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Research Paper

Schedule Optimization Using Deterministic and Probabilistic Analysis on Building Projects

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ABSTRACT:*The Nutrition Installation construction project at PambalahBatung Regional Public Hospital (Hulu Sungai Utara Regency, South Kalimantan, Indonesia) exhibited a schedule deviation of −20.35% at week 26 relative to its Existing Condition baseline. This study analyses the project's scheduling performance using the deterministic Critical Path Method (CPM) and the probabilistic Program Evaluation and Review Technique (PERT) to determine completion duration, the critical path, completion probability, and crashing requirements. Secondary data (Bill of Quantities, time schedule/S-curve, and Weekly Progress Reports) covering 21 activities were modelled as two network types: a pure Finish-to-Start (FS) network and a Precedence Diagramming Method (PDM) network incorporating Start-to-Start relationships with lag. Primary data — three-point time estimates (optimistic, most likely, pessimistic) — were obtained through structured interviews with 26 purposively selected expert respondents (the contractor, supervising consultant, owner, and design consultant). CPM analysis yielded a duration of 210 days for the pure FS network and 175 days for the PDM network, with 19 of 21 activities found critical in the PDM network. PERT analysis, run independently on the FS network using expert-elicited three-point estimates, produced an expected duration Te = 174.30 days (standard deviation σ = 7.54 days) along critical path A–C–E–F–M–U, with a completion probability of 77.5% within 180 days and approximately 100% within 204 days. These results indicate that the observed field deviation stems primarily from execution-level factors rather than an unrealistic schedule target. Time-Cost Trade-Off (TCTO) analysis shows that meeting a 204-day target requires a net additional cost of approximately IDR 11.95 million, while meeting the original 180-day target requires approximately IDR 164.94 million, concentrated along the shared upstream chain A–C–E. The study recommends that schedule control be focused on the PERT critical path, with particular attention to structural works, and that near-zero-float PDM scheduling be monitored closely to prevent delay accumulation.*

KEYWORDS:*Critical Path Method; Project Evaluation and Review Technique; Project Scheduling; Time-Cost Trade-Off; Probability*

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I. INTRODUCTION

The execution of a construction project requires accurate planning, scheduling, and resource management, including materials, equipment, environmental conditions, and other factors that influence project progress. When these factors are not adequately managed, project execution is delayed and scheduled durations are exceeded, ultimately compromising the intended project objectives and wasting time and cost [1]. Scheduling, in the context of construction projects, is the instrument used to determine the activities required to complete a project in a defined sequence and timeframe, in which each activity must be carried out so that the project finishes on time and at an economical cost [2]. Planning, in turn, is the process of establishing objectives and targets, including preparing all resources needed to achieve them [3]. Several methods are commonly applied in project scheduling, including the Critical Path Method (CPM), the Program Evaluation and Review Technique (PERT), the Precedence Diagramming Method (PDM), the Line of Balance (LoB), the S-curve, and the bar chart [4].

CPM, as defined by [9], is a method for planning and controlling projects that is among the most widely used network-based systems. Under CPM, the time required to complete each phase of a project is assumed to be known with certainty, as is the relationship between the resources deployed and the time needed for completion. CPM is a project management model that prioritises cost as its principal object of analysis [5] and is a network analysis technique that seeks to optimise total project cost through the reduction or acceleration of total completion time [6]. PERT, by contrast, plays a critical role not only in improving the accuracy of activity duration estimation but also in coordinating and controlling project activities [6]; it addresses the variability inherent in activity durations during project scheduling [7] and is applicable not only to large-scale, multi-year projects but also to improving execution efficiency in projects of any size [8], placing emphasis on obtaining the most probable and accurate duration estimate through the incorporation of probability via the beta distribution [5].

The Nutrition Installation construction project at PambalahBatung Regional Public Hospital, Hulu Sungai Utara Regency, is part of a broader effort to expand healthcare facilities supporting nutrition services for inpatients and outpatients. Preliminary observation of the project identified several concerns: scheduling still relies on the S-curve without network-based time control, making potential delays difficult to predict in advance; activities on the critical path have not been clearly identified, risking a lack of management focus on the work most influential to completion; no quantitative analysis of duration estimation has been undertaken; and no analysis of feasible acceleration measures and their cost consequences has been performed — despite a schedule deviation of −20.35% recorded at week 26, which demands corrective action to keep the project on target.

