining pump bearings.
A8	- Pipeline Unclamping.
A9	-PV of desaccosting and line reading.
A10	- Pipeline disconnection report and alignment reading.
A11	-Pump motor uncoupling and coupling cleaning.
A12	- Disassembly of the Pump and Transfer to the Workshop.
A13	-Checking spare parts and segregation.
A14	-Complete dismantling of the pump.
A15	-Cleaning of spare parts.
A16	-Inspection of spare parts.
A17	-Inspection report.
A18	-Replacement of damaged spare parts and gold tolerance parts.
A19	-Wear rings (impeller, impeller, channel rings and diffuser).
A20	-Impeller balancing.
A21	-Rotor assembly and balancing.
A22	-Reassembly of the pump in accordance with the pump manufacturer's recommended.
A23	- Pre-alignment.
A24	- Reassembling the auxiliary pipework.
A25	- Direction of motor rotation.

A26	**-** Pump coupling.
A27	**-** Filling and leakage check.
A28	- Maintenance report.
A29	**-** Start up pump.
A30	**-** Pump function test.
A31	**-** Pump flow test.
A32	**-** Final report.

IV.3. Steps for performing each task:

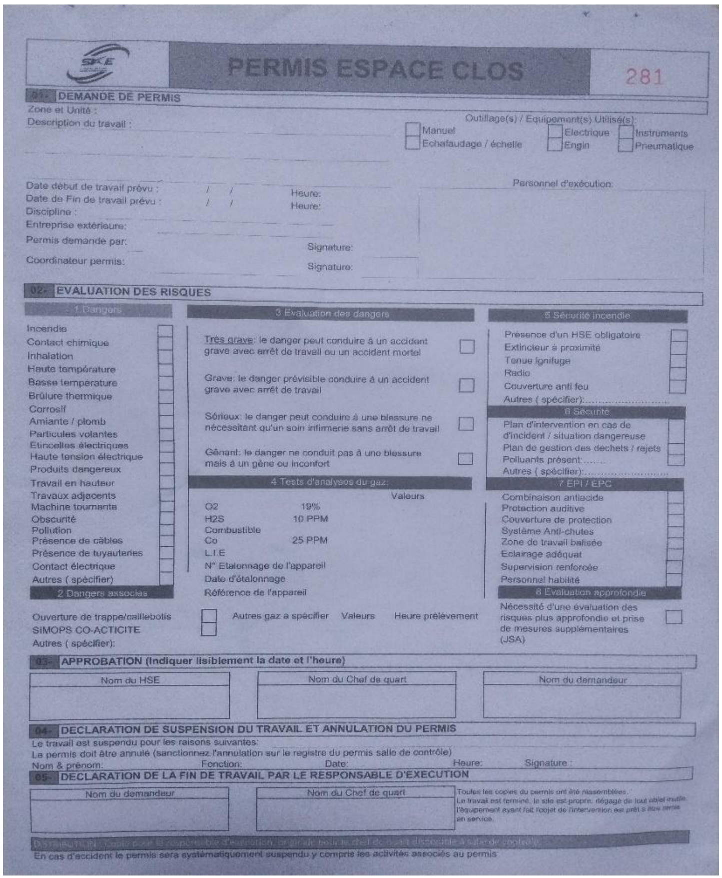
IV.3.1. Work Permit Preparation:

The maintenance process begins with the preparation of the Work Permit, a critical step to ensure the safety of all personnel involved. This phase takes approximately 1.5 hours and involves coordinated administrative and safety procedures between the maintenance team, Health, Safety & Environment (HSE) personnel, and the operations department.

Initially, the maintenance supervisor or team leader completes a standardized Work Permit.

Once filled out, the permit is reviewed and validated by the HSE representative to ensure that all safety conditions are met. The control room is also notified to isolate or shut down the relevant equipment if necessary.

Before work begins, a pre-job safety briefing (Toolbox Talk) is conducted with the entire



PERMIS ESPACE CLOS 281

01- DEMANDE DE PERMIS

Zone et Unité :
Description du travail :

Outillage(s) / Equipement(s) Utilisé(s):
Manuel / Echafaudage / échelle / Electrique / Engin / Instruments / Pneumatique

Date début de travail prévu : / / Heure:
Date de Fin de travail prévu : / / Heure:
Discipline :
Entreprise extérieure:
Permis demandé par: Signature:
Coordinateur permis: Signature:
Personnel d'exécution:

02- EVALUATION DES RISQUES

1 Dangers: Incendie, Contact chimique, Inhalation, Haute température, Basse température, Brûlure thermique, Corrosif, Amiante / plomb, Particules volantes, Etincelles électriques, Haute tension électrique, Produits dangereux, Travail en hauteur, Travaux adjacents, Machine tournante, Obscurité, Pollution, Présence de câbles, Présence de tuyauteries, Contact électrique, Autres (spécifier)

2 Dangers associés: Ouverture de trappe/caillebotis, SIMOPS CO-ACTICITE, Autres (spécifier):

3 Evaluation des dangers:
Très grave: le danger peut conduire à un accident grave avec arrêt de travail ou un accident mortel
Grave: le danger prévisible conduire à un accident grave avec arrêt de travail
Sérieux: le danger peut conduire à une blessure ne nécessitant qu'un soin infirmerie sans arrêt de travail
Gênant: le danger ne conduit pas à une blessure mais à un gène ou inconfort

4 Tests d'analyses du gaz:

	Valeurs
O2	19%
H2S	10 PPM
Combustible	
Co	25 PPM
L.I.E	
N° Etalonnage de l'appareil	
Date d'étalonnage	
Référence de l'appareil	

Autres gaz a spécifier — Valeurs — Heure prélèvement

5 Sécurité incendie: Présence d'un HSE obligatoire, Extincteur à proximité, Tenue ignifuge, Radio, Couverture anti feu, Autres (spécifier):

6 Sécurité: Plan d'intervention en cas de d'incident / situation dangereuse, Plan de gestion des dechets / rejets, Polluants présent:, Autres (spécifier):

7 EPI / EPC: Combinaison antiacide, Protection auditive, Couverture de protection, Système Anti-chutes, Zone de travail balisée, Eclairage adéquat, Supervision renforcée, Personnel habilité

8 Evaluation approfondie: Nécessité d'une évaluation des risques plus approfondie et prise de mesures supplémentaires (JSA)

03- APPROBATION (Indiquer lisiblement la date et l'heure)

Nom du HSE — Nom du Chef de quart — Nom du demandeur

04- DECLARATION DE SUSPENSION DU TRAVAIL ET ANNULATION DU PERMIS

Le travail est suspendu pour les raisons suivantes:
Le permis doit être annulé (sanctionnez l'annulation sur le registre du permis salle de contrôle)
Nom & prénom: Fonction: Date: Heure: Signature :

05- DECLARATION DE LA FIN DE TRAVAIL PAR LE RESPONSABLE D'EXECUTION

Nom du demandeur — Nom du Chef de quart

Toutes les copies du permis ont été rassemblées.
Le travail est terminé, le site est propre, dégagé de tout objet inutile, l'équipement ayant fait l'objet de l'intervention est prêt à être remis en service.

En cas d'accident le permis sera systématiquement suspendu y compris les activités associés au permis team to discuss hazards, assign responsibilities, and review the safety measures in place.Finally, the permit is signed by all relevant parties (operations, maintenance, HSE) and a copy is visibly posted at the worksite.

Fig IV.2.Work Permit.

IV.3. 2.Motor lockout:

The motor isolation procedure is a fundamental step to ensure the safety of maintenance operations. It typically requires around 1.5 hours and is intended to disconnect all energy sources from the motor to prevent unintended startup.

