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Project Scheduling of Aruna Solar Power Plant Access Road and Pond Construction Using CPM and PERT

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Abstract
The success of construction projects is highly influenced by scheduling effectiveness, as project delays may lead to cost overruns, reduced productivity, and failure to achieve project targets. The Access Road and Pond Construction Project for the Aruna Solar Power Plant, undertaken by PT Wan Artha Nata Indonesia, experienced delays compared to the planned schedule. This study aimed to analyze project scheduling using the Critical Path Method (CPM) and Program Evaluation and Review Technique (PERT), identify critical activities, determine project completion duration, and evaluate schedule uncertainty. A descriptive quantitative approach with a case study design was employed. Data were collected through field observations, interviews, and project documentation, including the Work Breakdown Structure (WBS), project schedules, activity durations, and precedence relationships. CPM analysis was used to identify the critical path and determine the project duration, while PERT analysis was applied to evaluate schedule uncertainty using optimistic, most likely, and pessimistic time estimates. The results indicated that the minimum project duration was 203 days, with several activities identified as critical activities having no scheduling flexibility. Furthermore, the PERT analysis revealed the existence of schedule uncertainty caused by weather conditions, site constraints, material delivery delays, and permit approval processes.
Keywords: *project scheduling, CPM, PERT, critical path, construction project*

Abstrak
Keberhasilan proyek konstruksi sangat dipengaruhi oleh efektivitas penjadwalan karena keterlambatan pelaksanaan dapat mengakibatkan peningkatan biaya, penurunan produktivitas, dan terganggunya pencapaian target proyek. Proyek Pembangunan Access Road dan Pond PLTS Aruna yang dilaksanakan oleh PT Wan Artha Nata Indonesia mengalami keterlambatan penyelesaian dibandingkan dengan jadwal yang telah direncanakan. Penelitian ini bertujuan untuk menganalisis penjadwalan proyek menggunakan metode Critical Path Method (CPM) dan Program Evaluation and Review Technique (PERT), mengidentifikasi aktivitas kritis, menentukan durasi penyelesaian proyek, serta mengevaluasi ketidakpastian durasi proyek. Penelitian menggunakan pendekatan kuantitatif deskriptif dengan studi kasus. Data diperoleh melalui observasi lapangan, wawancara, dan dokumentasi proyek yang meliputi Work Breakdown Structure (WBS), jadwal proyek, durasi aktivitas, serta hubungan ketergantungan antaraktivitas. Analisis CPM digunakan untuk menentukan jalur kritis dan durasi proyek, sedangkan PERT digunakan untuk mengukur ketidakpastian durasi aktivitas melalui estimasi waktu optimis, paling mungkin, dan pesimis. Hasil penelitian menunjukkan bahwa proyek memiliki durasi minimum sebesar 203 hari dengan beberapa aktivitas yang berada pada jalur kritis sehingga tidak memiliki kelonggaran waktu. Analisis PERT menunjukkan adanya ketidakpastian durasi proyek yang dipengaruhi oleh faktor cuaca, kondisi lapangan, keterlambatan material, dan proses perizinan.
Kata Kunci: *penjadwalan proyek, CPM, PERT, jalur kritis, proyek konstruksi*

1. Introduction

The construction and infrastructure sector in Indonesia has experienced significant growth in recent years, driven by the increasing demand for industrial areas, energy facilities, and supporting infrastructure [1]. This condition requires construction companies to manage projects effectively to achieve the targeted cost, quality, and completion time [2]. Among these three project constraints, time is considered a critical factor because delays in project completion may result in cost overruns, reduced productivity, inefficient resource allocation, and postponed utilization of project outputs [3]. Therefore, effective project scheduling plays a crucial role in ensuring the successful implementation of construction projects [4].