Based on this background, the research problems addressed in this study are: (1) what is the estimated completion duration of the project based on CPM and PERT analysis; (2) which activities fall on the project's critical path; (3) how does the completion duration compare between the Existing Condition schedule and the schedules derived from CPM and PERT analysis, and what is the probability that the project will be completed on time relative to the planned (Existing Condition) baseline; and (4) what crashing measures, through time-cost trade-off, are required to keep the execution target achievable, and at what additional cost.

Accordingly, this study aims to: (1) analyse the estimated completion time of the project using CPM and PERT; (2) identify the activities that constitute the project's critical path; (3) compare the completion duration between the Existing Condition schedule and the schedules obtained from CPM and PERT analysis; and (4) analyse the acceleration measures available through time-cost trade-off, together with the additional cost required to meet the execution target.

The scope of this study is bounded as follows. Data analysed comprise secondary data — the planned schedule (time schedule/S-curve), the Bill of Quantities (BoQ), and Weekly Progress Reports — and primary data consisting of three-point time estimates (optimistic, most likely, pessimistic), indirect project cost, and acceleration parameters (overtime policy and labour availability), obtained through expert-judgement interviews with the executing contractor, supervising consultant, project owner, and design consultant directly involved in the project, with labour coefficients referring to the Unit Price Analysis (AHSP) under Circular Letter of the Director General of Construction Development No. 47/SE/Dk/2026. Quality and risk aspects are excluded from the analysis. Cost analysis is limited to costs relevant to acceleration — direct overtime cost and indirect project cost — rather than a comprehensive cost estimate. Acceleration measures are limited to the addition of working hours (overtime).

II. LITERATURE REVIEW

2.1 CRITICAL PATH METHOD (CPM) AND THE PRECEDENCE DIAGRAMMING METHOD (PDM)

CPM represents project activities as a deterministic network in which each activity has a single, known duration. The forward pass computes the Earliest Start (ES) and Earliest Finish (EF) of each activity, while the backward pass computes the Latest Start (LS) and Latest Finish (LF); the Total Float (TF) of each activity is then obtained as the difference between these values, and activities with TF = 0 constitute the critical path [5]. Where activities may legitimately overlap — as is common in building construction practice — the Precedence Diagramming Method (PDM) extends CPM by allowing Start-to-Start (SS), Finish-to-Finish (FF), and Start-to-Finish (SF) relationships with a lag, in addition to the conventional Finish-to-Start (FS) relationship. CPM's principal strength lies in its clarity in identifying the activities that directly govern total project duration; its principal limitation is that it treats duration as fixed and therefore cannot represent the uncertainty inherent in field conditions.

2.2 PROGRAM EVALUATION AND REVIEW TECHNIQUE (PERT)

PERT addresses this limitation by treating each activity duration as a random variable following a beta distribution, characterised by three estimates: optimistic time (a), most likely time (m), and pessimistic time (b). The expected duration of an activity is calculated as $te = (a + 4m + b) / 6$, and its variance as $\sigma^2 = ((b - a) / 6)^2$[8]. The expected project duration (Te) is the sum of te along the critical path, and the project standard deviation (S) is the square root of the sum of activity variances along that path. Given a target completion time

(Ts), the probability of on-time completion is obtained from the standard normal variate Z = (Ts − Te) / S [7]. PERT's three-point estimates are typically obtained through expert judgement — structured elicitation from personnel with direct project experience — which is a well-established practice where historical duration data are unavailable or unreliable [6].

2.3 TIME-COST TRADE-OFF (TCTO)

Where a target duration shorter than the normal schedule must be achieved, time-cost trade-off (crashing) analysis identifies which activities to accelerate and at what cost. The cost slope of an activity — the additional direct cost per unit time saved — is calculated as the ratio of the increase in direct cost to the reduction in duration achieved through crashing (e.g., overtime work), and crashing is applied first to the critical-path activity with the lowest cost slope [2]. Total project cost is the sum of direct cost, which rises as duration is compressed, and indirect cost, which falls as duration is compressed; the optimum crash duration is, in principle, the point at which total cost is minimised, though in practice crashing may instead be driven by a fixed contractual deadline rather than cost optimisation [6].

2.4 PRIOR STUDIES AND RESEARCH GAP

Prior studies applying CPM and PERT to building construction projects report varied outcomes. [1], analysing the KONI Building in Central Jakarta, obtained a CPM duration of 262 days and a PERT duration of 263 days, with a 46.41% probability of on-time completion — the near-identical CPM and PERT durations suggesting a sequential design in which the most-likely-time estimate (m) was effectively set equal to the CPM duration. [10], studying a residential building, found a PERT duration of 109 days against a planned 140 days, with an acceleration cost of approximately IDR 5.57 billion and an 84% completion probability. [11], analysing Muhammadiyah Hospital Gresik, reported a CPM duration 19 days shorter and IDR 307.76 million less costly than the PERT-derived alternative. [4], studying the Tabernacle Church PIK 2, found that foundation work planned at 123 days against an actual 150 days implied a cost difference of approximately IDR 304 million. [12] similarly found CPM-PERT scheduling more efficient than a conventional bar chart.

