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Comparative Evaluation of Critical Path Method and Critical Chain Project Management for Ultra Low-Pressure Compressor Installation in the Oil and Gas Industry

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Abstract**—**Schedule overruns remain a persistent challenge in oil and gas Engineering, Procurement, and Construction (EPC) projects, where the Critical Path Method (CPM) fails to account for resource constraints and duration uncertainty, leading to unrealistic baselines. This study aims to evaluate Critical Chain Project Management (CCPM) as an alternative scheduling approach for an Ultra-Low Pressure (ULP) compressor installation at the Pamaguan Plant, PT Pertamina Hulu Sanga Sanga, by identifying the critical chain, sizing the project and feeding buffers, measuring actual buffer utilization, and analyzing factors driving excessive buffer consumption. A case study methodology was applied using actual project data. Work Breakdown Structure analysis was conducted across 1,096 activities; the critical chain was identified in Microsoft Project, and buffer sizes were calculated using the Root Square Error Method (RSEM) with aggressive durations set at 50% of safe durations. Eighty-six activities formed the critical chain, yielding a 28-day project buffer and 27 feeding buffers. The project was completed 48 days beyond the CCPM target, resulting in a buffer utilization rate of 171% and placing the project in the red zone. These findings demonstrate that standard RSEM-based buffer sizing underestimates schedule risk in high-complexity oil and gas installations, where correlated uncertainties, constrained specialist resources, and behavioral phenomena, including Student Syndrome and Parkinson's Law, collectively accelerate buffer depletion.

Keywords**—** Critical Path Method, Critical Chain Project Management, Work Breakdown Structure, Project Buffer, Buffer Utilization.

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I. INTRODUCTION

Indonesia's national energy demand continues to rise alongside rapid economic growth and expanding industrial activities. The country has experienced a persistent decline in oil lifting since 2015 [1], intensifying the need for the oil and gas industry to enhance operational efficiency and accelerate the development of production infrastructure. One of the most critical strategies to sustain hydrocarbon production is the timely and efficient execution of facility development projects. Construction projects in this industry are inherently complex, involving multiple interconnected activities, diverse resources, strict time constraints, and coordinated organizational structures [2].

Construction projects in Indonesia frequently encounter inefficiencies during the execution phase. Sarwani et al. [3] documented that nearly 90% of Engineering, Procurement, and Construction (EPC) projects conducted between 2010 and 2020 experienced significant schedule delays, despite the adoption of lessons learned from earlier projects. These delays resulted in cost overruns and extended project durations, with root causes including inadequate resource planning and, critically, the fundamental limitations of conventional scheduling methodologies that fail to account for duration uncertainty and resource constraints. These recurring challenges are particularly severe in oil and gas projects, where strict timelines and operational continuity are critically important.

A major contributor to project delays is the limitation of the Critical Path Method (CPM), which treats activity durations as deterministic values, assumes unlimited resource availability, and provides no mechanism for explicitly managing schedule uncertainty [4]. As project complexity increases, these assumptions consistently lead to unrealistic schedules. Critical Chain Project Management (CCPM), developed by Goldratt [4] as an advancement of CPM, addresses these limitations by integrating resource availability into the scheduling process and consolidating individual task safety margins into centralized time buffers, namely the project buffer, feeding buffers, and resource buffers [5]. CCPM is also

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designed to address behavioral phenomena inherent in project execution: Student Syndrome, the tendency to delay task initiation until deadlines approach, and Parkinson's Law, in which work expands to fill the available time [6].

Several recent studies [7], [8], [9], [10], [11] have examined CCPM implementation primarily in non-oil and gas industries such as building construction, tourism infrastructure, and manufacturing. However, two significant gaps remain in the literature. First, empirical studies of CCPM in the oil and gas sector, where projects involve highly specialized equipment, stringent safety requirements, and extreme resource constraints, remain scarce. Second, existing studies predominantly report planned schedule performance rather than actual buffer utilization performance during project execution, leaving project managers without data-driven guidance on whether RSEM-based buffer sizing is sufficient to absorb real variability in complex installation projects.

This case study focuses on the installation of an Ultra-Low Pressure (ULP) compressor at the Pamaguan Plant facility in the PT Pertamina Hulu Sanga Sanga field. The project involves installing two ULP compressors, each with a capacity of 5 Million Standard Cubic Feet per Day (MMSCFD), to support operational requirements. The addition of these units is expected to increase the overall plant capacity, enabling the Pamaguan plant to achieve a target throughput of 25 MMSCFD. An overview of the ULP compressor installation project is illustrated in Figures 1 and 2. The construction and installation of an Ultra-Low Pressure (ULP) compressor involves highly complex project management challenges due to the integration of specialized equipment, interdependent construction activities, limited resource availability, and stringent operational and safety requirements within oil and gas facilities. These conditions create a high-risk project environment in which schedule deviations and resource conflicts can significantly affect project performance, operational continuity, and overall investment efficiency.

Figure 1. Installation Progress of the ULP Compressor

Figure 2. Completed Installation of the ULP Compressor

This study contributes two distinct novelties to the existing body of knowledge. First, in an industrial novelty context: unlike previous studies focused on non-oil and gas industries, this research provides empirical evidence of CCPM application in a real ULP compressor installation project within the oil and gas sector, a context that is rarely discussed in the existing literature. Second, as a methodological novelty, this study provides a quantitative evaluation of buffer utilization effectiveness using actual execution data from the Pamaguan Plant, demonstrating that buffer consumption reached 171% of the planned project buffer, directly challenging the assumption that standard RSEM-based buffer sizing is sufficient for high-complexity oil and gas installation projects.

