



Analysis of Time and Cost Planning and Control for Waterproofing Work in Project X Multi-Story Data Center Jakarta

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Abstract

Waterproofing plays a crucial role in maintaining a building's integrity. However, subcontractor skill limitations and project constraints such as design changes, site readiness, and resource shortages often cause delays. This study analyses the planning and time control of waterproofing work in the Building X High-Rise Data Center project, covering eight work items. Using the Precedence Diagram Method (PDM), the work schedule indicates an effective duration of 34 weeks. The analysis methods used include Critical Path Method (CPM), Earned Value Analysis (EVA), Program Evaluation Review Technique (PERT), and crashing for project duration optimization. By the 30th week, the calculation results showed a Schedule Performance Index (SPI) of 0.96 and a Schedule Variance (SV) of -Rp120,057,209.0, indicating project schedule delays. In terms of cost, the Cost Performance Index (CPI) was 0.99, and the Cost Variance (CV) was -Rp26,459,888.0, showing cost overruns, though still within a relatively controlled limit. The probability of project completion reached 90% by the 30th week. Optimization through acceleration methods proved effective in reducing project duration with controlled additional costs. Therefore, better mitigation strategies are needed to minimize time and cost deviations in similar future projects.

Introduction

The construction of data center high-rise buildings is becoming increasingly important to support the growing needs of urban infrastructure and Information Technology. Behind this progress, however, lies the inevitable challenge of ensuring the structural sustainability and reliability of such buildings. Waterproofing works in the construction of data center multi-storey buildings have a crucial role in ensuring the durability and reliability of building structures, because failures in waterproofing can cause significant damage and losses such as downtime. Data center downtime can have a serious impact on data center operations, financial losses, security and data loss risks, and company reputation. While downtime may only affect specific systems and departments, such connectivity issues may not be immediately apparent to the rest of the organization's network (Larsen, Rao, & Sasangohar, 2020). The role of waterproofing becomes very strategic because data center buildings have sensitive spaces such as server rooms, high-priced electronic devices, and cooling systems that are susceptible to moisture. Waterproofing is required for balconies, whether made of wood or concrete (Borle & Ghadge, 2016). If the waterproofing work is not done properly or neglected, various threats can occur and the waterproofing subcontractor is responsible for

the execution of this work. However, often found some problems from subcontractors waterproofing, such as lack of expertise and experience when faced with certain conditions, such as changes, unpreparedness of the location to be done, so that they have limited time, energy, and costs in pursuit of a predetermined schedule, which dikhawatrikan reduce the quality of the waterproofing work. The wrong approach to waterproofing or improper installation of a waterproofing system can result in severe damage to the building structure, as well as high maintenance and repair costs (Luciani & Peila, 2019). In addition, poor communication between the main contractor and subcontractors leads to misunderstanding and misinterpretation of information, resulting in project inefficiencies and delays. In (Asmi et al., 2016), mentioned that there are five significant factors that most affect delays in construction activities, namely frequent design changes, financial difficulties of the owner, late payment of progress by the owner, schedule delays, and incompetent subcontractors. Thus, this study will try to overcome the problems in controlling the schedule.

This study will analyze in depth how the planning and control of time on subcontractors waterproofing. With planning and control, monitoring can be carried out on every activity that takes place in the project, ranging from costs to a certain time. This control also aims to maintain the quality of the field work implementation process, and encourage the possibility of accelerating the work process so that it can be completed as quickly as possible. In planning a project activity, the Critical Path Method (CPM) can be used to obtain a critical network of project activities, so that time is used more effectively. Critical Path Method can be done to do project planning and scheduling (Atin & Lubis, 2019). After that, Earned Value Analysis (EVA) can be applied to control project activities in accordance with the planned budget and time. Earned Value Analysis (EVA) is a method that has gained traction in several business sectors to report project progress and help control performance (Nouban, Alijl & Tawalbeh, 2020). The Program Evaluation and Review Technique (PERT) method can also be used to calculate the probability of completion of project activities, given the uncertainty in scheduling. Program Evaluation and Review Technique (PERT) is a method of Program Analysis and evaluation, which is based on the time estimation of three activities (Mishakova, Vakhrushkina, Anishchenko, & Tatarikina, 2017). In addition, if in the process of implementation there are activities that deviate from the schedule, the acceleration of time can be carried out using the Crashing method. With this method, the completion time can be accelerated, although there are additional costs or working hours to accelerate project activities.

By gaining a deeper understanding of the factors affecting waterproofing project activities, this study is expected to contribute to the improvement of the construction process, especially in terms of risk control, efficiency improvement, and Budget Optimization. This research is expected to also be the basis for the development of more effective strategies in overcoming the challenges of waterproofing work on data center high-rise building projects in the future.

Project Management

Project management is a discipline that involves planning, organizing, managing and controlling resources to achieve specific and measurable objectives, according to established success criteria. The project management framework includes five main phases: initiation, planning, execution, monitoring, and closure. Project Management serves to ensure that projects are completed on time, within budget, and with the expected quality. Project management efforts are coordinated to achieve specific goals or perform specific functions (Pollack, 2007). Project management as a managerial activity necessary to lead a project to a successful end . According to (Project Management Institute, 2017) this approach helps identify and manage risks, allocate resources efficiently, and communicate effectively with all stakeholders. Another understanding of (Lewis, 2011) that project management includes the implementation and integration of project management processes consisting of initiating,

planning, implementing, monitoring and controlling activities to be in accordance with project objectives. Project management approaches derived from best practices in the defense/aerospace, construction, and pharmaceutical industries during the early 1970s have proven effective for managing a small number of large projects in the relatively stable political, economic, and technological context of the post-World War II period (Levitt, 2011). Therefore, project management seems to be the right solution to the integration problems posed by these activities (Lenfle, 2008). In project management, time management has an important role in determining the success of a project. The success of a project is often judged on the ability to complete the project as quickly as possible with the least possible cost, while maintaining quality. Identifying and characterizing different aspects of project complexity in order to understand more efficiently the risks of project management complexity can provide great support in helping the global project management community (San Cristóbal, Carral, Diaz, Fraguera, & Iglesias, 2018). The main distinguishing feature of the project management approach is the division between traditional and Agile Project Management, which differ fundamentally in their structure and processes (Reiff & Schlegel, 2022).

Project Planning And Scheduling

Project planning is the process of defining project objectives as well as the steps required to achieve them. Project scheduling, which is part of planning, sets the timeline and sequence of activities required to complete the project. Project planning and scheduling aims at timely execution of works according to the planned schedule of the project and can implement corrective actions in case of time lapses (Sharanyasreenivas, Gajalakshmi, & Theja, 2017). Effective scheduling techniques help identify critical paths, manage resources, and reduce the risk of delays. Tools such as Gantt charts and network diagrams are often used in this process. Good planning and scheduling allows project managers to anticipate and overcome obstacles before they become major problems (Godfrey, 1996).

Project Cost And Time Control

Project cost and time control is a process that involves measuring the actual performance of the project against the plan, as well as taking the necessary corrective actions to address deviations. This process includes monitoring the costs incurred and the time spent, comparing them with the established budget and schedule, as well as making the necessary adjustments. Currently, the accuracy of cost assessment and cost control is an inclusive issue that hinders the effective completion of development projects (Abdel-Hamid & Abdelhaleem, 2023). Techniques such as Earned Value Management (EVM) are often used to integrate cost and time control, thus providing a more holistic picture of project performance (Kerzner, 2009).