Various studies have investigated project scheduling using the Critical Path Method (CPM) and the Program Evaluation and Review Technique (PERT) [5]. One of the previous studies reported that CPM effectively assists project managers in identifying critical activities and improving project schedule control [6]. Another study highlighted that activities located on the critical path have a direct impact on the overall project duration, and delays in these activities may lead to delays in the entire project completion [7]. However, most previous studies have primarily focused on identifying critical activities and estimating project duration using deterministic approaches [8]. Research that incorporates uncertainty in activity durations and evaluates the probability of project completion remains relatively limited, particularly in infrastructure projects supporting solar power plant development [9]. This limitation indicates the need for a more comprehensive scheduling analysis that not only identifies critical activities but also evaluates the likelihood of project completion under uncertain project conditions [10].

One of the projects facing scheduling challenges is the Access Road and Pond Development Project for the Aruna Solar Power Plant (PLTS Aruna), executed by PT Wan Artha Nata Indonesia. The project consists of several major activities, including clearing and stripping, site grading, cut and fill operations, access road construction, drainage system installation, and pond development as supporting facilities for the solar power plant area. According to the project schedule, the planned duration was 180 working days. However, during project execution, significant delays occurred, resulting in a 60-calendar-day extension of the completion deadline [11]. The delays were caused by several factors, including high rainfall intensity that hindered earthwork activities, changes in site conditions, material delivery delays, permit approval processes, and discrepancies between planned and actual project progress. These conditions indicate a gap between project planning and project execution, which may adversely affect the achievement of the targeted completion schedule [12].

To address these issues, a comprehensive scheduling analysis method is required to evaluate project schedule effectiveness. The Critical Path Method (CPM) can be used to identify critical activities that directly influence the overall project duration. However, CPM employs a deterministic approach by using a single duration estimate for each activity, which may not adequately represent the uncertainty commonly encountered in construction projects. Therefore, the Program Evaluation and Review Technique (PERT) is employed as a complementary method because it considers three time estimates, namely optimistic time, most likely time, and pessimistic time. Through this approach, PERT can be utilized to determine the expected project duration, assess schedule uncertainty, and calculate the probability of completing the project within the specified deadline [13].

The novelty of this study lies in the integration of CPM and PERT to evaluate scheduling performance in the Access Road and Pond Development Project for the Aruna Solar Power Plant, which experienced significant implementation delays. Unlike previous studies that generally focused only on critical path identification or project duration estimation, this study combines critical activity analysis with project completion probability assessment under uncertain activity durations. This integrated approach is expected to provide a more comprehensive understanding of the factors contributing to project delays and the likelihood of achieving project completion targets.

Based on the aforementioned background, this study aims to evaluate the effectiveness of project scheduling in the Access Road and Pond Development Project for the Aruna Solar Power Plant using CPM and PERT methods, identify critical path activities, determine the estimated project completion duration, and analyze the probability of project completion based on actual project conditions. The findings of this study are expected to provide valuable insights for improving project time control, minimizing delay risks, and supporting decision-making processes in similar construction and infrastructure projects.

2. Materials and Methods

This study employed a descriptive quantitative approach using a case study of the Access Road and Pond Construction Project for the Aruna Solar Power Plant (PLTS Aruna), which was executed by PT Wan Artha Nata Indonesia. The study aimed to analyze project scheduling performance using the Critical Path Method (CPM) and the Program Evaluation and Review Technique (PERT) to identify critical activities, estimate project completion time, and determine the probability of completing the project within the targeted schedule. The assumptions underlying this study were that the dependency relationships among project activities remained constant throughout the project duration, the activity duration data accurately represented actual project conditions, and all activities located on the critical path directly influenced the overall project completion time [14].

The study utilized both primary and secondary data sources. Primary data were collected through direct field observations and semi-structured interviews with project personnel involved in planning and execution activities. Observations were conducted to identify actual project conditions, monitor work progress, and recognize constraints affecting project performance. Interviews were carried out to obtain information regarding project scheduling practices, causes of delays, and time-control mechanisms implemented during project execution. Secondary data were obtained from company documents, including the Work Breakdown Structure (WBS), project schedules, activity duration records, activity dependency relationships, project progress reports, and other supporting documents related to project implementation [15].