This study, therefore, aims to: (1) identify the critical chain from 1,096 project activities using Microsoft Project; (2) calculate project and feeding buffers using the Root Square Error Method (RSEM); (3) evaluate buffer utilization performance against the planned CCPM schedule; and (4) analyze the technical and behavioral factors contributing to excessive buffer consumption. The findings are expected to make both theoretical and practical contributions to the advancement of project scheduling methodologies, particularly for EPC projects in the oil and gas sector.

II. Method

The compressor to be installed complies with API 11P/ISO 13631 specifications and is a three-stage reciprocating type with a horizontally opposed and balanced configuration, directly coupled to the driver without gearboxes. The maximum cylinder compression gas temperature is 330°F, and the maximum compressor speed is 1200 RPM. The suction pressure is 20 PSIG, while the discharge pressure reaches 275 PSIG. The design of the ULP is illustrated in Figure 3.

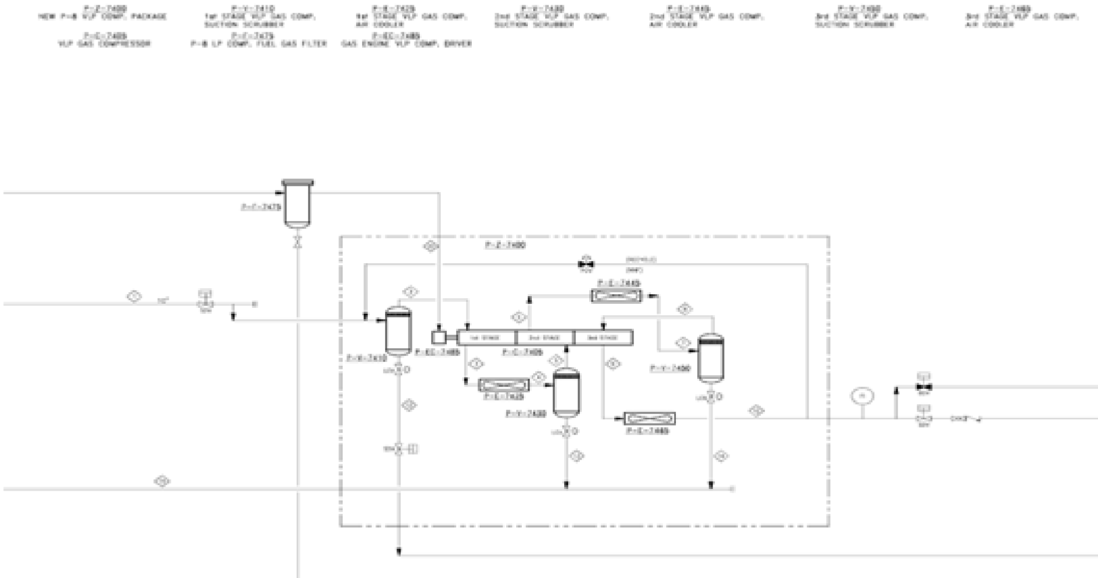

Figure 3. Process Flow Diagram of the ULP Compressor

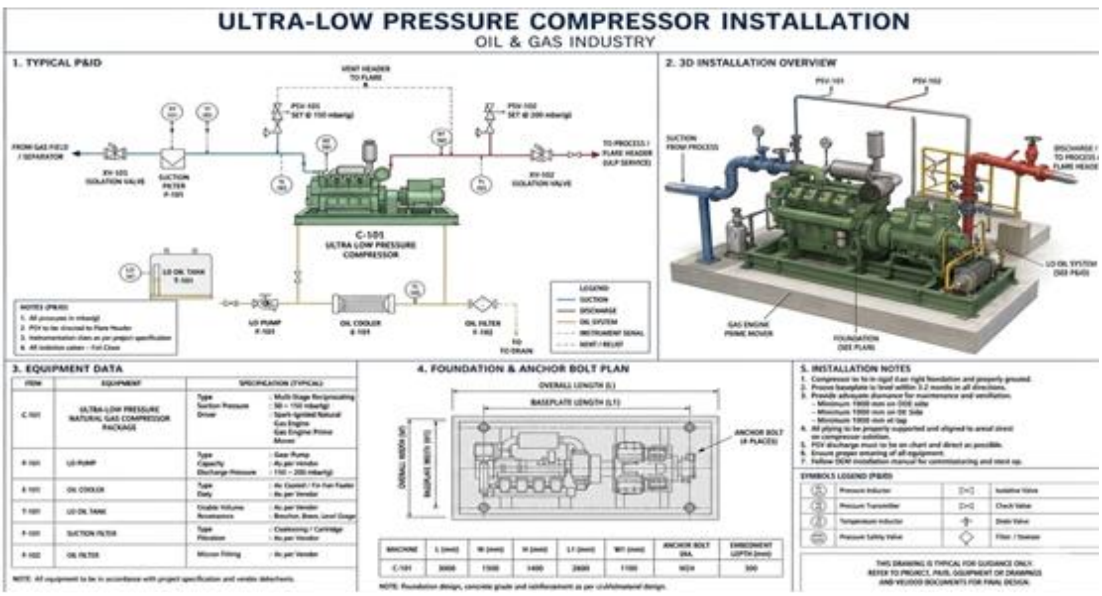

Figure 4. Ultra-Low Pressure Compressor Installation Diagram

Figure 4 presents a comprehensive engineering overview of a ULP compressor installation in the oil and gas industry, integrating process flow, mechanical layout, and installation requirements into a single cohesive design. It begins with a typical Piping and Instrumentation Diagram (P&ID) showing gas flow from the process suction drum through isolation valves and a suction filter into the compressor (C-101), with detailed instrumentation such as pressure and temperature indicators, and safety systems including pressure safety valves (PSVs) routed to a flare header. The compressor is supported by an auxiliary lubrication oil system consisting of an oil tank, lube oil pump, oil cooler, and filters to ensure reliable operation. A 3D installation view illustrates the physical arrangement of the compressor, Gas Engine as Prime Mover, piping, and structural base on a concrete foundation, highlighting suction and discharge lines, vent systems, and maintenance access. Supporting sections include equipment specifications (covering compressor type, operating pressures, and auxiliary systems), a foundation and anchor bolt plan detailing dimensions and mounting requirements, and installation notes emphasizing alignment, piping support, safety compliance, and commissioning procedures. Overall, the design reflects a fully integrated system that prioritizes operational safety, mechanical reliability, and maintainability for handling low-pressure gas streams typical of flare gas recovery or vapor-handling applications.

A. Research Method