Project Planning And Control Methods

Some common methods used for Project Planning and control include the Critical Path Method (CPM), Earned Value Analysis (EVA), and Program Evaluation and Review Technique (PERT). Each of these methods has specific advantages and applications according to the needs of the project. Critical Path Method (CPM): provides a sequence-based deterministic approach to critical activities. Although widely used, CPM takes less into account the uncertainty of the field. Earned Value Analysis (EVA): integrates cost and time aspects, using indicators such as SV, SPI, CV, and CPI. This study utilizes EVA to monitor the effectiveness of waterproofing implementation against the initial project plan. Program Evaluation and Review Technique (PERT): offers a probabilistic approach that takes into account the uncertainty of activity time. In the context of high-risk projects such as data center construction, PERT provides added value in realistic schedule predictions. Factors causing delays: project delays are divided into three types: Non-Excusable Delays (implementing errors such as poor planning and lack of manpower), Excusable Delays (external factors such as natural disasters and socio-political conditions), and Compensable Delays (project owner

errors such as too tight schedules and late payments). Crashing method: Crashing method is used to speed up the project by adding resources, although it increases the cost. The method includes overtime, shift work, adding personnel or tools, and alternative work methods. Its main focus is on critical pathways to keep projects completed on time with optimal duration and cost. Fishbone diagrams: Fishbone diagrams help to systematically identify the root cause of a problem through categories such as machine, method, material, labor, measurement, and environment. This method is effective for problem analysis and making the right decisions in the project.

Risk Management

Risk management theory emphasizes the process of identifying, analyzing, and handling project risks to reduce negative impacts and increase the chances of success (PMI, 2017; Habegger, 2008). Risk management is a systematic approach to reducing the negative consequences of certain phenomena. Approaches that define risk only from a negative perspective can lead to risk aversion (Mohammed & Knapkova, 2016). Risk management is closely related to policy and Policy Analysis. Policies can be defined as principles or plans to guide decisions and achieve desired outcomes, and the term applies to international organizations, governments, private sector organizations and groups, as well as individuals (Aven, 2016). Most countries today fail to establish national risk management plans and strategies, or even if they have, they are unable to implement them effectively (Ahmeti & Vladi, 2017). Previous studies have shown that this strategy is important from the earliest stages of project planning (Karim et al., 2012). The emerging gap is the lack of a specific approach to such a type of technical work as waterproofing, where risks tend to be technical and environmental.

Measurement of Potential Risks

Risk assessment is generally done through probability and impact approaches, combined in a risk matrix (Godfrey, 1996). Although there are risks inherent in risk measurement, the accuracy of risk measurement is expected to be high in practice (Wilkins & Moorhouse, 2023). The latest study (Zahriani, 2023) uses a quantitative approach through the Likert scale and the risk formula ($R = P \times I$), which simplifies risk classification. However, there is still little research that specifically links this scale of risk to cost and time control strategies in waterproof construction projects.

Table 1. Acceptance Rate Of Risk Categories

Value	Category	Description
1-2	Negligible	Can be ignored
3-4	Acceptable	Acceptable
5-12	Undesirable	Not expected, should be avoided
15-25	Unacceptable	Unacceptable, must be eliminated

Source: Godfrey, 1996

Waterproofing

Waterproofing is understood as an integral system in the design of the building envelope to prevent the ingress of water and moisture, as well as extend the life of the building (Senarathne et al., 2023). Good Waterproofing during construction or renovation of a building is essential to avoid infiltration into the building (Gomes, Gomes, & Reis, 2023). The system includes various components and techniques, such as dampproofing, flashing, and waterproofing membranes. Previous research emphasized the importance of proper sheath design (Kubal, 2008), but there are still limited studies linking this system planning to comprehensive time and cost management. Now there is a need to determine the technical condition of the

waterproofing and choose a solution for replacing it with an effective option, taking into account the conditions and design features of a particular object (Sokova & Smirnova, 2018). This opens up opportunities for further study, especially in the context of data center projects that demand high precision.

Multi-Storey Building

In accordance with PP No. 36 of 2005, high-rise buildings are defined as buildings over 8 floors or with a height exceeding 45 meters. These provisions affect aspects of technical planning, including structural systems, safety, and waterproofing integration. Previous studies have rarely highlighted the specifics of cost and time control on the elements of waterproofing work for multi-storey buildings, so it is a relevant gap in this study.

Data Center

Data center (data center) is a crucial facility that manages and stores the company's digital information system. Data centers enable IT solutions to facilitate e-commerce due to their great potential in reducing operational costs (Sun, Ansari, & Wang, 2016). In accordance with (Arregoces, 2004) and (Geng, 2015), data centers require infrastructure with high reliability, temperature control, and protection against moisture. Therefore, the waterproofing system becomes a vital element in preventing operational disruptions due to structural damage. International standards such as ANSI/BICSI 002 and ANSI / TIA-942 emphasize the importance of flexible space planning and precise infrastructure support.

Methods

This study adopted a mixed-methods approach to comprehensively analyze the time and cost planning and control for waterproofing work in a multi-story data center project. The research process was structured into distinct phases: preparation, data collection and implementation, and data processing and analysis.

Preparation Phase

The initial phase involved meticulous preparation, including finalizing the research title and proposal, securing necessary ethical and project-specific arrangements, and developing detailed descriptions of all research activities. Practical preparations for field operations were also undertaken, encompassing the procurement of personal protective equipment, observation instruments and documentation. The overarching aim of this phase was to establish a solid foundation for an in-depth analysis of the determinant factors affecting the schedule and cost realization of waterproofing work in a multi-story data center building.

Collaboration with Specialist Waterproofing Company

A cornerstone of this research was the strategic collaboration with a specialist waterproofing company based in Jakarta. This partnership was formalized through official university letters to ensure mutual understanding, commitment, and adherence to ethical research practices throughout the study. Specifically, the collaboration was documented via: a) For the Research Team: Letter No: 7539/IT2.IX.8/B/TU.00.09/III/2024, titled "Request for Willingness to be a Field Supervisor for Engineering Practice," outlining the research objectives, data requirements, and ethical commitments; b) For the Specialist Waterproofing Company: Letter No: 2477/IT2.IX.8/B/TU.00.09/V/2024, titled "Request for Willingness of Engineering Practice Partners," defining their role in providing access, facilitating interviews, and offering expert insights. This formal arrangement established a clear framework for the exchange of information and expertise, crucial for successfully executing this research.

The company's expert knowledge was integrated directly into the research process from its earliest stages, significantly influencing the research methodology and data collection process. Experts were consistently consulted during the initial formulation of research

questions and the identification of critical variables and factors to study. Their practical experience and in-depth understanding of industry challenges, particularly concerning waterproofing work in high-rise data centers, were crucial in refining the study's scope and ensuring its direct relevance to real-world issues. This direct input led to identifying specific common causes of delays (e.g., design changes related to waterproofing details, site readiness issues impacting membrane application, specific resource shortages for specialized crews or materials) and key cost drivers within waterproofing projects. Furthermore, the company provided direct input in the design and execution of the data collection process. Their project managers and technical specialists were directly involved in developing our research instruments. For instance, their expertise was crucial in refining observation protocols to identify critical aspects of waterproofing application, potential quality control issues, and common on-site challenges. They also helped shape interview questions to elicit relevant insights from project stakeholders, ensuring the questions probed specific pain points related to schedule delays and cost overruns in waterproofing work. They facilitated access to the project, including the site itself and all pertinent project documentation such as baseline schedules, actual progress reports, cost breakdowns, and resource allocation plans. Their team assisted in identifying and coordinating interviews with key personnel, such as site supervisors and quantity surveyors, who possessed firsthand knowledge of the waterproofing activities.