The procedure includes the following steps:

- Coordination with the control room to shut down the pump and obtain authorization for isolation.
- Disconnection of the electrical power supply from the circuit breaker or motor control panel.
- Installation of safety padlocks and identification tags at all isolation points.
- Verification of zero voltage using a calibrated multimeter.
- Documentation of the isolation process in the work permit, including names of responsible personnel and time of execution.

These safety measures are essential to protect technicians from electrical hazards and are mandatory before any mechanical or electrical intervention.

IV.3. 3.Motor decabling:

The motor decabling process is performed after complete electrical isolation has been verified. It takes approximately 1 hour and involves the safe removal of the motor's electrical connections to prepare for mechanical disassembly or transport.The procedure includes:

- Opening the motor terminal box to access internal cable connections.
- Labeling each wire according to the wiring diagram to ensure proper reinstallation.
- Using appropriate tools to loosen and remove cable lugs or terminals.
- Insulating and securing the disconnected cables to avoid short circuits or mechanical damage during handling.

- Logging the disconnection in the maintenance record for traceability.

Fig IV.3. Motor cables.

IV.3. 4.Instrumentation Isolation:

The instrumentation isolation process involves safely disconnecting and isolating all instrumentation related to the pump to prevent damage and ensure safety during maintenance. This steptypicallytakes about 1 hour**.** Key stepsinclude :

- Identifying all instrumentation lines connected to the pump (pressure sensors, flow meters, temperature probes, etc.).
- Closing isolation valves or disconnecting signal lines to electrically and hydraulically isolate the instruments.
- Depressurizing and draining instrument lines if necessary to avoid leaks.
- Securing disconnected instrumentation cables and tubes to prevent accidental damage.

IV.3. 5.Instrument decabling:

The instrument decabling process involves safely disconnecting all electrical and signal cables from instrumentation devices linked to the pump. This step typically takes 1 hour and is critical to ensure safe removal and avoid damage.Key steps include :

- Opening instrument junction boxes or terminal points.
- Labeling each cable for accurate reinstallation post-maintenance.
- Disconnecting cables carefully without damaging insulation or connectors.
- Securing and insulating disconnected cable ends to prevent short circuits or contamination.

IV.3. 6.Instrumentation Dismantling and Storage:

The instrumentation dismantling and storage process involves carefully removing all instrumentation components connected to the pump and safely storing them to prevent damage during maintenance.Key steps include :

- Physically detaching sensors, transmitters, and associated devices following manufacturer guidelines.
- Labeling and documenting each instrument for easy identification.
- Packing instruments in protective containers or designated storage areas to prevent mechanical or environmental damage.

This procedure preserves instrument integrity and facilitates reinstallation after pump maintenance.

IV.3.7. Drainingpump bearings:

The pump bearing drainage procedure involves draining the lubricant or oil from the pump bearings to prepare them for inspection, maintenance, or replacement. This tasktypicallyrequires 30 minutes.Keystepsinclude :

- Positioning appropriate containers to collect drained lubricant safely.
- Opening drain valves or plugs on the bearing housings.
- Allowing sufficient time for complete drainage of old lubricant.
- Inspecting the drained fluid for contamination or debris indicating bearing wear.

- Proper disposal or analysis of the drained lubricant according to environmental and safety regulations.

This procedure is critical for ensuring the bearings are properly serviced without

contaminating the environment.

Fig IV.4. Pump bearings.

IV.3.8. Pipeline Unclamping:

The pipeline unclamping operation involves the careful disconnection of all piping connected to the pump, including main and auxiliary lines. This procedure takes approximately 5.5 hours due to the complexity and safety precautions required.Key steps include :

- Reviewing piping and instrumentation diagrams (P&ID) to identify all connection points.
- Draining and depressurizing the piping system to ensure safe handling.
- Loosening and removing clamps, bolts, and flanges connecting pipes to the pump.
- Using appropriate lifting equipment to support pipes during detachment to prevent damage or injury.

Conducting a final inspection to verify complete disconnection and absence of leaks.

Fig IV.5. Pipeline Unclamping.

IV.3.9. PV of desaccosting and line reading:

The disconnection report (PV) and alignment reading is a verification and documentation step performed after pipeline disassembly. It takes approximately 1 hour and is essential to record the mechanical status of the pump before further work.Main stepsinclude:

- Documenting the exact disconnection points and methods used.
- Measuring shaft-to-shaft alignment between the pump and motor using precision tools (e.g., dial indicators or laser alignment).
- Logging all alignment data in an official PV (Procès-Verbal) report.
- Getting validation and sign-off from responsible technicians and supervisors.

This task ensures accurate reference for reassembly and reduces misalignment issues during reinstallation.

IV.3.10.Pipeline disconnection report and alignment reading:

The task of removing the main and auxiliary piping connected to the pump requires approximately 8.5 hours. This step is critical for gaining full access to the pump for maintenance or overhaul, especially in complex systems where multiple lines intersect. Main stepsinclude:

- Reviewing piping and instrumentation diagrams (P&ID) to locate all connections.
- Mechanically supporting the pipes to prevent stress on flanges or joints.
- Unbolting flange connections and dismantling supports.
- Carefully removing pipes using appropriate lifting tools or cranes.

- Labeling and storing pipes systematically to ease reinstallation.

Fig IV.6. Pipeline disconnection report and alignment reading.

IV.3.11. Pump motor uncoupling and coupling cleaning:

This task involves disconnecting the pump from the motor by decoupling the shaft coupling and thoroughly cleaning the coupling components. It takes approximately 5.5 hours due to the precision needed and the importance of preserving alignment surfaces. Key steps include:

- Verifying that both motor and pump are mechanically secured and electrically isolated.
- Removing the coupling guard for access to the shaft coupling.
- Identifying the coupling type (flexible, rigid, gear...) and removing coupling bolts.
- Using pullers or extractors to separate both coupling halves from the shafts.
- Cleaning all coupling parts (hub bores, keyways, mating faces) with degreaser and soft brushes.

- Inspecting components for signs of wear, misalignment, or damage.

This task is essential for ensuring safe and efficient reassembly with proper alignment.

Fig IV.7. Pump motor uncoupling and coupling cleaning.

IV.3.12. Disassembly of the Pump and Transfer to the Workshop:

This task involves dismantling the pump unit from its field installation and transferring it to the workshop for detailed maintenance. The operation takes approximately 2 hours and requires proper handling and lifting tools to prevent equipment damage.Key steps:

- Ensuring full disconnection from piping, electrical, and mechanical interfaces.
- Lifting the pump with a crane or forklift using manufacturer-recommended lifting points.
- Securing the unit during transfer to avoid mechanical shocks.
- Placing the pump safely on the workshop maintenance table or base.
- Logging the pump tag number and visual condition for maintenance records.

This step enables a controlled environment for internal inspection and repair.

Fig IV.8. Pump transfer to the Workshop.

IV.3.13. Checking spare parts and segregation:

This task involves the verification and segregation of spare parts prior to the reassembly phase. It takes approximately 3 hours, depending on the number and complexity of the parts.Key steps :

- Matching spare part names and reference numbers with the bill of materials (BOM) or OEM specifications.
- Performing dimensional and visual checks to verify integrity and conformity.
- Categorizing parts into:

Ready for use /Require rework or machining /Rejected or non-compliant

- Tagging and labeling all parts with clear identification.
- Staging accepted parts in a clean, designated assembly area.

This ensures only compliant components are used in the reassembly process.

Fig IV.9. Checking spare parts and segregation.

IV.3.14. Complete dismantling of the pump:

This task involves thecomplete disassembly of the pump, separating all rotating and stationary elements to allow for thorough inspection and repair. The operation takes approximately 12 hours due to the number of components and precision required. Key steps:

- Securing the pump on a stable workshop stand.
- Removing the casing cover and systematically dismantling:

Pump casing/Impeller(s)/Shaft/Wear rings/Bearings/Shaft sleeve/Mechanical seal or packing

- Using precision tools to avoid damaging sealing surfaces or alignment faces.