The research procedure began with identifying project activities based on the Work Breakdown Structure (WBS). Subsequently, a project network diagram was developed by determining the precedence relationships among activities. CPM analysis was then performed using forward pass and backward pass calculations to determine the Earliest Start (ES), Earliest Finish (EF), Latest Start (LS), and Latest Finish (LF) values for each activity. The total float value of each activity was calculated to identify activities with zero float, which constituted the project's critical path. The critical path was then used to determine the estimated project duration based on CPM analysis.

The next stage involved the application of the PERT method. Each project activity was analyzed using three-time estimates: optimistic time (a), most likely time (m), and pessimistic time (b). The expected activity duration was calculated using Equation (1):

$$te = \frac{a+4m+b}{6} \tag{1}$$

The variance of each activity was calculated using Equation (2):

$$te = \left(\frac{b-1}{6}\right)^2 \tag{2}$$

The variances of all activities on the critical path were summed to obtain the project variance, which was subsequently used to calculate the project standard deviation. The expected project duration was determined by summing the expected durations of all activities located on the critical path.

Statistical analysis was conducted through probability estimation using the normal distribution approach. The Z-score was calculated by dividing the difference between the target project duration and the expected project duration by the project standard deviation. The resulting Z-score was then used to determine the probability of project completion based on the standard normal distribution table. The results obtained from CPM and PERT analyses were subsequently evaluated to identify activities with the highest potential to cause project delays and to assess the likelihood of completing the project within the predetermined schedule.

3. Results and Discussion

Project Activity Identification

The Access Road and Pond Construction Project of the Aruna Solar Power Plant was analyzed using the Critical Path Method (CPM) and Program Evaluation and Review Technique (PERT). Based on the Work Breakdown Structure (WBS), eight major project activities were identified. These activities formed the basis for developing the project network and determining the sequence of work execution.

Table 1. Project Activities and Precedence Relationships

Activity Code	Activity Description	Duration (Weeks)	Predecessor
A	Preparation Work	3	-
B	Site Grading	8	A
C	Road Work	15	B
D	Drainage Construction	8	B
E	Pond Construction	8	B
F	Utility Crossing	1	C, D, E
G	Quality and Safety Control	26	A
H	Project Completion	1	F

The activity relationships indicate that several activities could be performed simultaneously after the completion of site grading activities. These relationships were subsequently used to construct the project network diagram and identify critical activities affecting project completion.

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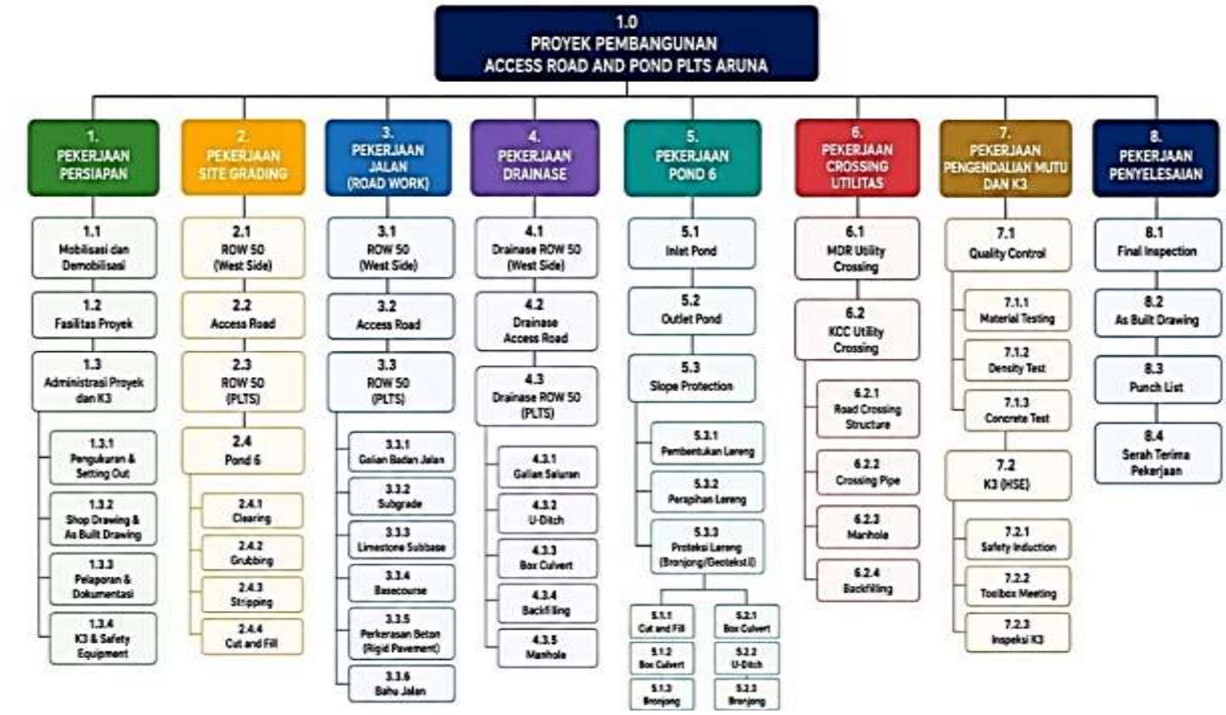