The collaboration was characterized by regular and structured consultations. These engagements typically occurred on a bi-weekly basis and/or during key project milestones throughout the data collection and analysis phases. These discussions provided invaluable contextual understanding of the project's dynamics and the nuances of waterproofing work within the specific context of the project. For example, when analyzing schedule deviations identified through Earned Value Analysis (EVA), the company's insights helped explain specific causes related to subcontractor performance, material delays, or unexpected site conditions. Similarly, their expertise informed the interpretation of cost overruns, allowing the research to differentiate between general project management issues and factors specifically related to the complexities of waterproofing. This continuous dialogue ensured the research remained grounded in real-world project dynamics and that the conclusions drawn were both accurate and realistically applicable to high-rise data center waterproofing projects.

By explicitly detailing the nature and extent of this formal partnership, including the specifics of expert involvement in research design, data collection instrument development, ongoing data interpretation, and validation of findings, this study significantly enhances its credibility and depth. The direct integration of real-world industry expertise ensures the analytical framework and derived conclusions are not merely theoretical but are robustly grounded in practical challenges and operational realities. This rigorous, collaborative approach ultimately strengthens the practical applicability of the study's recommendations, allowing readers particularly industry professionals and project managers to confidently assess and adopt the proposed strategies for optimizing time and cost planning and control in future waterproofing projects.

Data Collection and Implementation Phase

The study's implementation was strategically planned over a 16-week period, ensuring comprehensive data coverage. Both primary and secondary data were systematically collected using a multi-faceted approach: Literature Study: A comprehensive review of academic literature and industry reports was conducted to establish a robust theoretical framework for project planning and control, specifically focusing on critical path management, earned value analysis, program evaluation and review technique, and project crashing. Participatory Observation & Direct Site Observation: The research team conducted on-site observations at

the project. This involved dedicated periods of observation for specific waterproofing activities. Observations focused on capturing empirical data related to the technical implementation of waterproofing works, the real-time dynamics of schedules, the actual allocation and utilization of costs, and on-site resource management (labor, materials, equipment). Detailed observation logs were maintained. In-depth Interviews: Structured and semi-structured interviews were conducted with key project stakeholders, including Site Managers, Supervisors, Quantity Surveyors, and key personnel from the waterproofing subcontractor. These interviews aimed to gather qualitative data on perceptions of project challenges, decision-making processes related to time and cost control, and insights into subcontractor performance. Documentation Review: Secondary data were meticulously collected from project documentation provided by the main contractor and the waterproofing company. This included baseline schedules, actual progress reports, cost breakdown structures, resource loading schedules, and any formal change orders or delay notifications related to waterproofing work.

The core research activities within this phase specifically aimed to: 1) Intensive Supervision and Effectiveness Evaluation: Continuously monitor the actual implementation of waterproofing work against planned activities. This involved evaluating the suitability of execution methods, identifying deviations, and analyzing their direct impact on achieving schedule targets; 2) Detailed Cost Analysis: Conduct a comprehensive review of actual expenditure realization against the established budget. This involved identifying potential deviations, quantifying cost overruns or underruns, and tracing their root causes; 3) Resource Utilization Evaluation: Assess the utilization of both labor and material resources to ensure their adequacy and optimal allocation in supporting the smooth progression of the project schedule. This included analyzing productivity rates and material wastage; 4) Detailed Activity Scheduling Analysis: Develop and analyze detailed activity scheduling arrangements using techniques such as the Precedence Diagram Method (PDM). This involved reviewing work sequences, identifying dependencies, and optimizing time allocation for each activity while anticipating and analyzing potential scheduling conflicts.

Data Processing and Analysis Phase

All collected quantitative and qualitative data were systematically organized, tabulated, and processed. This stage involved a rigorous application of project management analytical techniques: 1) Critical Path Method (CPM): Used to identify the longest sequence of dependent activities (the critical path) which dictates the minimum project duration, allowing for precise schedule planning and identification of critical activities; 2) Earned Value Analysis (EVA): Applied to integrate project scope, cost, and schedule to assess project performance objectively. Key metrics such as Planned Value (PV), Earned Value (EV), and Actual Cost (AC) were calculated to derive the Schedule Performance Index (SPI), Schedule Variance (SV), Cost Performance Index (CPI), and Cost Variance (CV). This provided a quantitative measure of schedule delays and cost overruns; 3) Program Evaluation and Review Technique (PERT): Utilized to estimate project completion probabilities by considering three-time estimates (optimistic, pessimistic, and most likely) for each activity, thereby accounting for inherent uncertainties in scheduling; 4) Crashing Analysis: Employed to evaluate options for project duration optimization by identifying activities where additional resources (with associated costs) could accelerate completion. The analysis focused on identifying the most cost-effective methods for reducing the project's critical path duration.

The results from these analyses were then subjected to in-depth discussion, evaluating their theoretical implications in the context of construction project management literature and their practical implications for waterproofing works. The ultimate goal of this comprehensive analysis was to produce robust conclusions and actionable recommendations that can support

more effective decision-making in efforts to optimize schedules and costs in similar future projects within the data center construction sector.

Results and Discussion

Project Cost And Time Planning

Project planning includes estimating the volume of work and material prices for drawing up a budget. The project of this multi-storey data center building includes 8 items of waterproofing work. The duration is determined based on the effectiveness of the company's tools, labor and experience.

Budget plan and duration of work

The Total budget for waterproofing work is Rp 3 billion, covering 8 types of work. Scheduling is done by lag method Start to Start (SS) and Finish to Start (FS). The duration of the work includes optimistic, realistic (most likely), and pessimistic, based on actual data and project plans.

Table 2. Budget Plan and Duration of Waterproofing work

No	Description	Unit	QTY	Unit Price	Amount	Weight (%)	Successor	Total Duration (Week)		
				(Rp)	(Rp)			Optimist	Most Likely	Pessimistic
A	WATERPROOFING WORKS									
1	<i>Evalon 2.2 mm Waterproofing Membrane</i>	m2	2,856	600,000	1,713,670,056	57.12%	A2	11	4	18
2	<i>Versidrain P anchor Drainage</i>	m2	1,975	250,000	493,729,180	16.46%	A3	8	9	13
3	<i>CL Foam 50 mm Insulation Board</i>	m2	1,975	220,000	434,481,678	14.48%	A4	5	6	8
4	<i>Geotextile 300 g</i>	m2	2,224	46,229	102,821,711	3.43%	<i>Finish</i>	4	5	7
5	<i>Versicell</i>	m2	171	221,000	37,799,840	1.26%	<i>Finish</i>	1	1	2
6	<i>Versitape F 100 Sealing Tape</i>	m'	1,242	60,000	74,496,120	2.48%	A7	4	4	6
7	<i>Fleximent 201 Waterproofing Coating</i>	m2	240	150,000	36,058,665	1.20%	A8	1	1	1
8	<i>Eurethane 2000 Waterproofing Coating</i>	m2	428	250,000	106,942,750	3.56%	A5	2	2	3
	Grand Total				3,000,000,000	100%				

Table 2 gives an account of the budgetary and time estimation of each of the eight categories of waterproofing work computation not left out the financial and the scheduling aspects. There are unit price, quantity, and the total cost of each item, and percentage weights are attached to each of them as to show what proportion of the total project budget of Rp 3 billion each item will be. The Evalon 2.2 membrane is the most prominent of all and has a coverage over 57 percent of the entire cost which highlights the importance of the same in the waterproofing scope. The table also gives three time estimates; optimistic, most likely, and pessimistic, in assessment of each task giving possibility of probabilistic determination capability in subsequent PERT analysis of the time. Successor relationships are defined to outline the

sequence of work allowing the build up of a dependency based schedule of the project. As a whole, this table will provide a basic cost-time structure to which additional control tools like EVA and crashing will then be implemented.