This study analyzed the Work Breakdown Structure (WBS) to identify critical activities along with their respective durations. The Work Breakdown Structure was a key visual project tool, serving as a requirement for managing construction projects, as stated in [12]. Subsequently, a network diagram was developed using forward-pass calculations, consisting of Early Start (ES) and Early Finish (EF). ES represented the earliest time an activity could begin, while EF indicated the earliest time an activity could be completed, as described in [13]. Scheduling using the CCPM method was also performed to enable comparison with the conventional CPM method. The results of this comparison were then used to formulate recommendations for implementing CCPM strategies. The relationships among activities were represented using the Precedence Diagramming Method (PDM) [14], [15], [16], [17], [18], which was a project scheduling technique used to illustrate dependency relationships among activities in the form of a network, enabling the sequence of work execution to be determined logically and systematically.

B. Data Collection

To compare the CCPM and CPM methods in the ULP compressor installation project, data were collected through document-based analysis. This process involved gathering and reviewing various existing project scheduling documents, including the WBS, network diagrams, bar charts, CPM schedules, progress reports, and technical documents related to the installation of the ULP compressor. In addition, direct on-site observations were conducted to validate the schedule data and to understand the actual conditions of project execution, particularly for critical activities or bottlenecks. These observations aimed to confirm the consistency between documented data and field implementation.

C. Critical Chain Identification

The critical chain, representing the longest sequence of dependent tasks, was identified using Microsoft Project, as in [19]. Based on data from the ULP Compressor installation schedule at the Pamaguan Plant, there are 1,096 activities, comprising 86 critical and 1,010 non-critical. Critical and non-critical activities are illustrated in Figure 5.

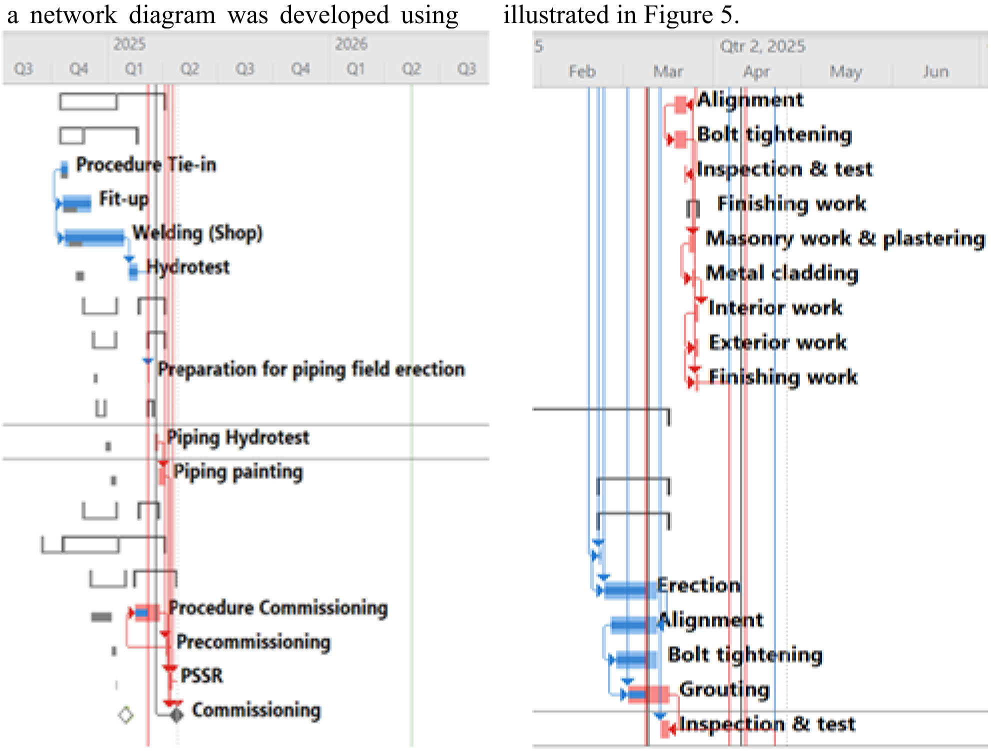

Figure 5. Critical and Non-Critical Activity Using Microsoft Project

D. Buffer Calculation and Positioning

In CCPM, there are three main types of buffers, namely project buffers, feeding buffers, and resource buffers, which protect the schedule while keeping the duration of individual tasks aggressive. The project buffer and feeding buffer were calculated using the Root Square Error Method (RSEM). The RSEM Formula employs safe durations and aggressive durations. Several studies [20], [21], [22] suggest that in CCPM, task durations are typically estimated at a 50% probability level, while the safety margins that are implicitly embedded within individual task estimates are consolidated into project buffers and feeding buffers. Buffer calculations are not performed for all project activities; they focus on activities on the critical chain and feeding chains to ensure that the buffer estimate is more representative of the project's schedule delay-risk flow. The resource buffer cannot be implemented because the researcher did not obtain comprehensive resource data (labor and equipment) for the VLP Compressor installation.