Across these studies, CPM and PERT are applied to recompute duration and the critical path from the existing schedule itself, with three-point estimates frequently anchored to the planned schedule rather than elicited independently. None positions the planned schedule as the object under test. The present study addresses this gap by deriving the CPM duration directly from the planned Existing Condition schedule and the PERT duration from independently elicited expert judgement, so that the discrepancy between the two serves as a diagnostic measure of the planned schedule's feasibility. As an additional methodological contribution, this study also demonstrates a simplified PERT computation that reuses the critical path already identified by CPM on the pure-FS network, rather than constructing a separate PERT network from scratch, and shows that the two approaches converge closely.

III. METHODOLOGY

3.1 RESEARCH DESIGN AND LOCATION

This study adopts a quantitative case-study design. The research was conducted on the Nutrition Installation construction project at PambalahBatung Regional Public Hospital, Hulu Sungai Utara Regency, South Kalimantan Province, Indonesia, a facility supporting nutrition services for inpatients and outpatients. The object of the study is the project's execution schedule — specifically activity durations and inter-activity relationships — analysed using CPM and PERT, focused on the time dimension of six main work components (K.1–K.6), with an original contract value of IDR 4,928,700,000 and a planned duration of 180 calendar days (Existing Condition baseline).

3.2 DATA AND SOURCES

The project was procured under contract No. 16/KONS/PGZ/RSUD-PB/2025 (11 June 2025) between PambalahBatung Regional Public Hospital as owner, CV. Arib Aiman as the executing contractor, and CV. Niskala ArsiteknikBanua as the supervising consultant. Two contract addenda were issued: Addendum-01 (No. 24.3/KONS/PGZ/RSUD-PB/2025, 10 July 2025) revised the contract value to IDR 5,021,600,000, and Addendum-02 (No. 53.3/KONS/PGZ/RSUD-PB/2025, 5 December 2025) extended the execution period to 204 calendar days. As of the week-26 progress report (3–7 December 2025), physical realisation stood at 79.65% against a planned 100.00%, a deviation of −20.35%.

Secondary data comprised the Bill of Quantities (BoQ), the time schedule/S-curve, and Weekly Progress Reports. Primary data comprised three-point time estimates (optimistic a, most likely m, pessimistic b), indirect project cost, and acceleration parameters (overtime policy and labour availability), obtained through structured interviews with 26 purposively selected expert respondents — comprising the executing contractor, supervising consultant, project owner representatives, and design consultant — with work experience ranging from under 3 years to more than 10 years. Labour coefficients for cost-slope calculation were drawn from the Unit Price Analysis (AHSP) under Circular Letter of the Director General of Construction Development No. 47/SE/Dk/2026.

3.3 ACTIVITY IDENTIFICATION AND NETWORK MODELLING

Twenty-one main activities were identified, coded A through V (code B was not used): A = Preliminary Works, C = Structural Works, D = Roofing, E = Wall & Plastering Works, F = Ceiling, G = Electrical Panel, H = Door/Window Frames, I = Floor & Wall Finishing, J = Feeder Cable, K = Lighting & Outlets, L = Sanitary Fixtures, M = Painting, N = Clean Water Installation, O = Waste Water Installation, P = Air Conditioning, Q = Mechanical Ventilation, R = Medical Gas Relocation, S = Fire Alarm System, T = CCTV, U = Façade, and V = Sewage Treatment Plant (STP). Each activity was modelled in two network types: (1) a Precedence Diagramming Method (PDM) network incorporating Start-to-Start (SS) relationships with lag, replicating the contractor's actual overlapping execution pattern; and (2) a pure Finish-to-Start (FS) network, in which each activity may begin only after its predecessor is fully complete, assuming no overlap. Relationship type was determined from construction-sequencing logic, and lag values were derived from the interval between corresponding bars on the planned S-curve; lag was treated as a deterministic constant. Ancillary activities spanning the full project duration were treated as Level of Effort (LoE) and excluded from critical-path determination.

3.4 CPM PROCEDURE

For both network types, CPM analysis followed the standard sequence: (1) compilation of the activity list with contractual durations and predecessor relationships; (2) construction of the Activity-on-Node (AON) diagram; (3) forward pass to obtain Earliest Start (ES) and Earliest Finish (EF); (4) backward pass to obtain Latest Start (LS) and Latest Finish (LF); (5) computation of Total Float (TF) and Free Float (FF); (6) identification of the critical path (TF = 0); and (7) comparison against the planned schedule to quantify the difference in duration and the potential for acceleration.