Project Time planning with Precedence Diagram Method (PDM)

PDM method is used to calculate the duration of the project taking into account the lag between activities.

Table 3. Data on the duration of the implementation and subsequent work

ID	Activity	Successor	Total Duration (Week)
A	START		
1	Evalon 2.2 mm Waterproofing Membrane	A2	14
2	Versidrain P anchor Drainage	A3	9
3	CL Foam 50 mm Insulation Board	A4	6
4	Geotextile 300 g	Finish	5
5	Versicell	Finish	1
6	Versitape F 100 Sealing Tape	A7	4
7	Fleximent 201 Waterproofing Coating	A8	1
8	Eurethane 2000 Waterproofing Coating	A5	2

Table 3 shows logical sequence and time on each waterproofing activity through the method of Precedence Diagram Method (PDM). The activities are identified by IDs, and they are connected in the sequence indicating the carrying out of each of the activities into the other one by grade, and also the allocated time duration contains the most probable time estimates. This methodical mapping will convert the budget items into network of interdependence tasks paving the way to determination of the critical path. Case in point, the insulation is done after the Evalon membrane installation which is followed by the Versidrain work and so on. The resultant schedule will give a total project completion of 34 weeks which will then be taken as the baseline to follow up on the progress and change. The table is the input down logic behind the Figure 1 graphical representation and it is the basis of all the schedule optimization scenarios such as crashing ones.

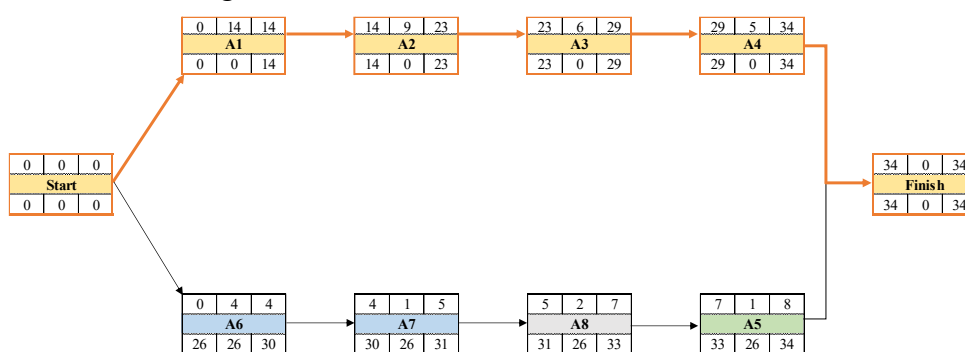


Figure 1. Diagram Precedence Diagram Method

In Table 3 the work breakdown structure was defined with Figure 1 illustrating it in the form of a network diagram. It traces interrelated and serial affiliation amongst activities, and the directed arrows are used to depict unfolding between predecessor and successor activities. The critical path the longest path in the network with zero slack, is determined by the figure and the result defines the shortest time project can possibly take. There are also non-critical activities, which may have the possibility to build float or flex the schedule. This form of graphical representation assists the stakeholders to comprehend processes involved in the flow of work tasks, the dependencies between the work and the points at the schedule highly

sensitive to delay. It is necessary when there is a need to coordinate subcontractors and crash candidates to be identified.

Project Bar Chart

The duration and percentage of weekly progress are calculated from the contribution of each work to the total project. The work runs from February to October 2024, and has achieved 100% progress by the 34th week. There was the biggest delay in week-13 at 18.1% compared to the plan.

Table 4. Barchart Scheduling Waterproofing Work

No.	Description	Weight (%)	Successor	Duration (Week)	Percentage /week	Feb-24				Mar-24				Apr-24				May-24				Jun-24				Jul-24				Aug-24				Sep-24				Oct-24				Remarks		
						1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4			
A. WATERPROOFING WORKS																																												
1	Install 2.0 mm Waterproofing Membrane	57.12%	A2	14	4.08%	4.08%	4.08%	4.08%	4.08%	4.08%	4.08%	4.08%	4.08%	4.08%	4.08%	4.08%	4.08%	4.08%	4.08%	4.08%	4.08%	4.08%	4.08%	4.08%	4.08%	4.08%	4.08%	4.08%	4.08%	4.08%	4.08%	4.08%	4.08%	4.08%	4.08%	4.08%	4.08%							
2	Vertical P anchor Drainage	16.40%	A3	9	1.87%																																							
3	CL Foam 50 mm Insulation Board	14.48%	A4	6	2.41%																																							
4	Glasswool 100 g	3.47%	Finish	5	0.69%																																							
5	Vynaflex	1.26%	Finish	1	1.26%																																							
6	Vynaflex P 100 Sealing Tape	2.48%	A7	4	0.62%																																							
7	Fluonon 201 Waterproofing Coating	1.20%	A8	1	1.20%																																							
8	Fluonon 2000 Waterproofing Coating	3.56%	A5	2	1.78%																																							
Grand Total						100.00%																																						
Progress Plan						4.1%	8.1%	12.2%	16.3%	20.4%	24.5%	28.6%	32.7%	36.7%	40.8%	44.9%	49.0%	53.1%	57.2%	61.3%	65.4%	69.5%	73.6%	77.7%	81.8%	85.9%	90.0%	94.1%	98.2%	100.0%														
Cumulative Plan						4.1%	8.2%	12.3%	16.4%	20.5%	24.6%	28.7%	32.8%	36.9%	41.0%	45.1%	49.2%	53.3%	57.4%	61.5%	65.6%	69.7%	73.8%	77.9%	82.0%	86.1%	90.2%	94.3%	98.4%	100.0%														
Progress Actual						3.2%	6.3%	9.3%	12.3%	15.3%	18.3%	21.3%	24.3%	27.3%	30.3%	33.3%	36.3%	39.3%	42.3%	45.3%	48.3%	51.3%	54.3%	57.3%	60.3%	63.3%	66.3%	69.3%	72.3%	75.3%	78.3%	81.3%	84.3%	87.3%	90.3%	93.3%	96.3%	99.3%	100.0%					
Cumulative Actual						3.2%	6.3%	9.3%	12.3%	15.3%	18.3%	21.3%	24.3%	27.3%	30.3%	33.3%	36.3%	39.3%	42.3%	45.3%	48.3%	51.3%	54.3%	57.3%	60.3%	63.3%	66.3%	69.3%	72.3%	75.3%	78.3%	81.3%	84.3%	87.3%	90.3%	93.3%	96.3%	99.3%	100.0%					
Deviation						-0.9%	-1.8%	-2.7%	-3.6%	-4.4%	-5.4%	-6.3%	-7.3%	-8.2%	-9.2%	-10.1%	-11.1%	-12.1%	-13.1%	-14.1%	-15.1%	-16.1%	-17.1%	-18.1%	-19.1%	-20.1%	-21.1%	-22.1%	-23.1%	-24.1%	-25.1%	-26.1%	-27.1%	-28.1%	-29.1%	-30.1%	-31.1%	-32.1%	-33.1%	-34.1%				

Table 4 is an indication of the weekly project growth under the weighted value of each of the waterproofing items. The project will be carried out between February to October 2024 and achieved cumulatively. The largest variance to be observed is in week 13, when the lag stands at 18.1 percentage points behind the planned curve, which indicates a temporary vital derailment of implementation. This bar chart data is directly used in the creation of S-curve and earned value analysis. By using per cent completion measures on weekly basis, this table becomes a focal point of tracking costs and time at least in evaluation of variances such as SV and SPI.