$$\sigma = \frac{Safe\ Duration - Aggressive\ Duration}{2} \quad (1)$$

$$\text{Buffer} = 2 \times \sqrt{\sum \sigma^2} \quad (2)$$

Buffer calculations are not performed for all project activities; they focus on activities on the critical chain and feeding chains to ensure that the buffer estimate is more representative of the project's schedule delay-risk flow. The resource buffer cannot be implemented because the researcher did not obtain comprehensive resource data (labor and equipment) during the ULP Compressor installation work.

The project buffer is placed at the end of the project's critical chain to maintain the project delivery date, as in [4]. Multiple feeding buffers are added to the end of non-critical chains to prevent them from becoming critical. Multiple resource buffers, which do not consume time, act as alerts for resource availability on the critical chain, as in [23].

E. Scheduling Tools

Microsoft Project is used for scheduling and includes features to achieve CCPM. MS Project functions allow for critical chain identification and the addition of buffers calculated using the Root Square Error Method (RSEM) to the schedule. Visualizing project buffers and buffer feeding within the schedule is useful for project monitoring.

F. Data Analysis

This analysis compares the CCPM schedule with the traditional (CPM), with an emphasis on project duration reduction. The CCPM approach highlights the importance of buffers as a mechanism for controlling uncertainty in project scheduling, as in [24]. In this study, more complex statistical measures, such as variance analysis, are not considered; therefore, the analysis remains focused on overall improvements in schedule performance. This simplified approach enables a direct assessment of the time-saving benefits offered by CCPM, particularly in the context of ULP Compressor installation.

III. Results and Discussion

This section summarizes the methodological implementation by identifying the critical chain, planning buffers, and rescheduling in Microsoft Project, and analyzes the impact of CCPM implementation on project time efficiency, including the schedule reduction achieved, while also discussing the limitations and challenges encountered during implementation.

A. Critical Chain Identification

The project's critical chain, which represents a sequence of interdependent activities that determines the total project duration, was identified and visualized as shown in Figure 6 through dependency and task-duration analyses. The determination of the critical chain and the project network structure was based on the planned schedule developed using the Critical Path Method (CPM) concept. The total project duration under the CPM approach is 329 days, with the planned schedule spanning from May 31, 2024, to April 25, 2025.

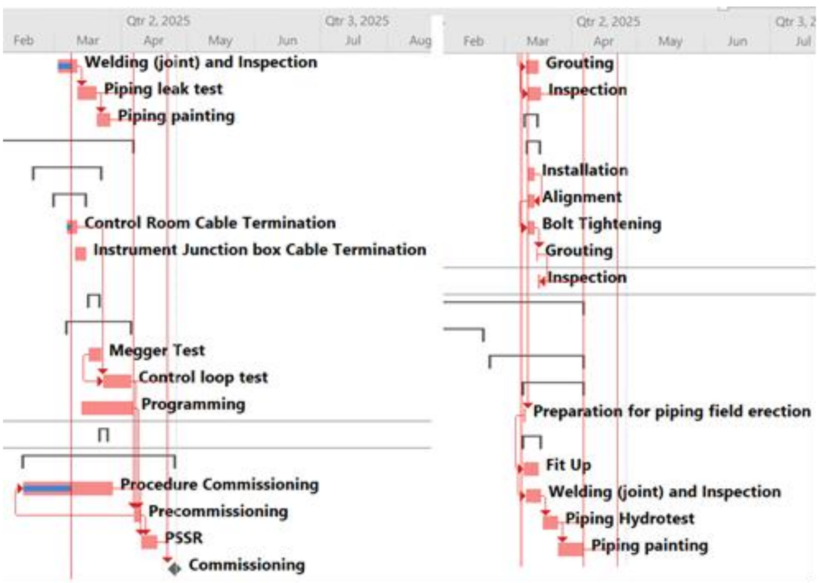

Figure 6. Critical Activities Filtered Using Microsoft Project

Using the RSEM, buffer planning was conducted to determine the size of the project buffer and feeding buffers. The project buffer is calculated as the square root of the sum of the squared variances of activity durations along the critical chain, while the feeding buffer, which serves to protect the critical chain from delays in non-critical paths, is calculated using the same approach based on the variances of activity durations within each feeding chain, as shown in Tables 1 and 2. This approach protects project completion and maintains the critical chain's stability against uncertainties in activity durations.