3.5 PERT PROCEDURE

PERT was applied independently on the pure-FS network using the three-point estimates (a, m, b) obtained from the 26 expert respondents. For each activity, the expected duration was calculated as $te = (a + 4m + b) / 6$ and the variance as $\sigma^2 = ((b - a) / 6)^2$. These values are identical for both network types, since duration estimation does not depend on the inter-activity relationship pattern. The AON network was then re-evaluated using te in place of the contractual duration to obtain the expected project duration (Te) and identify the PERT critical path; the sum of variances along that path ($\Sigma\sigma^2$) yields the project standard deviation $S = \sqrt{\Sigma\sigma^2}$. As a robustness check, an alternative, simplified PERT computation was performed by applying the three-point estimates directly to the critical-path activities already identified by CPM on the pure-FS network, without reconstructing the AON diagram. Completion probabilities for target durations Ts were obtained via the standard normal variate $Z = (Ts - Te) / S$.

3.6 TIME-COST TRADE-OFF (TCTO) PROCEDURE

Crashing analysis (time-cost trade-off) was performed on the pure-FS CPM network (210 days) as the un-optimised baseline, rather than on the PDM or PERT durations, so that the analysis captures the full acceleration effort without assuming overlap. Indirect project cost was compiled from project-management salary, occupational health and safety (K3), logistics/administration/finance, site office and storage, utilities and communications, stationery and documentation, transportation and fuel, and minor equipment, converted to a daily rate. Crashed duration was computed using an acceleration factor f = 1 + (overtime hours × an overtime productivity index of 0.75) / normal working hours. The cost slope of each activity — the additional direct (overtime) cost per day of duration reduction — was calculated using labour requirements derived from AHSP labour coefficients applied to BoQ volumes and divided by normal duration. Crashing was applied progressively to the critical-path activity (or activities, where multiple critical paths of equal length exist) with the lowest cost slope, until the target duration was reached, with net cost calculated as additional direct cost less the resulting saving in indirect cost.

IV. RESULTS

4.1 CPM ANALYSIS: PDM AND PURE-FS NETWORKS

Forward- and backward-pass computations were performed on both network types to obtain ES, EF, LS, LF, and Total Float (TF) for each of the 21 activities. The PDM network, which incorporates Start-to-Start relationships with lag to replicate the contractor's actual overlapping execution, yielded a project duration of 175 days, with critical path A–C–E–I–L–O (Figure 1); 19 of the 21 activities were found critical (TF = 0). This nearsimultaneous criticality is interpreted as an artefact of the contractor's just-in-time scheduling rather than a reflection of the work's underlying technical structure. The pure-FS network, which prohibits overlap, yielded a project duration of 210 days, with two critical paths of equal length — A–C–E–I–L–O and A–C–E–F–M–S, branching after activity E (Figure 2) — and only 9 of the 21 activities critical. Table 1 compares both CPM results against the contractual duration of 204 days established under Addendum-02: the PDM network completes 29 days ahead of this limit, while the pure-FS network exceeds it by 6 days.

Table 1. CPM results for the PDM and pure-FS networks

Network	Duration (days)	Critical activities	Critical path	vs. 204-day contract limit
PDM (SS + lag)	**175**	**19 of 21**	**A–C–E–I–L–O**	**29 days ahead**
Pure FS	**210**	**9 of 21**	**A–C–E–I–L–O / A–C–E–F–M–S**	**6 days over**