S-Curve Work

After getting the data on the Bar Chart, S-curve can be made to see whether the implementation of each work in each week is in accordance with the progress of planning in that week.

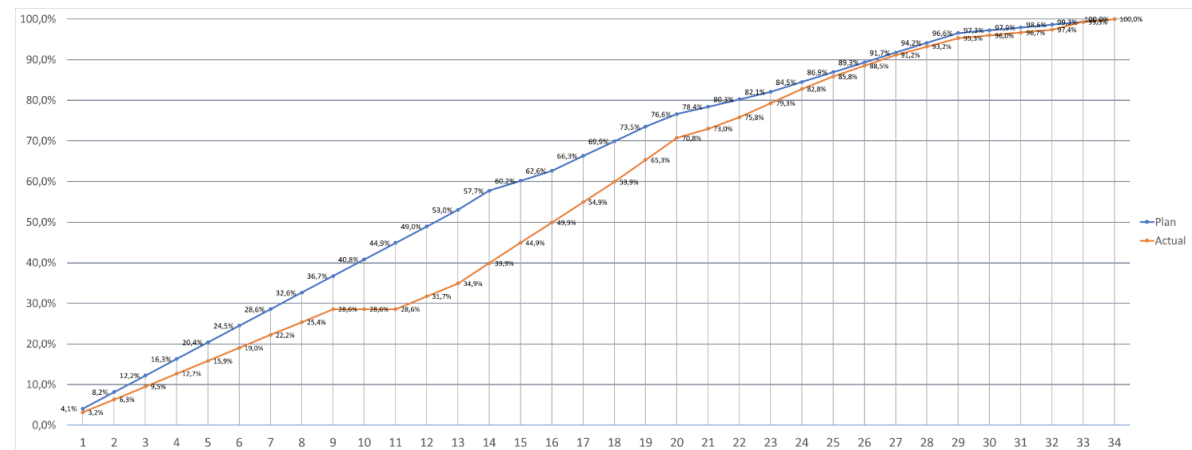


Figure 1. S-Curve Pekerjaan Waterproofing

Figure 2 shows the S-curve, which is a cumulative line graph plotting planned against actual progress against the 34 weeks of the project schedule. It uncovers that since the early days there was a mismatch between what was estimated to be done and what was done on the ground, a scenario that shows early on weaknesses or poor performance. This persistent departure is an affirmation that scheduling problems are structural, then again more likely

because of work force limitations, late materials, or coordination failures. The curve will become steeper and flatter depending on the density of activity and speed of executions.. As a diagnostic tool, the S-curve enables early detection of slippage and can guide timely corrective actions. It complements the earned value metrics by showing trends over time rather than snapshots.

Project Cost And Time Control

Project control is carried out by comparing actual and planned data to identify deviations and establish corrective actions to keep the project running according to schedule and budget.

Analysis Of Actual Implementation vs. Plan (Cost & Time)

Using the Earned Value Analysis (EVA) method, project performance evaluation was carried out at week-30:

Table 5. Barchart Scheduling Waterproofing Work

No.	Description	Unit	QTY	Unit Price (IDR)	Budget (BCWS) (IDR)	Weight (%)	Completion			BCWP (6) = (1) x (4)	ACWP (7)	Cost Performance Index (CPI) (8)	ETC = BAC - ACWP (9)	Estimate Cost (EAC=ACWP+ETC) (10)
							Plan %	Actual %	Total %					
					(1)	(2)	(3)	(4)	(5) = (4)x(2)					
A WATERPROOFING WORKS														
ROOF														
1	Evalon 2.2 mm Waterproofing Membrane	m2	2.856	600.000	1.713.670.056	57,12%	100,00%	100,00%	57,12%	1.713.670.056	1.713.670.056	1,00	0,00	1.713.670.056,00
2	Versidrain P anchor Drainage	m2	1.975	250.000	493.729.180	16,46%	100,00%	100,00%	16,46%	493.729.180	493.729.180	1,00	0,00	493.729.180,00
3	CL Foam 50 mm Insulation Board	m2	1.975	220.000	434.481.678	14,48%	100,00%	100,00%	14,48%	434.481.678	434.481.678	1,00	0,00	434.481.678,00
4	Geotextile 300 g	m2	2.224	46.229	102.821.711	3,43%	20,00%	20,00%	0,69%	20.564.342	20.564.342	1,00	82.257.369,00	102.821.711,00
PLANTER BOX														
5	Versicell	m2	171	221.000	37.799.840	1,26%	100,00%	0,00%	0,00%	0	26.459.888	0,00	11.339.952,00	37.799.840,00
TOILET														
6	Versitape F 100 Sealing Tape	m'	1.242	60.000	74.496.120	2,48%	100,00%	100,00%	2,48%	74.496.120	74.496.120	1,00	0,00	74.496.120,00
7	Fleximent 201 Waterproofing Coating	m2	240	150.000	36.058.665	1,20%	100,00%	100,00%	1,20%	36.058.665	36.058.665	1,00	0,00	36.058.665,00
GWT														
8	Eurethane 2000 Waterproofing Coating	m2	428	250.000	106.942.750	3,56%	100,00%	100,00%	3,56%	106.942.750	106.942.750	1,00	0,00	106.942.750,00
Grand Total					3.000.000.000	100,00%				2.879.942.791	2.906.402.679	0,99	93.597.321,00	3.000.000.000,00

From the above data dpat taken the calculation of SPI, SV, CPI, and CV by using the method of Earned Value Analysis (EVA) week-30: 1) SPI $0.96 < 1 \rightarrow$ the project is almost on schedule, there is a slight delay; 2) SV $(-) < 0 \rightarrow$ there is a delay of Rp120,057,209; 3) CPI $0.99 < 1 \rightarrow$ almost cost efficient use; 4) CV $(-) < 0 \rightarrow$ cost overruns of Rp26,459,888.

In general, it can be concluded that the project is close to schedule and budget, but there are slight delays and cost overruns. To correct the delay, it is necessary to take corrective measures, such as accelerating work and tighter cost control.