TABLE 1.
PROJECT BUFFER CALCULATION

Activity	Safe Duration (Days)	Aggressive Duration (Days)	σ^2
[ETA] Panel Safety Shutdown System, DCS dan F&G	0	0	0
[ETA] Panel Safety Shutdown System, DCS dan F&G	0	0	0
Backfill	6	3	2,3
Inspection	5	2,5	1,6
Inspection and test	1	0,5	0,1
Curing Time	3	1,5	0,6
Inspection and test	1	0,5	0,1
Curing Time	3	1,5	0,6
Water Proofing	1	0,5	0,1
Grating Installation	1	0,5	0,1
Formwork	1	0,5	0,1
Lean Concrete	1	0,5	0,1
Rebar	1	0,5	0,1
Formwork	1	0,5	0,1
Inspection & test	1	0,5	0,1
Concrete Pouring	1	0,5	0,1
Inspection and test	1	0,5	0,1
Erection	5	2,5	1,6
Alignment	4	2	1
Inspection	1	0,5	0,1
Installation	3	1,5	0,6
Alignment	3	1,5	0,6
Gas detector	5	2,5	1,6
Gas detector	4	2	1
Megger Test	5	2,5	1,6
Control loop test	5	2,5	1,6
Programming	14	7	12,3
Hand fire extinguisher	3	1,5	0,6
Procedure Commissioning	35	17,5	76,6
Pre-Commissioning	3	1,5	0,6
PSSR	7	3,5	3,1
Commissioning	7	3,5	3,1
Project Buffer = 2 x $\sqrt{\sum \sigma^2}$	28		

Note: Not all critical activities are presented in the table above; however, the Project Buffer calculation has included all critical activities

The feeding buffer is determined separately for each feeding chain (FC) leading into the critical chain, because each path has distinct variability and delay-risk characteristics. Feeding chains are not explicitly displayed in Microsoft Project; therefore, they are identified by analyzing precedence relationships and tracing non-critical paths leading to the critical chain. Not all non-critical activities are categorized as feeding chains; only those with dependency relationships that directly feed into the critical chain are included in feeding buffer calculations. The number of feeding buffers in a project is not fixed but depends on the number of identified feeding chains, with each non-critical path leading to the critical chain requiring its own buffer.

TABLE 2.
FEEDING BUFFER CALCULATION RESULT

Item	Safe Duration (Days)	Aggressive Duration (Days)	σ2	Feeding Buffer Calculation (Days)
Feeding Buffer 1				49
Feeding Buffer 2				0
Feeding Buffer 3				0
Feeding Buffer 4				20
Feeding Buffer 5				25
Preparation	1	1	0	
Erection	38	19	90,3	
Alignment	38	19	90,3	
Bolt tightening	38	19	90,3	
Grouting	22	11	30,3	
Inspection & test	21	11	25,0	
Feeding Buffer 6				36
Feeding Buffer 7				17
Feeding Buffer 8				18
Feeding Buffer 9				2
Feeding Buffer 10				24
Feeding Buffer 11				4
Feeding Buffer 12				31
Feeding Buffer 13				12
Feeding Buffer 14				3
Feeding Buffer 15				51
Feeding Buffer 16				0
Feeding Buffer 17				0
Feeding Buffer 18				3
Feeding Buffer 19				2
Feeding Buffer 20				0
Feeding Buffer 21				0
Feeding Buffer 22				0
Feeding Buffer 23				2
Feeding Buffer 24				4
Feeding Buffer 25				32
Feeding Buffer 26				9
Feeding Buffer 27				4

B. Buffer Positioning

The positioning of buffers in this study is based on the principles of CCPM, where feeding buffers are placed at the junction between non-critical paths (feeding chains) and the critical activity, while the project buffer is placed at the end of the critical chain. This placement aims to protect the critical chain from potential delays arising from both internal variability within critical activities and external disturbances originating from non-critical paths. Table 3 presents the relationships between activities on the critical path and those on the non-critical path. Critical activities are denoted by the code "C," while non-critical paths (feeding chains) are identified using the code "FC".

A *feeding chain* (FC) refers to a sequence of activities that are not part of the critical path but are still connected to the *critical chain*. Although these activities do not directly determine the total project duration, any delays within them can impact the critical chain, as they eventually merge into it at certain points. To mitigate this risk, CCPM introduces *feeding buffers* placed at the junctions where feeding chains connect to the critical chain. These buffers act as protective mechanisms that prevent delays on non-critical paths from directly affecting the overall project duration. Therefore, although feeding chain activities generally have greater scheduling flexibility than critical activities, their management remains essential given their potential influence on overall project performance. For example, Feeding Chain 1 (FC1) consists of several non-critical activities such as concrete pouring, formwork, lean concrete, and excavation, which serve as predecessors to the critical activity *Inspection and Test (C5)*. In this case, a feeding buffer is placed between Feeding Chain 1 and the *Inspection and Test (C5)* activity to protect the critical chain from potential delays originating from the non-critical sequence.

TABLE 3.
RELATIONSHIP BETWEEN CRITICAL ACTIVITIES AND NON- CRITICAL PATH (FEEDING CHAIN)

Activity	Predecessors	Successors
[ETA] Panel Safety Shutdown System, DCS dan F&G (C1)		C67
[ETA] Panel Safety Shutdown System, DCS dan F&G (C2)	C1	C67
Backfill (C3)	C10	C4
Inspection (C4)	C3	C86
Inspection and test (C5)	FC1	C6
Curing Time (C6)	C5	C7
Inspection and test (C7)	FC2	C8
Curing Time (C8)	C7	C9
Water Proofing (C9)	C8	C10
Grating Installation (C10)	C9	C3
Formwork (C11)	FC3	C12
Lean Concrete (C12)	C11	C13
Rebar (C13)	C12	C14
Formwork (C14)	C13	C15
Inspection & test (C15)	C14	C16
Concrete Pouring (C16)	C15	C17
Inspection and test (C17)	C16	C18
Curing Time (C18)	C17	C19
Water Proofing (C19)	C18	C20
Grating Installation (C20)	C19	C86
Erection & Assembly (C21)	FC4	C40
Preparation (C22)	FC5, FC6, C37	C23
Control Room Cable Termination (C70)	FC23 & FC24	C80
Pressure transmitter (C71)	C61	C72
Pressure gauge/indicator (C72)	C71	C73
Pressure differential gauge/indicator (C73)	C72	C74
Pressure control valve (C74)	C73	C75
Pressure safety valve (C75)	C74	C76
Shutdown valve & blowdown valve (C76)	C75	C77
Flame detector (C77)	C76	C78
Gas detector (C78)	C77	C80 & C82
Megger Test (C79)	C67 & FC25	C80
Control loop test (C80)	C79 & C70 & C60	C59 & C84 & C86
Programming (C81)	C78	C84
Hand fire extinguisher (C82)	C78 & C69	C86
Procedure Commissioning (C83)	C84	C85
Pre-Commissioning (C84)	C35 & C54 & C57 & C39 & C31 & FC26 & C50 & C80 & C81	C83 & C85
PSSR (C85)	C83 & C84	C86
Commissioning (C86)	C80 & C82 & C85 & C33 & C20 & C4 & C55 & C58 & FC27	