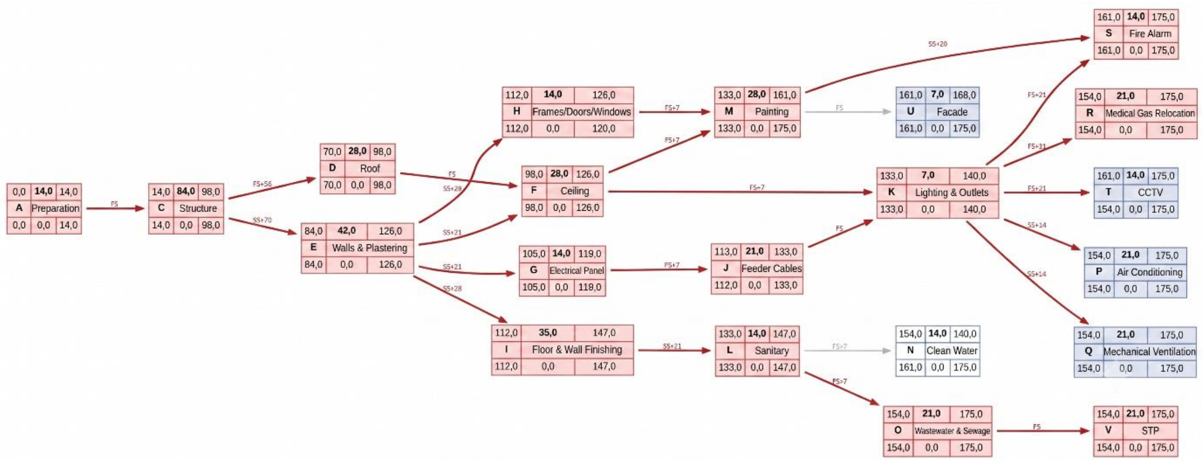

Figure 1. Activity-on-Node (AON) network for the PDM schedule (Start-to-Start relationships with lag)

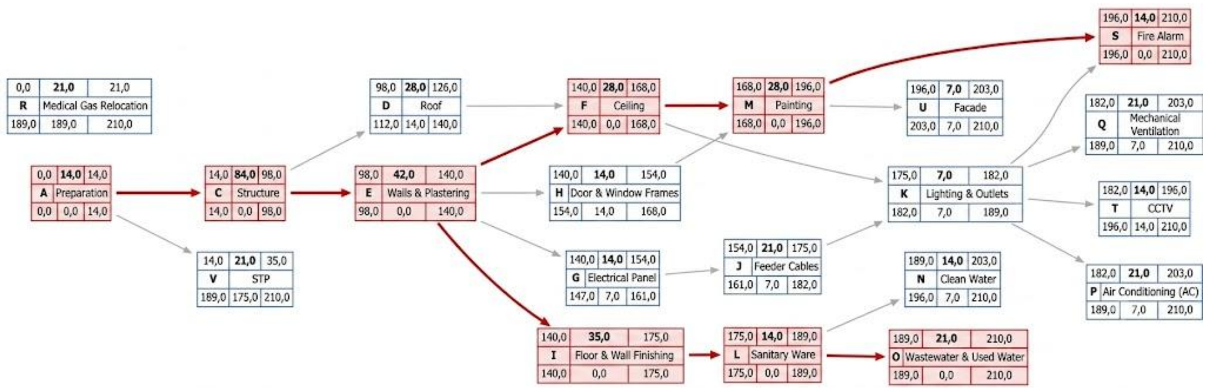

Figure 2. Activity-on-Node (AON) network for the pure Finish-to-Start (FS) schedule

4.2 PERT ANALYSIS: THREE-POINT ESTIMATES AND EXPECTED DURATION

Three-point time estimates (a, m, b) were collected from the 26 expert respondents for each of the 21 activities and used to compute the expected duration (te) and variance (σ^2) of each activity; these values are identical for both network types, as duration estimation is independent of the inter-activity relationship pattern. Table 2 summarises the results for the six activities that constitute the PERT critical path identified below, together with the two additional activities (I, L, O) that define the alternative CPM-derived critical path used as a robustness check. Substantial dispersion was observed among respondents' estimates, particularly for structural, wall, and selected mechanical/electrical/plumbing (MEP) activities, reflected in comparatively large variances.

Table 2. Three-point estimates, expected duration (te), and variance (σ^2) for critical-path activities

Code	Activity	a (days)	m (days)	b (days)	te (days)	σ^2
A	**Preliminary Works**	**13.35**	**16.62**	**21.04**	**16.81**	**1.64**

Code	Activity	a (days)	m (days)	b (days)	te (days)	σ^2
C	**Structural Works**	**50.88**	**65.46**	**83.31**	**66.01**	**29.20**
E	**Wall & Plastering Works**	**24.50**	**32.50**	**43.58**	**33.01**	**10.11**
F	**Ceiling**	**15.12**	**21.27**	**28.54**	**21.46**	**5.00**
M	**Painting**	**11.62**	**18.12**	**27.31**	**18.56**	**6.84**
U	**Façade**	**13.31**	**18.00**	**25.42**	**18.46**	**4.08**
I	**Floor & Wall Finishing**	**17.23**	**23.62**	**31.92**	**23.94**	**6.00**
L	**Sanitary Fixtures**	**12.85**	**18.38**	**26.69**	**18.85**	**5.33**
O	**Waste Water Installation**	**10.35**	**14.85**	**21.58**	**15.22**	**3.50**