Fig. 1: Work Breakdown Structure (WBS) of the Access Road and Pond Construction Project

Critical Path Analysis Using CPM

The CPM analysis was performed using POM-QM for Windows based on activity durations and precedence relationships. The analysis generated scheduling parameters consisting of Early Start (ES), Early Finish (EF), Late Start (LS), Late Finish (LF), and Float values. The results indicated that the project required a total duration of 29 weeks for completion. Activities with zero float were classified as critical activities because any delay occurring in these activities would directly affect the overall project duration.

Table 2. Summary of Critical Path Analysis Results

Activity	Duration (Weeks)	Float (Weeks)	Status
A	3	0	Critical
B	8	0	Critical
C	15	1	Non-Critical
D	8	0	Critical
E	8	0	Critical
F	1	0	Critical
G	26	0	Critical
H	1	0	Critical

The analysis identified two critical paths within the project network, namely A–B–D–E–F–H and A–G. Both paths produced the same project duration of 29 weeks, indicating the existence of multiple critical paths. Consequently, project managers must monitor both paths simultaneously because delays in either path will directly extend the project completion time. Activity C (Road Work) was identified as the only non-critical activity, with a float value of one week. This indicates that the activity can tolerate minor delays without affecting the overall project schedule.

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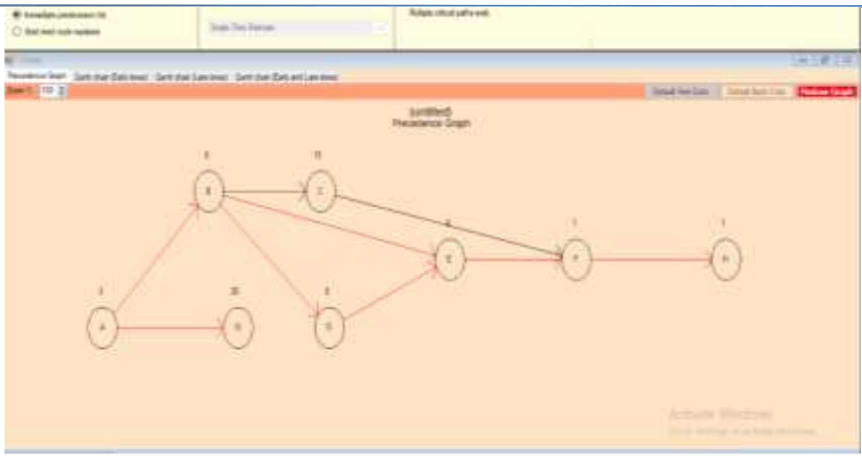


Fig. 2: CPM Network Diagram Generated Using POM-QM for Windows

The existence of multiple critical paths suggests that project completion was highly dependent on the successful execution of site grading, drainage construction, pond construction, utility crossing, quality and safety control, and project completion activities. Therefore, these activities should receive priority attention during project implementation.