Note: Not all critical activities are presented in the table above

The identification results indicate several main integration points between feeding chains and the critical chain, such as activities Preparation for piping field erection (C51) and Pre-Commissioning (C84), which receive multiple critical activities and non-critical paths (feeding chains) simultaneously. This condition reflects a high level of project network complexity; therefore, at these points, more than one feeding buffer is assigned for each feeding chain, ensuring that each source of uncertainty can be controlled separately. At the last critical activity/commissioning (C86), there are eight critical activities and one feeding chain leading into the critical chain.

This study does not employ a work-time reduction approach, as buffer calculations are based on actual project data, thereby enabling empirical representation of duration uncertainty without requiring assumptions of activity duration compression. This study provides a novel contribution by analyzing the planning schedule of the ULP compressor project at the Pamaguan Plant PHSS, thereby demonstrating the relevance and practical benefits of CCPM implementation in a specific, high-variability project context. These findings emphasize that although CCPM is effective in managing activity duration uncertainty, additional approaches are required to address systemic risks to achieve more optimal protection of project schedules.

C. Project Rescheduling (CCPM Schedule)

By transforming safe durations into aggressive durations (50% of the planned duration), hidden safety was systematically removed from individual activities and reallocated into centralized buffers. This restructuring produced a CCPM-based schedule in which uncertainty is explicitly managed through project and feeding buffers. The CCPM method utilizes buffer time added at the end of the critical chain network to reduce safety time, as in [25]. The project buffer is set by adding 28 days to the final critical activity, namely commissioning (C86). A total of 27 feeding buffers are incorporated into the CCPM schedule to serve as links between the feeding chains and the corresponding critical activities, as shown in Figure 7 below. Resource reallocation was also carried out, resulting in a more realistic schedule and minimizing the potential for project delays. The total project duration before the implementation of CCPM was 328 days, with the schedule spanning from 31 May 2024 to 24 April 2025.

D. Buffer Utilization

Based on the calculation results, a 28-day project buffer was obtained. The CCPM schedule spanned from 31 May 2024 to 24 April 2025, while the actual completion date was 11 June 2025, resulting in a delay of approximately 48 days. This resulted in a buffer utilization of approximately 171%, indicating that, within the CCPM framework, the planned buffer was unable to accommodate the duration deviations that occurred during project execution fully. Consequently, buffer utilization exceeded the planned tolerance threshold, placing the project in the red zone of the CCPM buffer management mechanism. This condition reflects a high risk of project delay and suggests that corrective actions should have been implemented earlier to prevent further escalation of schedule deviations.

When implementing buffer zones, companies need to carefully monitor the use of the project buffer. The buffer time is divided into three categories: the green zone (0 – 9 days), the yellow zone (10 –18 days), and the red zone (more than 18 days), as shown in Table 4. The determination of each zone boundary is based on the calculated 28-day project buffer.