Analysis of Standard Deviation and Variance of Activities

Table 6. Analysis of standard deviation and variance of activities

No.	Description	Unit	QTY	Unit Price (IDR)	Amount (IDR)	Weight (%)	Successor	Total Duration (Week)			Expected Duration (Weeks) (a)+4*(b)+(c)/6	Standard Deviation (c)-(a)/6	Variance √STD Dev
								Optimist (a)	Most Likely (b)	Pessimistic (c)			
A WATERPROOFING WORKS													
1	Evalon 2.2 mm Waterproofing Membrane	m2	2,856	600,000	1,713,670,056	57,12%	A2	11	14	18	14	1,17	1,36
2	Versidrain P anchor Drainage	m2	1,975	250,000	493,729,180	16,46%	A3	8	9	13	10	0,83	0,69
3	CL Foam 50 mm Insulation Board	m2	1,975	220,000	434,481,678	14,48%	A4	5	6	8	6	0,50	0,25
4	Geotextile 300 g	m2	2,224	46,229	102,821,711	3,43%	Finish	4	5	7	5	0,50	0,25
5	Versicell	m2	171	221,000	37,799,840	1,26%	Finish	1	1	2	1	0,17	0,03
6	Versitape F 100 Sealing Tape	m'	1,242	60,000	74,496,120	2,48%	A7	4	4	6	4	0,33	0,11
7	Fleximent 201 Waterproofing Coating	m2	240	150,000	36,058,665	1,20%	A8	1	1	1	1	0,00	0,00
8	Eurethane 2000 Waterproofing Coating	m2	428	250,000	106,942,750	3,56%	A5	2	2	3	2	0,17	0,03
Grand Total												σ E	1,65

From the above data dpat taken the calculation of SPI, SV, CPI, and CV by using the method of Earned Value Analysis (EVA) week-30:

SPI $0.96 < 1 \rightarrow$ the project is almost on schedule, there is a slight delay.

SV $(-) < 0 \rightarrow$ there is a delay of Rp120,057,209.

CPI $0.99 < 1 \rightarrow$ almost cost efficient use.

CV $(-) < 0 \rightarrow$ cost overruns of Rp26,459,888.

In general, it can be concluded that the project is close to schedule and budget, but there are slight delays and cost overruns. To correct the delay, it is necessary to take corrective measures, such as accelerating work and tighter cost control.

Analysis of Standard Deviation and Variance of Activities

Table 7. Probability Calculation Of Project Completion Time

Case		Z Formula	Z Value	Result
Probability of project completion by the end of the 36th week	36	1,21	0,64	0,89
Probability of project completion by the end of the 42th week	42	4,85	0,75	1,00
Probability of project completion by the end of the 58th week	58	14,55	1,03	1,00
Completion Date with Minimum 90% Confidence Level	36,11	1,28		0,90

STD Dev Proyek (σE)	1,65
TE (Critical Duration)	34

Based on the analysis of the duration obtained from Table 8, Evalon Waterproofing Membrane work has the longest duration with the Expected Duration (TE) of 14 weeks and the highest level of uncertainty, indicated by the Standard Deviation (SD) of 1.17 weeks. In contrast, Versicell and Fleximent 201 Waterproofing Coating work has the lowest TE, which is 2 weeks, which indicates the fastest estimated completion among all work items. The higher the SD value, the greater the variability of the duration of the work, which reflects the risk of uncertainty in the implementation.

Meanwhile, from Table 9, information is obtained related to the probability of completion of the project. At week-28, the probability of completion of the project is 50%, indicating that at this point, the probability of the project not being fully completed is quite significant. However, in the 34th, 35th, and 46th weeks, the probability of completion of the project reached 100%, indicating that the project was confirmed to be completed no later than the 46th week. Using a confidence level of 90%, the estimated completion time of the project is expected to occur in the 30th week.

This conclusion indicates that although the project has the risk of uncertainty in some work items, the overall project is still within acceptable estimates, with a high probability of being completed earlier than normal estimates if strategic acceleration and risk control are carried out effectively.

Analysis of Time and Cost Acceleration (Crashing)

Table 8. Project Time Acceleration Analysis

No.	Description	Normal			Crashed			Δ Duration (Week)	Δ Cost (IDR)	Slope (Week)	Rank
		Duration (Week)	Cost (IDR)	Cost / week (IDR)	Duration (Week)	Cost (IDR)	Cost / week (IDR)				
		(a)	(b)	(c)	(d)	(e)	(f)	(g) = (a) - (d)	(h) = (b) - (e)	(i) = (h) / (g)	(j)
A WATERPROOFING WORKS											
ROOF											
1	Evalon 2.2 mm Waterproofing Membrane	14	Rp 1,713,670,056	Rp 122,405,004	11	Rp 1,729,735,713	Rp 157,248,701	3.00	Rp 16,065,657	Rp 5,355,219	5
2	Versidrain P Anchor Drainage	9	Rp 493,729,180	Rp 54,858,798	8	Rp 497,432,149	Rp 62,179,019	1.00	Rp 3,702,969	Rp 3,702,969	8
3	CL Foam 50 mm Insulation Board	6	Rp 434,481,678	Rp 72,413,613	5	Rp 438,184,647	Rp 87,636,929	1.00	Rp 3,702,969	Rp 3,702,969	7
4	Geotextile 300 g	5	Rp 102,821,711	Rp 20,564,342	4	Rp 106,992,040	Rp 26,748,010	1.00	Rp 4,170,329	Rp 4,170,329	6
PLANTER BOX											
5	Versicell	1	Rp 37,799,840	Rp 37,799,840	1	Rp 38,120,540	Rp 39,978,203	0.05	Rp 320,700	Rp 6,901,687	3
TOILET											
6	Versitape F 100 Sealing Tape	4	Rp 74,496,120	Rp 16,800,000	4	Rp 76,824,124	Rp 19,206,031	0.43	Rp 2,328,004	Rp 5,360,447	4
7	Fleximent 201 Waterproofing Coating	1	Rp 36,058,665	Rp 36,058,665	1	Rp 37,410,865	Rp 41,872,852	0.11	Rp 1,352,200	Rp 12,689,520	2
GWT											
8	Eurethane 2000 Waterproofing Coating	2	Rp 106,942,750	Rp 53,471,375	2	Rp 109,348,962	Rp 57,315,918	0.09	Rp 2,406,212	Rp 26,105,911	1
Grand Total		34	Rp 3,000,000,000		28	Rp 3,034,049,039			Rp 34,049,039		

Table 10 brings in the crashing analysis that is used to assess possible acceleration of projects by inputting resources more especially lengthening working hours. Individual critical-path activities are singled out in the table and are the focus of acceleration efforts-as only the activities of the critical path can have any significant impact on the project completion time

as a whole. The strategy has a situation of no material limitation and sequencing bottlenecks and the application of 3 hours of overtime daily. The savings on time that are yielded are calculated and each one is linked to the cost that has been incurred. This table forms the premise on which the time-cost trade-offs can be made, and the decision-makers can therefore decide on whether the advantage of execution of the project sooner supersedes the incremental increase in costs. The connotations are graphically supported by Figure 4.

Table 9. Summary of Project duration and cost after Crashing

Description	Crashed Activity	Project Duration	Project Cost
	Normal Condition	34	Rp 3,000,000,000
Evalon 2.2 mm Waterproofing Membrane	Crashed for 3 Weeks	31	Rp 3,016,065,657
Versidrain P anchor Drainage	Crashed for 1 Week	30	Rp 3,019,768,626
CL Foam 50 mm Insulation Board	Crashed for 1 Week	29	Rp 3,023,471,595
Geotextile 300 g	Crashed for 1 Week	28	Rp 3,027,641,924
Versicell	Crashed for 1 Week	28	Rp 3,027,962,624
Versitape F 100 Sealing Tape	Crashed for 1 Week	28	Rp 3,030,290,627
Fleximent 201 Waterproofing Coating	Crashed for 1 Week	28	Rp 3,031,642,827
Eurethane 2000 Waterproofing Coating	Crashed for 1 Week	28	Rp 3,034,049,039

The results of the crashing strategy on time and financial performance are summed up in Table 11. It demonstrates that the project time line would be cut down by 6 weeks, which will be 34 weeks to 28 weeks. Nonetheless, this quicker transport is done at an incremental cost of Rp 34 million. Although this increase is still within reasonable limit in as far as the Rp 3 billion budget is concerned it leads to decrease of the contractor profit margin that was 30% (Rp 900 million) to 26.54% (Rp 865.95 million). This is a trapped result that describes a typical managerial dilemma of gaining a quick solution at the expense of less profitability. The table provides the quantitative clarity in order to give decision-makers a clear picture to assess whether the strategic value of early completion is sufficient to warrant the marginal diminution of the earnings.