IV.3.15. Cleaning of spare parts:

This task involves cleaning all spare and dismantled pump parts prior to inspection or reassembly. The process takes around 7.5 hours, depending on the number, size, and condition of the components. Key steps:

- Sorting parts by material and sensitivity.
- Applying suitable cleaning agents (solvents, degreasers, non-corrosive solutions).
- Cleaning manually with brushes or using pressurized systems or ultrasonic baths.
- Drying parts with compressed air or in a moisture-controlled environment.

- Performing visual checks to confirm cleanliness.
- Storing parts in a clean, dust-free area until further use.

Proper cleaning is essential to avoid contamination and ensure accurate inspection and reliable performance.

Fig IV.10. Cleaning of spare parts.

IV.3.16. Inspection of spare parts:

This task involves the inspection of spare parts after cleaning, to verify dimensional accuracy and surface integrity prior to reassembly. The process takes approximately 3 hours, and is carried out using precision instruments.Key steps :

- Measuring critical dimensions (diameter, length, clearance) using calipers, micrometers, or CMM tools.
- Performing visual inspection for wear, scratches, cracks, or deformation.
- Verifying material specifications and surface finish against OEM standards.

IV.3.17.Inspection report:

This task consists of preparing the Inspection report following the detailed examination of all spare parts. It summarizes the condition and conformity status of each component. Duration : 1.5 hours.Keysteps :

- Collecting dimensional and visual inspection results.
- Completing the official inspection report form (digital or paper-based).
- Classifying each part (Accepted / Requires Repair / Rejected).
- Report approval by the maintenance supervisor or engineer.
- Archiving the report as part of the maintenance documentation.

This ensures traceability and supports decision-making for repair or replacement.

IV.3.18. Replacement of damaged spare parts and gold tolerance parts:

This task involves replacing all damaged or out-of-tolerance spare parts identified during inspection to ensure the pump operates safely and efficiently. The process lasts approximately 10.5 hours, requiring precise installation and verification.Key steps:

- Reviewing the inspection report to identify parts to be replaced.
- Carefully removing damaged components without harming adjacent parts.
- Preparing and verifying new spare parts for conformity.
- Installing new parts following OEM guidelines and tolerance limits.
- Checking alignment and fitting of seals, rings, and gaskets.

IV.3.19. Wear rings (impeller, impeller, channel rings and diffuser):

This task involves the machining and refurbishment of wear rings, including the impeller, wear rings, and diffuser components. Precision machining is performed to restore original dimensions and tolerances, thereby enhancing component life and pump efficiency. Duration : approximately 11 hours**.**Key steps :

- Mounting parts on precision machining equipment (milling or grinding machines).
- Setting machining parameters according to OEM tolerance specifications.
- Performing fine machining to remove wear, deformation, or surface damage.
- Conducting dimensional checks using precision measurement tools (micrometers, CMM).

- Cleaning parts and preparing them for reassembly.

IV.3.20. Impeller balancing:

This task involves the dynamic balancing of the pump impeller to ensure smooth rotation and prevent premature mechanical failure caused by vibrations.

For this specific case, the impeller was transported to Setif city, where specialized balancing equipment and technical expertise are available to perform the procedure with high precision. The process takesapproximately 11.5 hours**.** Key steps :

- Preparing and transporting the impeller to the balancing workshop in Setif.
- Mounting the impeller on a dynamic balancing machine.
- Rotating at operational speeds to simulate real working conditions.
- Measuring vibrations and unbalance points using precise sensors.
- Adjusting balance by adding or removing small weights.
- Retesting to verify balance within acceptable limits.

IV.3.21. Rotor assembly and balancing:

This task involves the assembly of rotor components (impeller, shaft, rings, etc.) and performing a dynamic balance to ensure smooth, vibration-free rotation within the pump. Estimated duration: 3.5 hours.Key steps:

- Assembling all rotor components following OEM specifications.
- Verifying alignment and securing parts properly.
- Mounting the rotor on a dynamic balancing machine.
- Performing balance correction as needed.

- Using precision measurement tools to validate results.

Fig IV.11. Rotor assembly.

IV.3.22. Reassembly of the pump in accordance with the pump manufacturer's recommended:

This task involves reassembling the pump in full compliance with the manufacturer's recommended clearances and torque specifications. It ensures mechanical integrity and optimal operational performance. Estimated duration: 1.5 hour. Key steps:

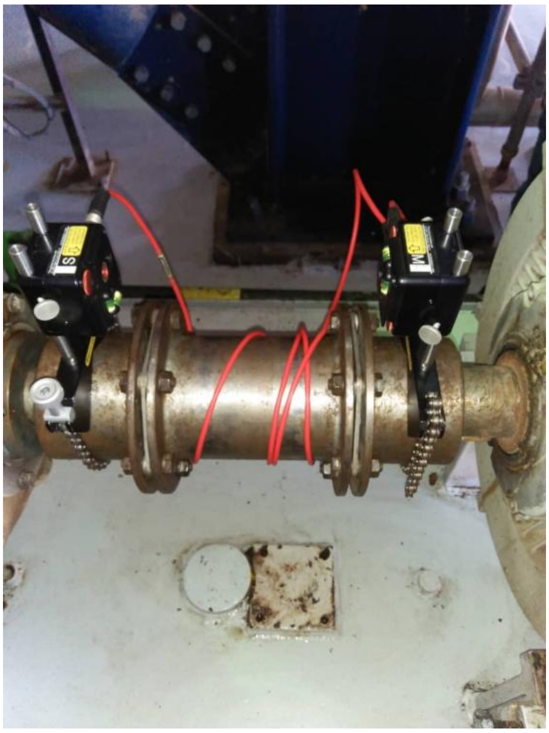
- Installing the rotor and internal components with precision.
- Verifying radial and axial clearances using precision gauges (e.g., feeler gauges).
- Applying the correct torque values to all fasteners using calibrated torque wrenches.
- Ensuring smooth rotor rotation post-assembly.

Fig IV.12. The pump manufacturer's recommended.

IV.3.23. Pre-alignment:

The pre-alignment process ensures initial angular and parallel alignment between the pump and motor shafts before final coupling. It is critical to minimize vibration, wear, and energy loss. Estimated duration: 4 hours.Key steps :

- Securing the base of the pump and motor.
- Using alignment tools (e.g., dial indicators or laser alignment systems).
- Measuring angular and parallel misalignment.
- Adjusting motor or pump position with shims or screw adjustments.



- Verifying results.

Fig IV.13. Pre-alignment.

IV.3.24. Reassembling the auxiliary pipework:

This task involves reinstalling the auxiliary piping systems associated with the pump, including cooling lines, drain piping, and lubrication circuits. These systems are essential for safe and efficient pump operation. Estimated duration : 4 hours.Keysteps :

- Identifying all auxiliary connection points based on technical drawings.

- Installing pipes, flanges, gaskets, and valves with proper alignment.
- Ensuring all joints are tightened and leak-free.
- Reconnecting sensors or instruments linked to the piping.
- Cleaning and inspecting lines prior to startup.