Project Duration Uncertainty Analysis Using PERT

To account for uncertainty in activity durations, PERT analysis was conducted using three-time estimates consisting of optimistic time (a), most likely time (m), and pessimistic time (b). These estimates were derived from historical project records, project schedules, and expert judgment obtained from project personnel.

Table 3. Three-Time Estimates Used in PERT Analysis

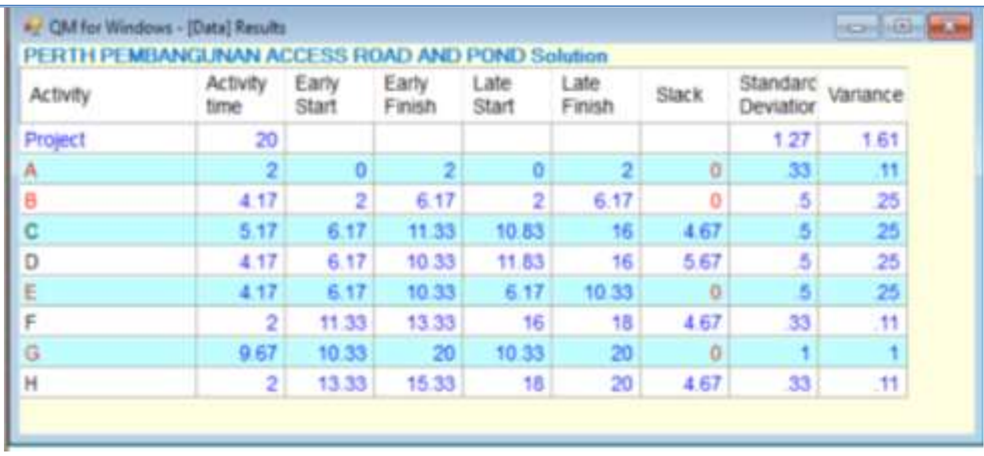
Activity	Optimistic (a)	Most Likely (m)	Pessimistic (b)
A	1	2	3
B	3	4	6
C	4	5	7
D	3	4	6
E	3	4	6
F	1	2	3
G	6	10	12
H	1	2	3

The PERT analysis produced expected activity durations, variances, and standard deviations for each activity. The results indicated that Activity G (Quality and Safety Control) had the highest level of uncertainty compared with other project activities. This activity exhibited the largest variance and standard deviation values, indicating greater sensitivity to potential project risks and operational disruptions.

At the project level, the calculated variance was 1.61 and the standard deviation was 1.27. These values indicate that the project completion time was subject to uncertainty and could vary depending on actual field conditions during project implementation.

Table 4. Summary of PERT Results

Parameter	Value
Project Variance	1.61
Project Standard Deviation	1.27
Activity with Highest Uncertainty	G (Quality and Safety Control)


QM for Windows - [Data] Results

PERTH PEMBANGUNAN ACCESS ROAD AND POND Solution

Activity	Activity time	Early Start	Early Finish	Late Start	Late Finish	Slack	Standard Deviation	Variance
Project	20						1.27	1.61
A	2	0	2	0	2	0	.33	.11
B	4.17	2	6.17	2	6.17	0	.5	.25
C	5.17	6.17	11.33	10.83	16	4.67	.5	.25
D	4.17	6.17	10.33	11.83	16	5.67	.5	.25
E	4.17	6.17	10.33	6.17	10.33	0	.5	.25
F	2	11.33	13.33	16	18	4.67	.33	.11
G	9.67	10.33	20	10.33	20	0	1	1
H	2	13.33	15.33	18	20	4.67	.33	.11

Fig. 3: PERT Analysis Output Generated Using POM-QM for Windows

The PERT results complement the CPM findings by providing information regarding schedule uncertainty. While CPM identifies critical activities, PERT helps project managers evaluate potential variations in project duration and prepare appropriate mitigation strategies.