Applying these expected durations to the pure-FS Activity-on-Node network yielded an expected project duration Te = 174.30 days (Figure 3), with critical path A–C–E–F–M–U, a sum of variances along that path $\Sigma\sigma^2 = 56.88$, and a project standard deviation S = 7.54 days. As a robustness check, an alternative computation applied the three-point estimates directly to the critical path already identified by CPM on the pure-FS network (A–C–E–I–L–O), without reconstructing the AON diagram, yielding Te = 173.84 days, $\Sigma\sigma^2 = 55.78$, and S = 7.47 days — closely matching the full PERT computation despite the two paths differing beyond their shared upstream segment A–C–E, supporting the robustness of the duration estimate to the choice of critical path.

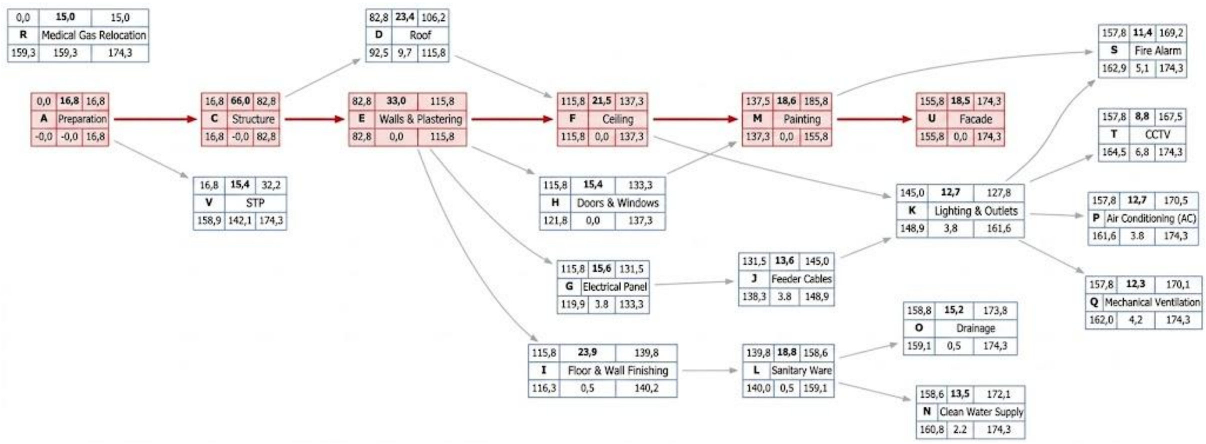

Figure 3. Activity-on-Node (AON) network for the pure-FS schedule using PERT expected durations (te)

4.3 COMPLETION PROBABILITY

Using Z = (Ts − Te) / S, the completion probability was computed for two target durations: the original contractual duration of 180 days and the Addendum-02 duration of 204 days. Table 3 reports the results for the primary PERT computation (critical path A–C–E–F–M–U) and the alternative CPM-derived computation (critical path A–C–E–I–L–O). At Te itself (174.30 days), the completion probability is, by definition, 50%.

Table 3. Completion probability for the 180-day and 204-day targets

PERT variant	Critical path	Te (days)	S (days)	Z (180 d)	P (180 d)	Z (204 d)	P (204 d)
Primary (full AON)	**A–C–E–F–M–U**	**174.30**	**7.54**	**0.76**	**77.5%**	**3.94**	**≈100%**
Alternative (CPM-derived path)	**A–C–E–I–L–O**	**173.84**	**7.47**	**0.82**	**≈79.5%**	**4.04**	**≈100%**

The PERT critical path (A–C–E–F–M–U) is governed by Preliminary Works (A), Structural Works (C), Wall & Plastering Works (E), Ceiling (F), Painting (M), and Façade (U), of which Structural Works, Wall & Plastering Works, and Painting contribute the largest variances (σ^2 = 29.20, 10.11, and 6.84 respectively), making them the principal sources of duration uncertainty. The −20.35% deviation recorded at week 26 is therefore more plausibly attributable to field-execution factors than to an unrealistic schedule target.

4.4 COMPARISON OF EXISTING CONDITION, CPM, AND PERT DURATIONS

Table 4 consolidates all duration estimates obtained in this study against the Existing Condition baseline and the Addendum-02 contractual limit.