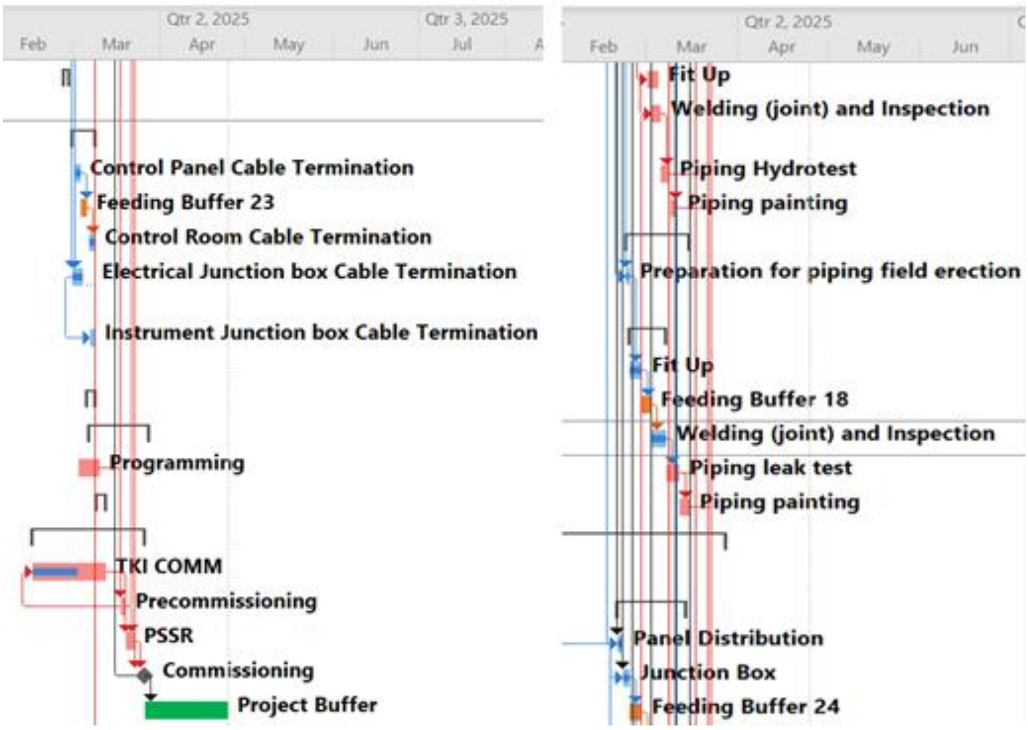

Figure 7. CCPM Schedule and Buffer Positioning

TABLE 4.
PROJECT BUFFER CONSUMPTION ZONES

Buffer Consumption Zone	Buffer Used Duration	Description
< 33%	0 - 9 Days	Safe
33% ≤ x ≤ 67%	10 - 18 Days	Caution
> 67%	> 18 Days	Critical

Nugroho and Suroso [26] and Saputra [27] explained that project success and the effectiveness of the CCPM schedule are determined by proper management of buffer time. In the ULP Compressor Installation project, the buffer zone position falls within the red category. This condition reflects a high risk of project delay and indicates that corrective actions should have been implemented earlier to prevent the escalation of schedule deviations. The buffer's inability to absorb delays may be attributed to several factors, including high variability in activity durations, limited resources from the executing contractor, and delays in the delivery of construction materials. In addition to technical factors, project delays were influenced by behavioral aspects such as the Student Syndrome and Parkinson's Law, in which activities are not initiated optimally, and work tends to expand to fill the available time, thereby eliminating opportunities for earlier completion. The combination of these phenomena increases the deviation between actual and planned durations and accelerates buffer consumption. These findings indicate that the effectiveness of CCPM implementation depends not only on buffer calculations but also on the control of behavioral and managerial factors in project execution.

From a project management perspective, these results indicate that although the CCPM approach has been implemented, the level of uncertainty and complexity in the ULP Compressor installation project remains very high. This suggests that the buffer estimates calculated using the safe-duration and aggressive-duration approaches have not fully captured the project's actual risks. In addition, the limited implementation of resource buffers due to the lack of comprehensive resource data may also have affected the effectiveness of project schedule control. Therefore, the findings of this study emphasize the importance of periodic buffer monitoring through buffer management and Fever Charts, so that potential delays can be identified earlier, before excessive buffer consumption occurs. Overall, the research findings demonstrate that buffer utilization exceeding the established threshold indicates low project schedule reliability and suggest that the initial baseline schedule was highly optimistic. These findings further reinforce the argument that project control cannot rely solely on CPM but also requires a buffer–management–based approach, such as CCPM, to improve visibility into project delay risks. These findings raise two critical questions that warrant deeper examination: first, how does the buffer utilization observed in this project compare to outcomes reported in comparable CCPM studies, and second, whether the RSEM buffer sizing methodology is inherently limited in its ability to adequately protect high-complexity oil and gas installation projects.

E. Comparison of Buffer Utilization

The buffer utilization rate of 171% observed in this project is a central finding that requires contextual interpretation. To assess whether this outcome reflects a project-specific failure or a systemic characteristic of high-complexity installation projects, the present finding is compared against buffer utilization rates reported in comparable CCPM studies across different industries and project contexts.

TABLE 8.
COMPARATIVE SUMMARY OF BUFFER UTILIZATION

Study	Industry / Project Type	Buffer Method	Buffer Size	Zone
Walidonna & Vanany (2020) [5]	Tourism landscape design	RSEM	17,86 Days	Yellow
Mirayudia et al. (2021) [8]	Airport building (Indonesia)	RSEM + Lean	26 Days	Yellow
Nugroho & Suroso (2023) [26]	Flyover toll road (Indonesia)	RSEM	149 Days	Red
Samodra et al. (2025) [19]	Security vessel construction	RSEM	10,8 Days	—
Present study (2024–2025)	ULP Compressor, Oil & Gas	RSEM	28 days	Red (critical)

The comparative data in Table 8 reveal that buffer utilization in the present study substantially exceeds that reported in comparable CCPM implementations. While studies in general construction and infrastructure projects typically report buffer utilization within the yellow to red zone boundary (33% – 100%), the 171% utilization observed in the ULP compressor installation project represents a qualitatively different outcome, one in which the project buffer was entirely consumed, and the project still experienced a 48-day delay beyond the CCPM completion date.

Three distinguishing characteristics of oil and gas compressor installation projects likely explain this divergence. First, activity duration variability in oil and gas projects is systematically higher than in general construction, driven by equipment delivery lead times, specialized inspection requirements (such as piping hydrotest and PSSR), and the frequency of scope changes arising from interface management between new and existing facility systems. Second, resource availability is more constrained in oil and gas projects, as specialized trades, such as certified welders, instrumentation technicians, and commissioning engineers, are often shared across multiple concurrent projects in the same field area, creating resource contention that cannot be fully anticipated during initial scheduling. Third, the Procedure Commissioning activity, which contributed the single largest variance term ($\sigma^2 = 76.6$) in the project buffer calculation, represents a multi-disciplinary commissioning coordination activity that is uniquely complex in oil and gas contexts, where simultaneous commissioning of process, mechanical, electrical, and instrumentation systems must be orchestrated under live facility operating conditions.