Comparison Between Analytical Results and Actual Project Conditions

The original project schedule established a completion target of 180 calendar days. However, based on project documentation and field observations, the project experienced a delay of approximately 60 calendar days, requiring an extension of the completion date from 2 February 2026 to 3 April 2026.

Table 5. Comparison Between Planned and Actual Project Duration

Description	Duration (Days)
Planned Duration	180
Actual Duration	240
Delay	60

Several factors contributed to the project delay. These factors included high rainfall intensity, changes in site conditions, delays in material procurement, permit approval delays, and discrepancies between planned and actual work progress. Most of these factors affected earthwork-related activities, particularly site grading, drainage construction, and pond construction.

The CPM results provide a logical explanation for the observed delay. Since most affected activities were located on the critical path, any disruption immediately shifted subsequent activities and increased the overall project duration. This finding is consistent with CPM theory, which states that delays occurring on critical activities directly affect project completion time.

Similarly, the PERT analysis demonstrates that uncertainty was inherent in project implementation. External factors such as weather conditions, material availability, and administrative procedures introduced variability that could not be fully captured using deterministic scheduling methods. Therefore, integrating uncertainty analysis into project planning is essential for improving schedule reliability.

The comparison between analytical results and actual project performance indicates that the delay was not solely caused by scheduling deficiencies but was also influenced by external risks that were not fully anticipated during the planning stage. Consequently, project schedules should incorporate risk considerations and contingency measures to enhance resilience against unforeseen disruptions.

Managerial Implications

The combined application of CPM and PERT provides a comprehensive approach to project scheduling and control. CPM assists project managers in identifying critical activities that determine project completion time, whereas PERT provides insights into schedule uncertainty and risk exposure.

Based on the findings, several managerial recommendations can be proposed. First, additional time buffers should be allocated to activities with high uncertainty and high risk, particularly site grading, drainage construction, and pond construction activities. Second, material procurement, equipment mobilization, and permit processing should be completed before critical activities commence. Third, project progress should be monitored periodically through updated scheduling analyses to identify deviations at an early stage and enable corrective actions.

Furthermore, integrating CPM and PERT into project control systems can improve decision-making and enhance project performance. By continuously monitoring critical activities and evaluating schedule uncertainty, project managers can minimize delay risks and improve the likelihood of completing future projects within the planned schedule.

Overall, the results demonstrate that CPM and PERT are effective tools for identifying critical activities, evaluating schedule uncertainty, and supporting project scheduling decisions in construction projects. The application of these methods can contribute to improved project control and reduce the probability of schedule overruns in future infrastructure development projects.

4. Conclusion

This study evaluated the scheduling performance of the Access Road and Pond Construction Project for the Aruna Solar Power Plant using the Critical Path Method (CPM) and Program Evaluation and Review Technique (PERT). The findings revealed that the project experienced a delay compared to the original schedule due to several factors, including high rainfall intensity, changes in site conditions, delays in material procurement, permit approval constraints, and discrepancies between planned and actual work progress. The CPM analysis identified several critical activities with zero float values, indicating that any delay in these activities would directly affect the overall project completion time. Furthermore, the analysis showed that the minimum project duration required to complete all project activities was 203 days based on the established activity precedence relationships. The PERT analysis complemented the CPM results by incorporating uncertainty in activity durations and providing an estimate of project completion probability, thereby offering a more realistic assessment of project scheduling performance under uncertain conditions.

The results demonstrate that the integration of CPM and PERT can serve as an effective decision-support tool for project planning, scheduling, and control in construction projects. By identifying critical activities and evaluating schedule uncertainty, project managers can prioritize monitoring efforts, allocate resources more efficiently, and develop mitigation strategies to reduce the risk of project delays. Therefore, construction companies are encouraged to integrate CPM and PERT into their project management practices to improve schedule reliability and overall project performance. Future studies may extend this research by incorporating time–cost trade-off analysis, advanced scheduling software such as Microsoft Project or Primavera P6, and comprehensive risk assessment approaches to develop more robust and adaptive project scheduling models for infrastructure development projects.

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