IV.3.25. Direction of motor rotation:

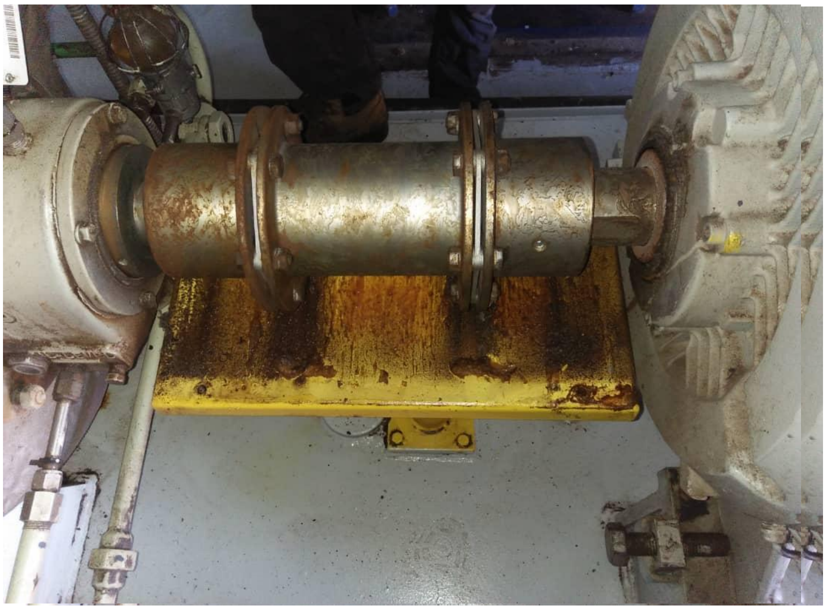
Verifying the motor rotation direction is a critical step before final coupling with the pump. This ensures the motor shaft rotates in the correct direction as specified by the pump manufacturer. Incorrect rotation can cause hydraulic damage. Estimated duration: 1 hour. Key steps:

- Coordinate with control room to run the motor briefly (dry run).
- Observe shaft rotation direction and compare with directional arrow on housing.
- If rotation is incorrect, swap two of the power supply phases (L1, L2, L3).
- Recheck rotation after adjustment.

IV.3.26. Pumpcoupling :

This task involves the mechanical coupling of the pump shaft and the motor shaft using a precision coupling. Accurate alignment and secure fastening are crucial for efficient power transmission and to prevent vibration or premature wear. Estimated time : **3 hours**.Key steps :

- Cleaning the coupling surfaces and components.
- Installing the coupling halves on both shafts.
- Securing bolts and tightening them to the specified torque.
- Checking axial and radial alignment (gap and offset) using feeler gauges or dial indicators.



- Manually rotating the shaft assembly to ensure smooth, friction-free motion.

Fig IV.14. Pump coupling.

IV.3.27. Filling and leakage check:

This task involves filling the pump system with the required fluids (lubricating oil, coolant, or process fluid), followed by a leak tightness verification. The process may take up to 11 hours due to the complexity of the system and the time needed for pressure testing and observation.Key steps :

- Ensure all valves and seals are correctly closed.
- Fill the appropriate fluids as per manufacturer recommendations.
- Perform air bleeding to remove trapped air in the system.
- Pressurize the system and inspect all flanges, gaskets, and connections.
- Detect leaks using cloth, sensors, or visual inspection.

IV.3.28. Maintenance report:

This task involves drafting the final maintenance report for the pump, summarizing all interventions, inspections, and parts replacements. The report is a critical document for quality assurance, compliance, and traceability. Estimated time : 7.5 hours.Report contents include :

- Pump identification data (tag number, location, date).
- Chronological description of all maintenance tasks performed.
- Names of technicians and supervisors involved.
- List of spare parts replaced (with reference numbers and condition).
- Inspection and test results (vibration readings, pressure tests, etc.).
- Technicalcomments and future recommendations.
- Final validation and signatures.

IV.3.29. Startup pump:

The pump start-up phase marks the controlled reactivation of the system following maintenance. It must follow a step-by-step protocol to ensure proper operation and to detect anomalies early. The process typicallylasts1 hour.Keysteps :

- Confirm readiness of all support systems (electrical, lubrication, cooling).
- Verify motor rotation direction one final time.
- Start the pump gradually while monitoring key parameters (pressure, flow rate, vibration).
- Check for any leaks, unusual noises, or abnormal readings.
- Log operational data and observations in the start-up checklist.

IV.3.30. Pump function test:

The pump performance test is conducted post start-up to verify that the unit is operating within its design parameters. The test lasts approximately 4 hours and includes monitoring of hydraulic and mechanical behavior under standard or simulated load conditions. Key steps:

- Operate the pump under nominal or simulated operating conditions.
- Continuously monitor pressure, flow rate, vibration levels, and temperature.
- Ensure operational stability and absence of irregular behavior or noise.
- Compare performance against OEM specifications.

IV.3.31. Pump flow test:

This task involves measuring and analyzing vibration levels of the pump using specialized vibration analyzers. It aims to assess the condition of internal components and detect early signs of mechanical faults such as imbalance or bearing wear. The estimated time is 2.5 hours. Key steps:

- Installing vibration sensors at specified pump locations.
- Recording vibration data during operation under varying loads.
- Analyzing data to identify abnormal frequencies and vibration amplitudes.
- Comparing findings against equipment reference standards.

IV.3.32. Final report:

This task involves compiling and finalizing the comprehensive report documenting all phases of pump maintenance, from preparation through execution, inspections, and final testing. This final report serves as an official reference for technical assessment, traceability, and quality assurance.

Reports contents:

- Comprehensive summary of maintenance activities performed.
- Inspection and test data (vibration, pressure, flow, etc.).
- Lists of replaced and used spare parts.
- Technical recommendations for future maintenance.
- Signatures from responsible personnel and technicians.

IV.4. Establishment of the PERT network:

To enhance the utilization of time and human resources during maintenance operations, several compatible tasks can be grouped and executed simultaneously by specialized teams. Each team focuses on its specific scope (electrical, mechanical, instrumentation). Therefore, a coordination table has been created to summarize and organize this integrated approach.

IV.4. 1.Create the table containing the tasks, their duration, predecessors, and successors:

Table IV.2. Task ID and its duration.

ID	Task	Duration (h)
A1	- Work Permit Preparation.	1,5
A2-6	-Isolation and disconnection of the motor and instrumentation.	1,5
A7-10	- Draining of bearings and disconnection of process piping.	8,5
A11-13	-Motor-pump uncoupling, dismantling, and sorting of spare parts.	5,5
A14	-Complete dismantling of the pump.	12
A15	-Cleaning of spare parts.	7,5
A16	-Inspection of spare parts.	3
A17	-Inspection report.	1,5
A18	-Replacement of damaged spare parts and gold tolerance parts.	10,5
A19	-Wear rings (impeller, impeller, channel rings and diffuser).	11
A20	-Impeller balancing.	11,5
A21-24 -	-Rotor assembly, pump reassembly, pre-alignment, and auxiliary piping reconnection.	15
A25-27	-Rotation check, coupling, and leak testing	11
A28	- Maintenance report.	1
A29	- Start up pump.	7,5
A30	- Pump function test.	4
A31	- Pump flow test.	2,5
A32	- Final report.	7,5

Table IV. 3. Task predecessors, task duration, and successor tasks.

Task ID	Predecessor	Successor	Duration (h)
A1	/	A2-6	1.5
A2-6	A1	A7-10	1.5
A7-10	A2-6	A11-13	8.5

A11-13	A7-10	A14 / A15 / A16	5.5
A14	A11-13	A17	12
A15	A11-13	A18 / A16	7.5
A16	A11-13	A18	3
A17	A14	A19 / A20	1.5
A18	A15 / A16	A19 / A20	10.5
A19	A17 / A18	A21-24	11
A20	A17 / A18	A21-24	11.5
A21-24	A19 / A20	A25-27	15
A25-27	A21-24	A28 / A30 / A31	11
A28	A25-27	A29	1
A29	A28	A31	7.5
A30	A25-27	A32	4
A31	A25-27	A32	2.5
A32	A28 / A29 / A30 / A31	/	7.5

Based on the table **Table IV. 3,** we have constructed the classical PERT network.