Table 4. Comparison of scheduling methods

Method	Duration (days)	Nature	Remarks
Existing Condition(baseline/original contract)	**180**	**Deterministic (bar chart)**	**No critical path or float shown**
CPM – PDM network (SS + lag)	**175**	**Deterministic (network)**	**19 of 21 activities critical; 5 days ahead of original contract**
CPM – pure FS network	**210**	**Deterministic (network)**	**9 of 21 activities critical; 35-day gap reflects the value of overlap**
PERT – Te (FS network, primary)	**174.30**	**Probabilistic**	**S = 7.54 d; path A–C–E–F–M–U; P(180) ≈ 77.5%; P(204) ≈ 100%**
PERT – Te (CPM-FS path, alternative)	**173.84**	**Probabilistic**	**S = 7.47 d; path A–C–E–I–L–O; P(180) ≈ 79.5%; P(204) ≈ 100%**
Addendum-02 (actual contract limit)	**204**	**Contractual fact**	**Revised execution deadline after extension**

The PERT durations (174.30 or 173.84 days) closely match the CPM-PDM duration (175 days), while the CPM pure-FS duration (210 days) is substantially longer and less representative of actual conditions, as it disregards legitimate activity overlap. The recommended reference duration therefore falls within the 174–175-day range (CPM-PDM and PERT), on three grounds: it is approximately 5–6 days ahead of the Existing Condition/original contract (180 days), providing contingency margin; it is supported by an adequate confidence level (P(180) ≈ 77.5–79.5%); and it remains well within the Addendum-02 limit of 204 days. The pure-FS CPM duration of 210 days is not recommended as a planning reference, as it overestimates achievable duration.

4.5 TIME-COST TRADE-OFF (TCTO) OPTIMISATION

Indirect project cost was estimated at IDR 13,900,000 per month (equivalent to IDR 463,333 per day), comprising project-management salary, occupational health and safety (K3), logistics/administration/finance, site office and storage, utilities and communications, stationery and documentation, transportation and fuel, and minor equipment. Cost slopes were derived from labour coefficients under AHSP Circular Letter No. 47/SE/Dk/2026 applied to BoQ volumes; the two largest contributors to the crashed critical path were Structural Works (C), with a cost slope of IDR 6,365,217 per day over a maximum crashable duration of 21 days, and Wall & Plastering Works (E), with a cost slope of IDR 10,145,455 per day over a maximum crashable duration of 35 days. Crashing was applied to the pure-FS CPM baseline (210 days), as this baseline represents the un-optimised condition without assumed overlap; because the 210-day duration is shared by two critical paths of equal length (A–C–E–I–L–O and A–C–E–F–M–S) branching after activity E, crashing was applied in parallel along the shared upstream activities (A, C, E) to shorten both paths simultaneously, consistent with standard TCTO practice for multiple concurrent critical paths.

Table 5. TCTO results for the 204-day and 180-day targets

Target duration	Activities crashed	Total days crashed	Additional direct cost	Indirect cost saving	Net additional cost
204 days (Addendum-02)	**A (4 d) + C (2 d)**	**6**	**IDR 14,730,435**	**IDR 2,780,000**	**IDR 11,950,435**

Target duration	Activities crashed	Total days crashed	Additional direct cost	Indirect cost saving	Net additional cost
180 days (original contract)	**A (4 d) + C (23 d) + E (3 d)**	**30**	**IDR 178,836,364**	**IDR 13,900,000**	**IDR 164,936,364**

Because the daily indirect cost (IDR 463,333) is small relative to the activity cost slopes, the indirect-cost saving does not offset the additional direct cost of crashing at either target; the minimum-total-cost point therefore remains at the normal (uncrashed) duration. Crashing on this project is consequently effective for meeting a contractual time target rather than for reducing total project cost.

V. DISCUSSION

The CPM-PDM analysis, which replicates the contractor's actual overlapping schedule, produced a duration of 175 days — 5 days ahead of the contractual/Existing Condition baseline of 180 days. A more consequential finding, however, is that 19 of the 21 activities carry zero total float, indicating that the contractor's schedule was constructed on a just-in-time basis with practically no internal slack to absorb delay. The 175-day CPM-PDM duration does not, by itself, demonstrate that the target is easily achievable, because that duration is derived from the S-curve itself and therefore tests only the schedule's internal consistency. A genuine test of feasibility is provided by PERT, whose three-point estimates are elicited independently of the schedule: Te = 174.30 days, with P(180 days) = 77.5% and P(204 days) ≈ 100%, indicating that the contractual target is reasonably achievable.