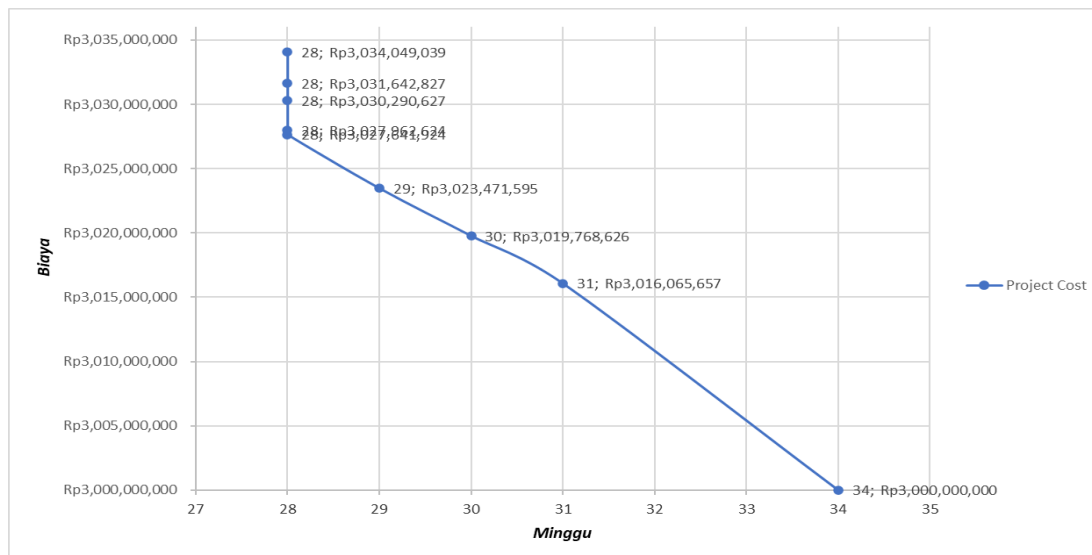


Figure 2. Curve Result Crushing Method

The output of crashing analysis generated a time-cost trade-off curve as shown in figure 4. The figure shows the reverse correlation between the time and the cost, the shorter the project gets the higher its total cost. The curve is probably not linear with decreasing returns- the time savings that are initially accrued are more suitable to be obtained rather than those experienced at later stages. This figure acts as a decision-support tool, helping project managers determine the optimal balance point where acceleration is worthwhile without excessively

compromising profit. It visualizes the strategic consequences of pursuing faster delivery and anchors them in quantifiable trade-offs.

Data From Questionnaires And Interviews

In the process of collecting data, questionnaires were distributed to three respondents who served as managers in construction companies involved in the project for the construction of the X-storey data center building. The respondents have more than 10 years of experience in the field of construction, so the data are considered credible. In addition to questionnaires, interviews were also conducted with reference to research by Asmi et al., (2020) which identifies various risk variables in construction projects based on PMBOK and project dynamic cycle.

Table 10. Research Risk Variables

ID	Risk Variables	ID	Risk Variables	ID	Risk Variables
A	Material and equipment risks	C	Contractual Risks	E	Design and technology risks
A1	Material price fluctuation	C3	Unrealistic contract duration and terms	E5	Cumbersome and cumbersome design
A2	Lack of material	C4	Late payment by owner	E6	Incomplete design at the time of tender
A3	Changes in material specifications and types	C5	Late payment to subcontractors	F	Risk Management
A4	Late delivery of materials and equipment	C6	Ways of financing, bonds and payments	F1	Cashflow and financial difficulties of contractors
A5	Equipment availability and failure	C7	Cost difficulties of the owner	F2	Poor financial control in the field
A6	Insufficient amount of equipment	D	Execution Risk	F3	Inadequate planning and scheduling
A7	High cost of equipment and maintenance	D1	Inaccurate field investigations	F4	Inaccurate time and cost estimates
A8	Delay in material procurement	D2	Additional work	F5	Lack of contractor experience
B	Labor Risks	D3	Repeating work	F6	Delay in scheduling
B1	High labor costs	D4	Obsolete construction methods	F7	Delay in decision making
B2	Labor productivity	D5	Number of concurrent constructions	F8	Poor project management
B3	Shortage of technical personnel	D6	Errors in construction	F9	Lack of coordination and communication
B4	Employee absenteeism	D7	Waste material in the field	F10	Slow flow of information
B5	Lack of field workers	D8	Late inspection and approval	F11	Changes in the scope of work
B6	Overtime work	D9	Lack of supervision and control	F12	Contractual claims
B7	Incompetent workers	E	Design and technology risks	F13	Owner intervention
B8	Lack of technical consulting experience	E1	Frequent design changes	F14	Omissions and errors in the bill
C	Contractual Risks	E2	Poor design and design delay	G	Risk Of Force Majeure
C1	Bureaucracy in the tender method	E3	Errors and omissions in the design	G1	Weather effects

C2	Poor contract management	E4	Delay in preparation and approval of drawings	G2	Unexpected soil / land conditions
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Sources: (Asmi et al., 2020)

Based on the results of the questionnaire from all respondents, obtained the value of probability x impact for each risk variable. With this total value, the top ranking is obtained for the largest risk variable that affects the scheduling of the X-storey data center building.

Table 11. The value of probability x impact for each risk variable

Risk Variables	R1	R2	R3	Total P+I	Rank
E6. Incomplete design at the time of tender	16	20	25	61	1
B6. Overtime work	16	16	25	57	2
B2. Labor productivity	16	12	20	48	3
D8. Late inspection and approval	12	20	15	47	4
G1. Weather effects	12	20	15	47	4
D2. Additional work	16	20	10	46	5
D5. Number of concurrent constructions	16	15	15	46	5
B4. Employee absenteeism	12	16	15	43	6
F4. Inaccurate time and cost estimates	12	15	15	42	7
E5. Cumbersome and cumbersome design	16	15	10	41	8
A2. Lack of material	12	12	15	39	9
B3. Shortage of technical personnel	12	12	15	39	9
F9. Lack of coordination and communication	8	15	15	38	10
A8. Delay in material procurement	15	12	10	37	11
D7. Waste material in the field	16	12	9	37	11
D9. Lack of supervision and control	12	15	10	37	11
F6. Delay in scheduling	12	15	10	37	11
G2. Unexpected soil / land conditions	12	15	10	37	11
A4. Late delivery of materials and equipment	15	6	15	36	12
E1. Frequent design changes	16	10	10	36	12
E4. Delay in preparation and approval of drawings	16	15	5	36	12
B5. Lack of field workers	12	8	15	35	13
C1. Bureaucracy in the tender method	16	4	15	35	13
F13. Owner intervention	12	15	8	35	13
B1. High labor costs	16	9	9	34	14
E2. Poor design and design delay	16	15	3	34	14
D3. Repeating work	12	10	10	32	15
D6. Errors in construction	12	10	10	32	15
E3. Errors and omissions in the design	12	15	3	30	16
F1. Cashflow and financial difficulties of contractors	12	15	3	30	16
F3. Inadequate planning and scheduling	12	15	3	30	16
F14. Omissions and errors in the bill	12	15	3	30	16
C4. Late payment by owner	12	8	9	29	17
F10. Slow flow of information	4	15	10	29	17
F7. Delay in decision making	8	15	5	28	18
A3. Changes in material specifications and types	9	3	15	27	19
D1. Inaccurate field investigations	12	5	10	27	19
D4. Obsolete construction methods	16	5	5	26	20