IV.4.2. PERT network:

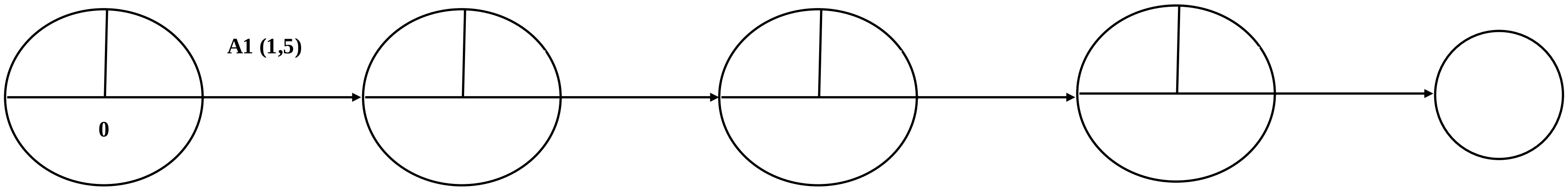


Fig IV.15. Section 1 of the path.

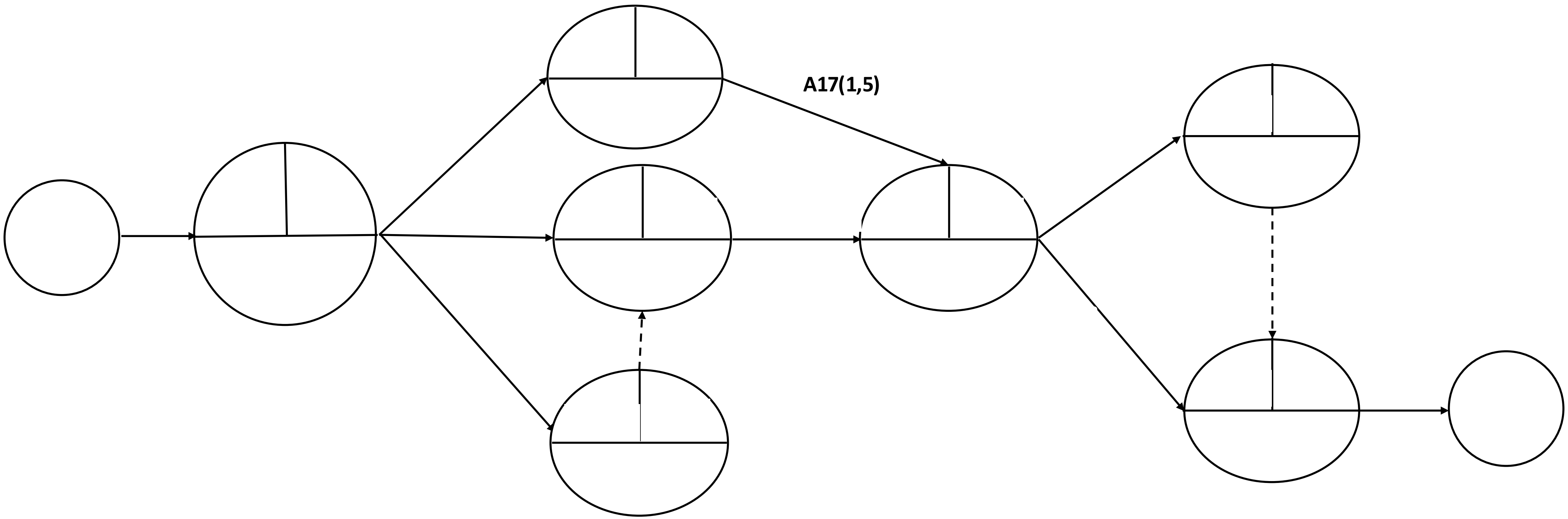


Fig IV.16. Section 2 of the path.

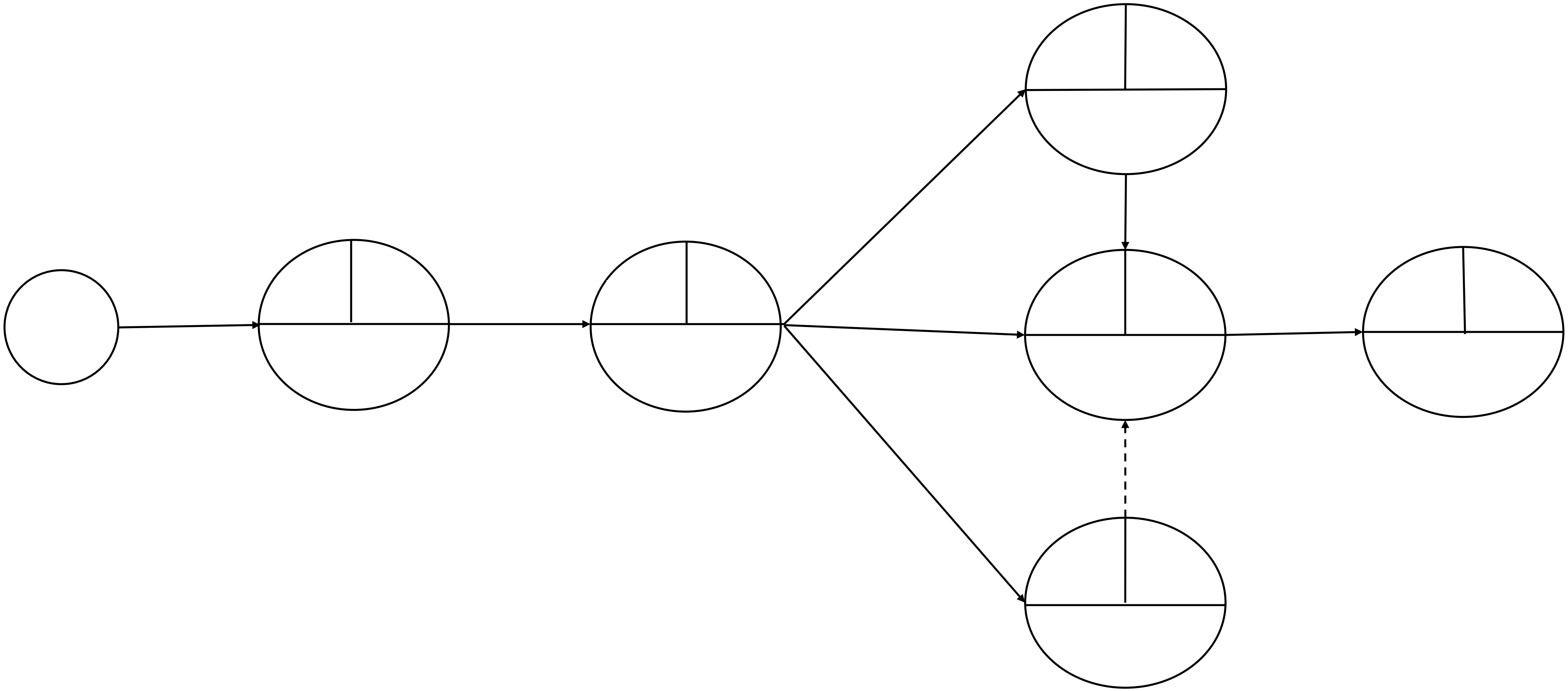


Fig IV.17. Section 3 of the path.

IV.4. 3.Critical Path:

After calculating the earliest and latest start times, we can determine the critical path, where the earliest and latest dates are equal (the critical path is shown in red).