These findings contribute to a growing body of evidence suggesting that CCPM's buffer management framework, while theoretically robust, requires industry-specific calibration. The standard RSEM buffer sizing parameters, aggressive durations at 50% of safe durations, may be appropriate for general construction environments where activity duration distributions are moderately skewed, but appear insufficient for oil and gas installation projects where duration uncertainty is significantly higher, and resource constraints are more severe. This observation aligns with Ghaffari and Emsley's [21] call for context-specific refinement of CCPM implementation parameters and reinforces the need for empirical validation studies across diverse project environments.

F. Limitations of RSEM-Based Buffer Sizing in Oil and Gas Projects

The Root Square Error Method (RSEM) is based on the statistical principle that independent, normally distributed uncertainties combine according to the square root of the sum of their squares, a principle derived from the Central Limit Theorem. While this statistical foundation is theoretically sound, its application to oil and gas construction projects entails several assumptions that may not hold in practice, which may explain the inadequacy of the 28-day project buffer calculated in the present study.

First, RSEM assumes that activity duration uncertainties are statistically independent. In oil and gas projects, this assumption is frequently violated. Weather disruptions, equipment delivery delays, and contractor resource shortages affect multiple activities simultaneously, creating correlated uncertainties that cause delays to cluster rather than cancel out. When activity delays are positively correlated, as they systematically are in oil and gas construction, the actual combined uncertainty is greater than the RSEM formula predicts, resulting in undersized buffers.

Second, RSEM assumes that setting aggressive durations at 50% of safe durations adequately captures the uncertainty range. However, in the present project, the safe-to-aggressive duration ratio of 2:1 may underestimate the actual variability for high-uncertainty activities. The Procedure Commissioning activity, for example, had a safe duration of 35 days and an aggressive duration of 17.5 days, yet the actual execution of commissioning-related activities contributed disproportionately to the overall delay. This suggests that the 50% aggressive duration assumption significantly underestimates the right-tail risk of the duration distribution for complex multi-disciplinary activities in oil and gas environments.

Third, RSEM does not account for systemic risk events that are rare but high-impact and not reflected in historical duration data used for buffer sizing. In oil and gas projects, systemic risks include regulatory hold points that suspend work pending approval by the inspection authority, safety incidents that trigger facility-wide work stoppages, and late equipment deliveries due to global supply chain disruptions. These risks fall outside the duration variability captured by the safe-to-aggressive duration differential in RSEM, yet their occurrence can consume a large portion of the project buffer in a single event.

The limitations identified above suggest that RSEM-based buffer sizing, as conventionally implemented with 50% aggressive durations, may be systematically inadequate for oil and gas installation projects. Future research should investigate whether modified RSEM parameters, such as aggressive durations at 40% or 45% of safe durations rather than 50%, or hybrid approaches combining RSEM with Monte Carlo simulation-based risk assessment, would produce more adequate buffers for this project context [28]. Additionally, developing industry-specific buffer-sizing multipliers for oil and gas projects, analogous to the location factors used in cost estimation, offers a practical avenue to improve CCPM implementation in this sector.

IV. CONCLUSION

This study examined Critical Chain Project Management (CCPM) as an alternative to the Critical Path Method (CPM) for the Ultra-Low Pressure (ULP) compressor installation project at the Pamaguan Plant, PT Pertamina Hulu Sanga Sanga, with the aim of pursuing four objectives. The findings are reported in correspondence with each objective. Of the 1,096 activities comprising the project schedule, 86 were classified as critical through dependency and resource analysis in Microsoft Project. These activities formed the critical chain, the longest resource-constrained sequence governing the total project duration of 328 days under the CCPM framework.

Applying the Root Square Error Method with aggressive durations set at 50% of safe durations, a project buffer of 28 days was calculated and positioned at the end of the critical chain. Twenty-seven feeding buffers were also placed at the junctions between non-critical feeding chains and the critical chain, providing layered protection against delays propagating from parallel workstreams. Actual project completion occurred on 11 June 2025, representing a 48-day overrun against the CCPM target date of 24 April 2025. This delay produced a buffer utilization rate of 171%, exceeding the full 28-day project buffer and placing the project in the red zone of the CCPM buffer management framework. The result indicates that the RSEM-based buffer was insufficient to absorb the cumulative schedule deviations encountered during execution, calling into question the suitability of standard RSEM parameters for high-complexity oil and gas installation projects.

Three categories of contributing factors were identified. Technically, high activity-duration variability, particularly in multi-disciplinary commissioning (Procedure Commissioning, $\sigma^2 = 76.6$), combined with constrained specialist resources and material delivery delays, generated correlated uncertainties that the RSEM formula's independence assumption could not capture. Methodologically, the standard 2:1 safe-to-aggressive duration ratio underestimated right-tail risk for complex activities, and RSEM does not account for systemic, high-impact events such as regulatory hold points or supply chain disruptions. Behaviourally, Student Syndrome — observed in activities including lighting fixture and lightning system installation, and Parkinson's Law, evident in structural erection, welding and inspection, and piping hydrotest, delayed task initiation, and caused work to expand to fill available time, further accelerating buffer depletion.

Collectively, these findings confirm that CCPM provides a structurally superior scheduling framework relative to CPM by making uncertainty explicit through buffer management rather than embedding it within individual task durations. However, its practical effectiveness in the oil and gas sector depends on two conditions: (i) buffer sizes calibrated with industry-specific parameters such as aggressive durations at 40–45% of safe durations or hybrid RSEM–Monte Carlo approaches rather than the generic 50% convention, and (ii) availability of comprehensive resource data to enable resource buffer implementation.

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