The gap between the CPM pure-FS duration (210 days) and the PERT-FS duration (174.30 days) arises from two sources: first, the FS network prohibits overlap, forcing activities that are legitimately concurrent in practice into strict sequence; and second, the contractual per-activity durations are comparatively generous relative to expert estimates — for example, the contractual duration for Structural Works (84 days) approximates the pessimistic end of the expert estimate (b ≈ 83 days), even though its expected duration (te) is only 66.01 days. This helps explain the observed field deviation: at week 26, physical realisation stood at only 79.65% (a −20.35% deviation that had been widening since week 10) — not because the 180-day target was unrealistic (PERT places P(180) at 77.5%), but because of execution-level factors: with a schedule that carries almost no float, any delay accumulates directly into overall project delay. Addendum-02 (204 days) provided additional margin, raising the completion probability to approximately 100%.

The CPM-PDM network's finding of 19 broadly distributed critical activities is best understood as a scheduling artefact rather than evidence of technical necessity, arising because the contractor scheduled nearly all activities to finish in close succession. PERT-FS, by contrast, filters this criticality down to a single, technically coherent chain: A–C–E–F–M–U (Preliminary Works → Structural Works → Wall & Plastering Works → Ceiling → Painting → Façade), with Structural Works (C), Wall & Plastering Works (E), and Painting (M) contributing the largest variances ($\sigma^2 \approx 29.20$, 10.11, and 6.84 respectively). The managerial implication is that schedule control should be concentrated on the PERT critical path, with Structural Works prioritised given both its longest expected duration (te = 66.01 days) and its largest variance. Activities with substantial float on the pure-FS network — notably the Sewage Treatment Plant (V) and Medical Gas Relocation (R), with float of approximately 142 and 159 days respectively — should be rescheduled earlier in the project timeline to avoid end-loading, at no additional cost. Where the contractual target is to be maintained, controlled overlap combined with acceleration measures (additional working hours, additional labour crews, controlled parallel execution) becomes necessary.

VI. CONCLUSION

This study analysed the scheduling of the Nutrition Installation construction project at PambalahBatung Regional Public Hospital using CPM and PERT. Four conclusions follow. First, the CPM-PDM duration (175 days) and the PERT expected duration (Te = 174.30 days) are nearly identical and both cluster around the 180-day contractual duration, whereas the pure-FS network yields a substantially longer duration (210 days) because contractual per-activity durations exceed expert-elicited expected durations and the FS network disallows overlap. Second, on the CPM-PDM network, 19 of 21 activities are simultaneously critical (TF = 0), leaving almost no schedule slack; this widespread criticality resolves, under PERT, into a single technically coherent chain — Preliminary Works (A) → Structural Works (C) → Wall & Plastering Works (E) → Ceiling (F) → Painting (M) → Façade (U) — which governs project duration, with Structural Works and Wall & Plastering Works contributing the largest variance. Third, relative to the Existing Condition baseline (180 days), the CPM-PDM result (175 days) is nearly identical but tests only internal schedule consistency, whereas PERT — based on independent expert judgement — yields Te = 174.30 days with a 77.5% probability of completion within 180 days and approximately 100% within the Addendum-02 duration of 204 days; the −20.35% deviation recorded at week 26 is attributable more to field-execution factors than to an unrealistic schedule target, a conclusion corroborated by an alternative PERT computation (Te = 173.84 days; P(180) ≈ 79.5%; P(204) ≈ 100%) using the CPM-derived critical path, which shows results robust to the choice of critical path. Fourth, time-cost trade-off analysis shows that meeting the 204-day target requires a net additional cost of approximately IDR 11.95 million, and meeting the original 180-day target requires approximately IDR 164.94 million, concentrated on accelerating the shared upstream chain A–C–E common to both pure-FS critical paths (A–C–E–I–L–O and A–C–E–F–M–S); because daily indirect cost is small relative to activity cost slopes, crashing is effective for meeting the time target but not for reducing total project cost.

Based on these findings, three recommendations are offered for practice. Schedule control should be concentrated on the PERT critical path — Structural Works (C), Wall & Plastering Works (E), Ceiling (F), Painting (M), and Façade (U) — with Structural Works receiving priority attention given its combination of longest duration and largest variance. Activities with substantial float, particularly the Sewage Treatment Plant (V) and the Air Conditioning/Mechanical Ventilation/Medical Gas Relocation group (P, Q, R), should be rescheduled earlier in the project timeline to avoid end-loading, a measure that requires no additional cost. Finally, because the planned schedule carries almost no float and delays therefore accumulate directly, completing the project within the contractual deadline requires close control of the critical path together with contingency acceleration measures — additional working hours, additional labour crews, and controlled parallel execution — should delay occur. Future research could extend this approach to multiple similar healthcare-facility projects to test the generalisability of the near-zero-float pattern observed here, and could incorporate resource-levelling and risk-based simulation (e.g., Monte Carlo) alongside PERT to further refine completion-probability estimates.

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