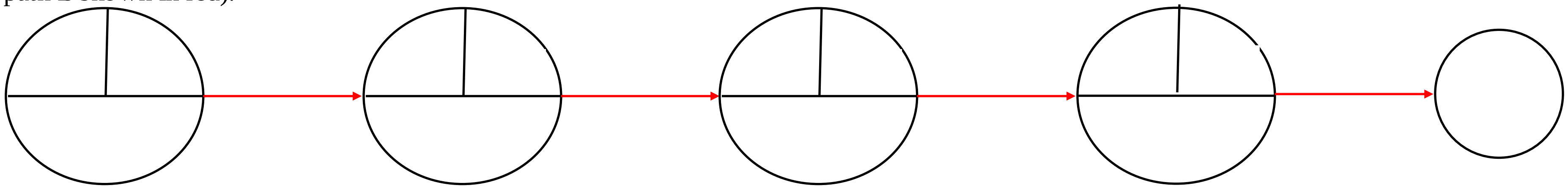


Fig IV.18. Section 1 of thecriticlpath.

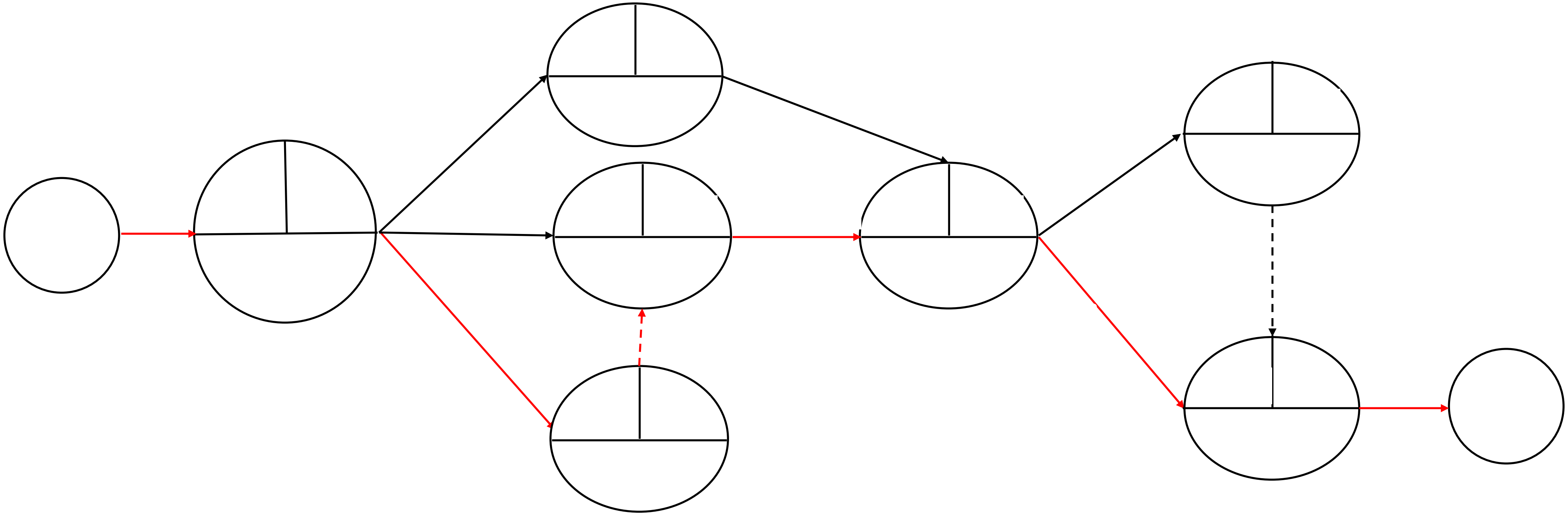


Fig IV.19. Section 2 of thecriticlpath.

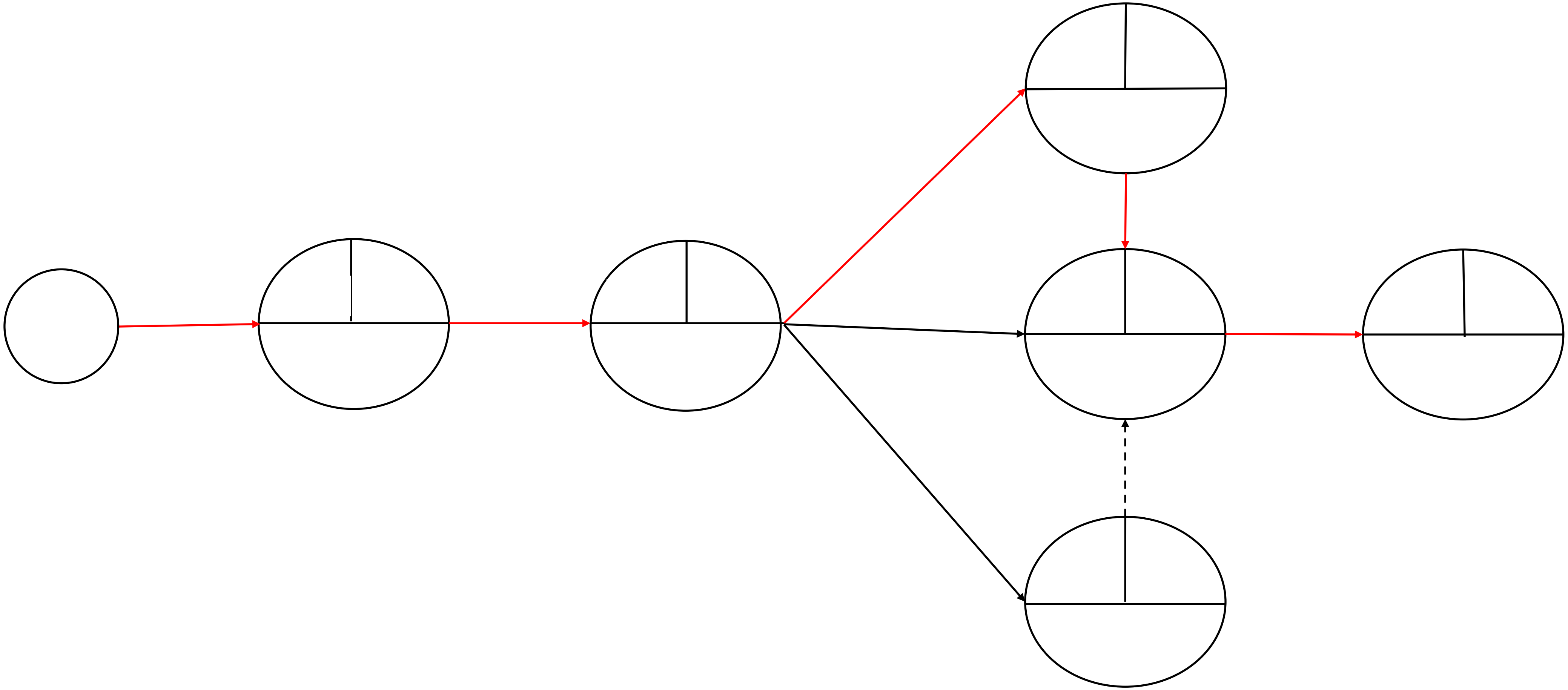


Fig IV.20. Section 3 of thecriticlpath.

- The total duration of the project is 88 hours.
- The critical path is A1/A2-6/A11-13/A16/A16’(0)/A18/A20/A21-24/A25-27/A28/29/32.

In the projects studied under conditions of uncertainty and within a probabilistic framework, we assumed that each project path is independent from the others. In such cases, the activities of each path appear solely within that path, and no activity is shared among two or more different paths.

However, when paths share a common task, they become interdependent. As a result, the duration of each path is partially influenced by the duration of the others.

Therefore, we will apply the probabilistic PERT method.To accurately identify critical tasks and paths.

IV.5. The probabilistic PERT method:

IV.5. 1.Creating table: First, create a table that includes the optimistic, pessimistic, and most likely durations in Excel.