F2. Poor financial control in the field	8	15	3	26	20
A5. Equipment availability and failure	12	3	10	25	21
C7. Cost difficulties of the owner	12	1	9	22	22
F12. Contractual claims	4	15	3	22	22
B7. Incompetent workers	12	4	5	21	23
B8. Lack of technical consulting experience	12	4	5	21	23
C2. Poor contract management	12	4	5	21	23
C3. Unrealistic contract duration and terms	12	4	5	21	23
A6. Insufficient amount of equipment	12	4	4	20	24
C6. Ways of financing, bonds and payments	12	4	3	19	25
F11. Change of scope of work	3	6	10	19	25
F8. Poor project management	4	8	5	17	26
A7. High cost of equipment and maintenance	9	4	3	16	27
C5. Late payment to subcontractors	12	1	3	16	27
A1. Material price fluctuation	9	3	3	15	28
F5. Lack of contractor experience	4	5	5	14	29

Based on the recapitulation of the risk scores of the three respondents (R1, R2, R3), most of the risk variables identified in construction projects fall into the category of "Unacceptable" (values 15-25 per respondent), according to the classification of Godfrey (1996). The risk with the highest rating is E6. An incomplete design at the time of tender with a total score of 61, followed by B6. Overtime work (57) and B2. Labor productivity (48). These risks have individual scores from each respondent consistently in the range of 15-25, indicating that they are unacceptable and should be immediately eliminated or strictly controlled, especially since they directly impact the cost and timing of the project as a whole. Conversely, risks with a total value below 20, such as F5. Lack of contractor experience, A1. Material price fluctuations, and C5. Delays in payments to subcontractors, showing a tendency to be in the category of "Undesirable" or even "Acceptable", depending on the individual assessment. However, these risks still require attention, especially when there is a change in project conditions or work environment.

Analysis of Key Factors And Risks With Fishbone Diagrams

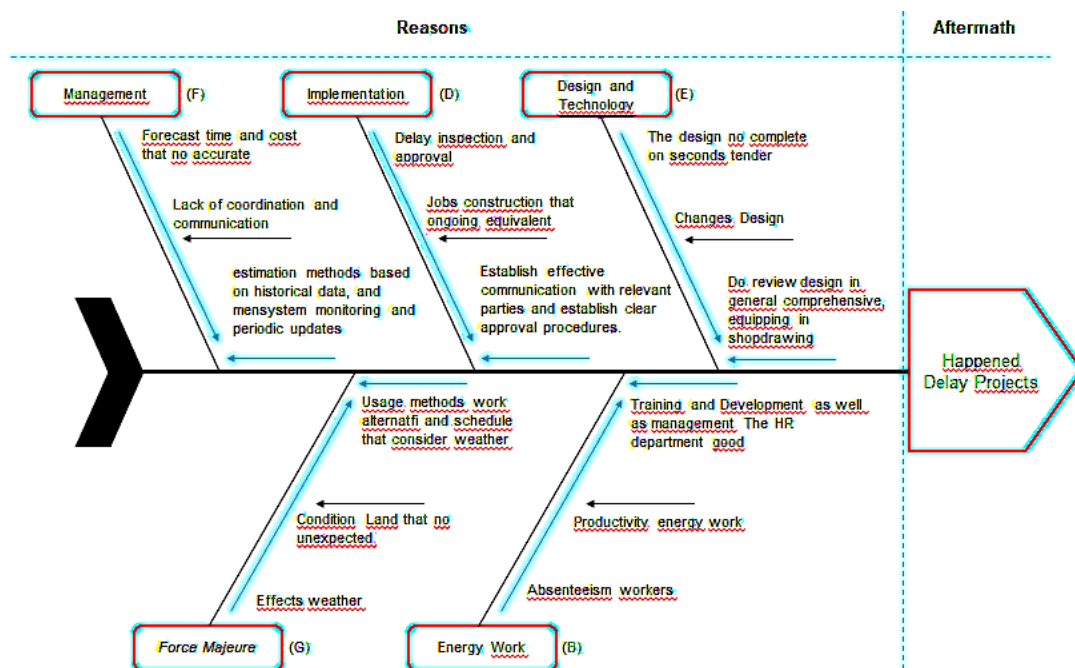


Figure 5. Causal Fishbone Diagram

Analysis using Fishbone diagram (Ishikawa) was conducted to identify the root cause of delays in scheduling waterproofing work on multi-storey data center building projects.

Causal Fishbone (Ishikawa) diagram presented in Figure 5 divides root causes of schedule delay into categories using a systematic methodical approach and visually represents them. It has five main areas which are Design and Technology, Labor, Execution, Management and Force Majeure. Under these domains, there are clearly mentioned issues under each domain e.g. Design, lack of design at tender (Design), lack of attendance (Labor), and lackadaisical coordination (Management). These further fall into three categories of delays namely, Non-Excusable, Excusable and Compensable delays. This is because this classification facilitates distribution of responsibility and development of specific mitigation techniques. As an example, Non-Excusable delays (e.g. inefficiency of the subcontractor) require the contractual enforcement to be more intense, whereas Compensable delays (e.g. the late provision of design documentation by the owner) require planning on the client side to be changed.

Conclusion

This paper has established that the significant element of the planning and control of time and cost in waterproofing work on high-rise data center constructions is an efficient coordinated inclusion of deterministic and probabilistic scheduling, performance monitoring in real-time and structured risk analysis. Applying Precedence Diagram Method, Critical Path Method allowed coming up with a 34-week schedule of the project with the critical sequencing clearly identified, and using Earned Value Analysis allowed getting near-equilibrium measures of performance with their slight, yet significant, inefficiencies being displayed. Even though cost and schedule variances were maintained under manageable levels, the fact that actual progress remained lagging continuously demonstrated the necessity to identify variances in an early stage and address it halfway through the process especially in high-dependency like subcontracts (i.e. waterproofing).

The use of Program Evaluation and Review Technique has enabled the project to have more confidence in estimation it variance adjusted project completion probabilities, and crashing analysis has served to demonstrate the schedules speed vs. marginal profit curve trade-offs. These insights justify the usefulness of modal and data-smart decision mechanisms that are dynamic and adapt to project and program unique constraints as opposed to a fixed plan premise. Similarly, the systematic recognition of delaying factors using risk ranking and causal analysis highlighted that much of the most problematic disruptions were driven not due to external shocks, but by some fundamental weaknesses in designing, labor and coordination aspects of the project system. While this study focuses on a specific scope within a defined construction typology, the methodological approach and findings offer broader implications for managing specialized work packages in high-risk infrastructure environments. Future projects of similar complexity would benefit from adopting integrated control frameworks that combine predictive scheduling models with embedded risk intelligence and participatory monitoring. Continued research may extend this framework through real-time simulation, multi-project comparisons, and deeper integration of BIM-based predictive analytics to enhance responsiveness and reliability in construction management. By emphasizing foresight over reactivity and integration over isolation, this study contributes to the evolving understanding of project control in technically demanding, time-sensitive construction contexts.

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