Table IV.4. includes the optimistic, pessimistic, and most likely durations in Excel.

Task	Opt	M	Pess
A1	1	1,5	2,5
A2-6	1	1,5	4
A7-10	7	8,5	14
A11-13	4	5,5	10
A14	9	12	18
A15	5,5	7,5	11,5
A16	2	3	5
A17	1	1,5	3
A18	7,5	10,5	15
A19	8	11	16
A20	10	11,5	24
A21-24	12	15	24
A25-27	10	11	17
A28	0,75	1	1,5
A29	5,5	7,5	11,5
A30	3	4	6
A31	1,5	2,5	4
A32	7	7,5	12

Where:

Opt : stands for optimistic,

M: for most likely,

And Pess: for pessimistic.

Add to the table:K, U, and d.

K :Constant. $\boldsymbol{K} = \frac{\boldsymbol{M-opt}}{\boldsymbol{pess-opt}}$

U= RAND ()is a pure random number in the interval (0, 1).

d:The triangular distribution is a probability distribution used to model uncertain durations when only three estimates are known:

(Opt), (Pess), (M).

Its probability density forms a triangle with a peak at the most likely value. This distribution is often applied in Monte Carlo simulations to generate random activity durations in project planning.

In its inverse form, a uniform random variable U between 0 and 1, and a constant K (representing the relative location of the mode within [opt,pess][opt, pess][opt,pess]) are used to calculate the simulated duration d.

$$d = \mathrm{if\ U < K\ \ (pess - (pess - opt)\sqrt{(1 - U)(1 - K)}), (opt + (pess - opt)\sqrt{UK}, if\ U \leq K)}$$

Table IV.5. Results of calculating.

Task	Opt	M	Pess	K	U	D
A1	1	1,5	2,5	0,333333333	0,341498449	1,506142703
A2-6	1	1,5	4	0,166666667	0,82807111	2,86445314
A7-10	7	8,5	14	0,214285714	0,550567622	9,840294896
A11-13	4	5,5	10	0,25	0,62682691	6,825779869
A14	9	12	18	0,333333333	0,803938182	14,74618098
A15	5,5	7,5	11,5	0,333333333	0,13369551	6,766627855
A16	2	3	5	0,333333333	0,502050172	3,271503843
A17	1	1,5	3	0,25	0,63577732	1,95469237
A18	7,5	10,5	15	0,4	0,975983762	14,0996956
A19	8	11	16	0,375	0,251292511	10,45581356
A20	10	11,5	24	0,107142857	0,764730461	17,58344568
A21-24	12	15	24	0,25	0,751834891	18,82295145
A25-27	10	11	17	0,142857143	0,97697055	16,01651797
A28	0,75	1	1,5	0,333333333	0,276079745	0,977519125
A29	5,5	7,5	11,5	0,333333333	0,640932512	8,564421742
A30	3	4	6	0,333333333	0,921437084	5,313430633
A31	1,5	2,5	4	0,4	0,175119967	2,161664505
A32	7	7,5	12	0,1	0,220294994	7,811520248

IV.5.2.Executing the simulation by pressing the F9 key in Excel:

We constructed a table that, for each path in the PERT network, indicates the duration in hours, the path length, and whether or not it is critical. For each path, the total duration is calculated by summing the durations of the corresponding activity cells.

The project duration corresponds to the duration of the longest path, which is also the critical path. This duration is computed as the maximum of all path durations in the network.

Thus, we simply selected the maximum value among all calculated durations.

If a path's duration is equal to the project duration, then that path is identified as critical.In the third column, we used a conditional formula:if the path duration equals the project duration, the cell displays 1 (true), indicating a criticalpath; otherwise, it displays 0 (false), indicating a non-critical path.

This analysis is conducted through dynamic simulation using the F9 key in Excel.

Table IV.6. Simulation Table.

ID	Path	Lenth	Criticl
1	A1A2-6A7-10A11-13A14A17A19A19'(0)A21-24A25-27A28A29A32	107,3382895	0
2	A1A2-6A7-10A11-13A14A17A20A21-24A25-27A28A29A32	107,6538904	0
3	A1A2-6A7-10A11-13A14A17A19A19'(0)A21-24A25-27A30A32	101,0463647	0
4	A1A2-6A7-10A11-13A14A17A20A21-24A25-27A30A32	101,3619655	0
5	A1A2-6A7-10A11-13A14A17A19A19'(0)A21-24A25-27A31A31'(0)A32	97,59363033	0
6	A1A2-6A7-10A11-13A14A17A20A21-24A25-27A31A31'(0)A32	97,90923116	0
7	A1A2-6A7-10A11-13A15A18A19A19'(0)A21-24A25-27A28A29A32	112,8044872	0
8	A1A2-6A7-10A11-13A15A18A20A21-24A25-27A28A29A32	113,1200881	1
9	A1A2-6A7-10A11-13A15A18A19A19'(0)A21-24A25-27A30A32	106,5125624	0
10	A1A2-6A7-10A11-13A15A18A20A21-24A25-27A30A32	106,8281632	0
11	A1A2-6A7-10A11-13A15A18A19A19'(0)A21-24A25-27A31A31'(0)A32	103,059828	0
12	A1A2-6A7-10A11-13A15A18A20A21-24A25-27A31A31'(0)A32	103,3754289	0
13	A1A2-6A7-10A11-13A16A16'(0)A18A19A19'(0)A21-24A25-27A28A29A32	105,8593472	0
14	A1A2-6A7-10A11-13A16A16'(0)A18A20A21-24A25-27A28A29A32	106,174948	0
15	A1A2-6A7-10A11-13A16A16'(0)A18A19A19'(0)A21-24A25-27A30A32	99,56742236	0
16	A1A2-6A7-10A11-13A16A16'(0)A18A20A21-24A25-27A30A32	99,8830232	0
17	A1A2-6A7-10A11-13A16A16'(0)A18A19A19'(0)A21-24A25-27A31A31'(0)A32	96,11468801	0
18	A1A2-6A7-10A11-13A16A16'(0)A18A20A21-24A25-27A31A31'(0)A32	96,43028884	0
	Project duration	113,1200881	

IV.5.3.Calculate the percentage of simulation cases in which each path appears as the critical path: We conducted 1000 simulations to calculate the percentage of occurrences for each path as the critical path.

Table IV.7. Path and degree of criticality.

Path	Criticity
1	0.60%
2	10.40%
3	0.00%
4	0.00%
5	0.00%
6	0.00%
7	21.50%
8	62.60%
9	0.00%
10	28%
11	0.00%
12	0.00%
13	0.00%
14	21%
15	0.00%
16	0.00%
17	0.00%
18	0.00%

IV.5.4.Calculate the percentage of simulation cases in which each task appears as the critical task:

By identifying the critical path, the critical tasks that directly affect the project duration can be determined.

Table IV.8 Task and degree of criticality.

Task	Criticity
A1	100%
A2-6	100%
A7-10	100%
A11-13	100%
A14	11%
A15	86.90%
A16	2.10%
A17	11%
A18	29%
A19	22.10%
A20	75.80%
A21-24	100%
A25-27	100%
A28	97.20%
A29	97.20%
A30	2.80%
A31	0.00%
A32	100%

IV.6.Analysis:

IV.6.1. Criticl path:

The histogram generated from the time analysis displays the percentage likelihood that each path in the project may be critical.
Each bar in the histogram represents a specific path, and its height reflects how frequently that path appears as critical during simulation or schedule analysis.

Paths with high percentages indicate areas that require strict and continuous monitoring, due to their strong influence on the total project duration.
Conversely, paths with low probabilities are considered less critical, but should not be completely disregarded, especially in dynamic project environments.

The path:
A1 → A2–6 → A7–10 → A11–13 → A15 → A18 → A20 → A21–24 → A25–27 → A28 → A29 → A32
is identified as the most likely critical path in the project. It requires close supervision during execution, as any delay in its activities will directly extend the overall project timeline.

Paths 7, 10, and 14 are non-critical in most scenarios, but may become critical if certain activities are delayed or others are accelerated. Therefore, they should be subject to moderate monitoring, particularly when they are temporally close to the critical path.

On the other hand, paths 1 and 2 show a very low probability of becoming critical. However, a convergence in path durations could necessitate attention to them in case of changes in project conditions or unforeseen developments.

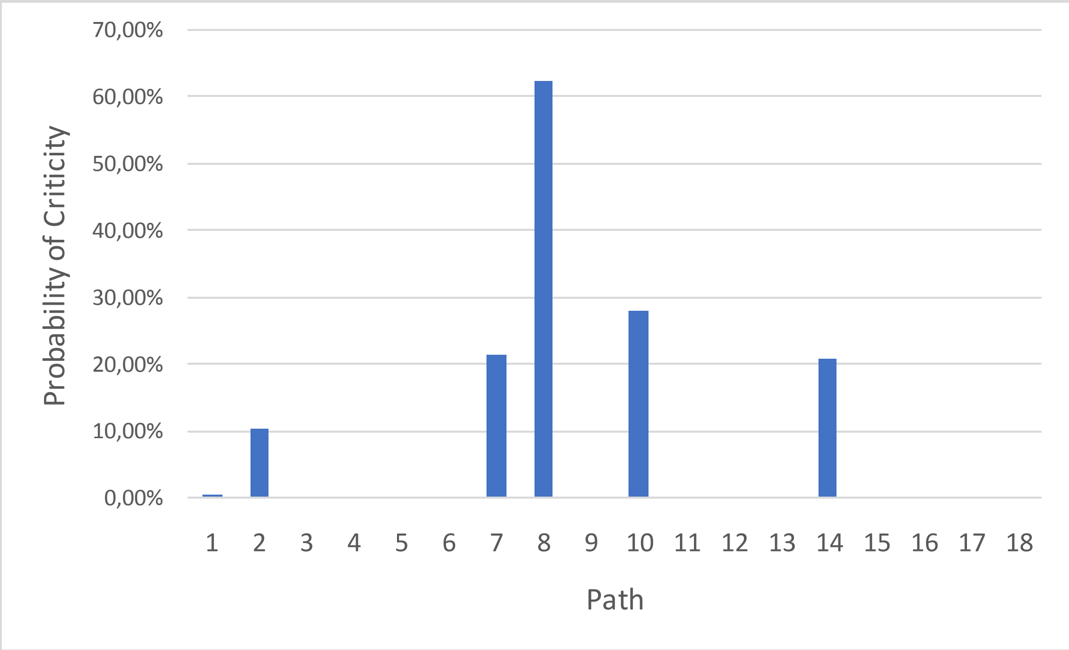


Fig IV.21. The histogram presents the critical paths.

IV.6.2. Criticl Task:

The histogram generated from the time analysis displays the percentage probability that each task in the project is critical.

Each bar in the histogram represents a specific task, and its height indicates how frequently that task appears as critical during simulation or schedule analysis.

The tasks A1, A2–6, A7–10, A11–13, A21–24, A25–27, and A32 are considered the most critical tasks in the project, each showing a 100% probability of being on the critical path. This indicates a direct impact on the total project duration and necessitates strict monitoring.

In contrast, tasks A15, A20, A28, and A29 are moderately critical, with probabilities ranging between 75% and 97%, suggesting the need for regular but less intensive supervision.

All remaining tasks show very low criticality, while task A31 has a zero probability of being critical.

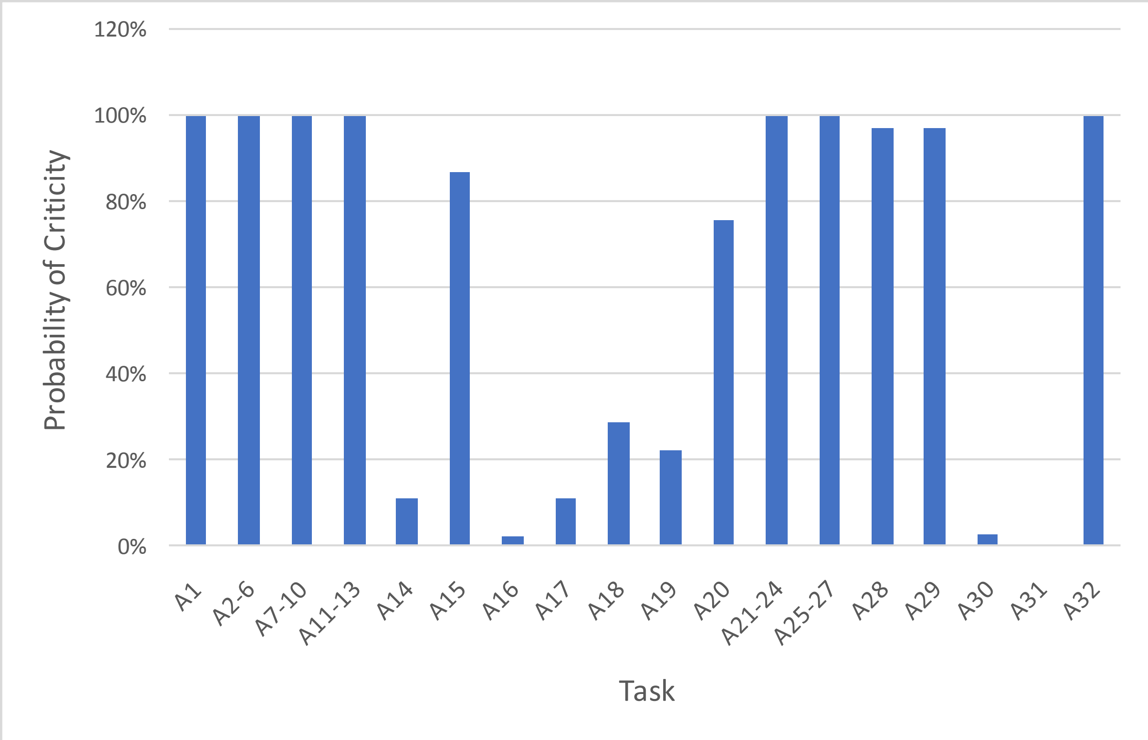


Fig IV.22. The histogram presents the critical tasks.

Conclusion:

In this chapter, we examined the PERT method in its probabilistic form, which enables the management of projects under uncertainty. We developed tables incorporating optimistic, most likely, and pessimistic durations for each task, and employed simulation techniques in Excel to obtain empirical results that allow for the analysis of the final project duration distribution.

Based on the data collected and the simulations performed in Excel using the probabilistic PERT approach, it became evident that multiple critical tasks and critical paths can exist simultaneously. The simulation results demonstrated that any delay in a critical task directly results in a delay in the overall project completion.

These findings highlight the importance of closely monitoring critical paths and offer quantitative indicators that improve the accuracy of schedule estimation, thereby enhancing the management of time-related risks and optimizing resource planning.

General Conclusion

General conclusion:

At the end of this work, we emphasize the growing importance of employing mathematical models and simulation techniques in the management and maintenance of projects, particularly in industrial environments characterized by complexity and uncertainty. The application of the probabilistic PERT method, combined with simulation using Excel, has demonstrated its capability to provide accurate analytical tools for more realistic estimation of project durations and for the precise identification of critical tasks and paths that directly affect project deadlines.

This study represents a first step toward the wider adoption of probabilistic methods in industrial project management and opens new avenues for future research. These could include the integration of advanced tools such as linear programming, risk analysis, and overall organizational performance.

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