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Optimization of the Duration of a Steam Power Plant Overhaul Project Using Resource-Constrained Critical Path Method (RCPM)-Based Scheduling

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Resource-Constrained Critical Path Method (RCPM); Critical Path Method (CPM); Project Duration Optimization; Project Scheduling; Steam Power Plant Overhaul.

Abstract

Steam Power Plant (Pembangkit Listrik Tenaga Uap [PLTU]) overhaul projects require effective scheduling to maintain electricity supply reliability. These projects are characterized by shutdown maintenance activities, limited availability of specialized labor resources, and strict outage windows. Conventional scheduling practices generally do not integrate labor resource constraints with activity precedence relationships, resulting in project schedules that are less reliable during execution. This study presented an empirical application of the Resource-Constrained Critical Path Method (RCPM)-based scheduling approach in a steam power plant overhaul project. The objectives were to identify critical and non-critical activities in the baseline Critical Path Method (CPM) schedule, implement RCPM, analyze the characteristics of the resulting schedule, and evaluate project duration optimization. A quantitative applied research approach was employed through project scheduling modeling using Microsoft Project. Resource leveling was applied to resolve labor resource conflicts under fixed resource availability conditions without increasing maximum resource units (Max Units) or working hours. The results showed that RCPM produced a resource-feasible schedule with a project duration of 33 days, representing an 8.33% reduction from the established 36-day project duration target. The optimized schedule also had implications for improving project cost efficiency by reducing time-dependent labor costs and project operational overhead costs. Furthermore, sensitivity analysis showed that reductions in labor resource availability significantly increased project duration beyond the established target, indicating that sufficient labor availability was essential for maintaining schedule performance.

INTRODUCTION

Steam Power Plants (Pembangkit Listrik Tenaga Uap [PLTU]) play a vital role in maintaining the reliability of electricity supply systems (Akbar et al., 2025; Jibril et al., 2025; Mi'rajuddin et al., 2026; Putra, 2025). To sustain operational reliability, generation efficiency, and equipment service life, power generation units require periodic maintenance activities, including major overhauls. An overhaul project involves the planned disassembly, inspection, testing, repair or replacement, reassembly, and commissioning of major equipment after the generating unit has been temporarily shut down for maintenance (shutdown maintenance) (Al Ameeri et al., 2023; Babcock & Wilcox Company, 2015; Brown, 2018). Therefore, the successful execution of an overhaul project depends largely on developing a project schedule that achieves the required project duration while maintaining quality, occupational safety, and cost efficiency (Danfulani et al., 2023; Kerzner, 2021; Littler et al., 1991).

Unlike conventional construction projects, Steam Power Plant overhaul projects are characterized by shutdown maintenance activities, limited outage windows, and numerous multidisciplinary tasks that must be completed within a relatively short period (Basu & Debnath, 2019; Kim, 2020; Liu et al., 2024). In addition, many maintenance activities require specialized labor resources that are available in limited quantities. Consequently, project scheduling is governed not only by activity precedence relationships but also by labor resource availability. If labor resource constraints are not adequately considered during project planning, resource conflicts may occur, potentially delaying project completion, increasing project costs, and extending the planned outage period (Electric Power Research Institute [EPRI], 2013; International Energy Agency [IEA], 2022; Kolisch, 1996). Therefore, optimizing project duration while considering labor resource constraints is a critical aspect of Steam Power Plant overhaul planning.

In practice, overhaul project schedules are still frequently developed using conventional Gantt charts that primarily illustrate activity sequences without systematically identifying critical activities, non-critical activities, or labor resource limitations (Danfulani et al., 2023; Kerzner, 2021; Littler et al., 1991). The Critical Path Method (CPM) is one of the most widely adopted scheduling techniques because it determines project duration based on activity precedence relationships and activity durations (Danfulani et al., 2023; Kerzner, 2021; Littler et al., 1991). However, CPM assumes unlimited resource availability and therefore cannot adequately represent actual project conditions in which multiple activities compete simultaneously for the same labor resources (EPRI, 2013; IEA, 2022; Mohamed et al., 2021). Consequently, although a CPM schedule may be logically feasible, it is not necessarily resource-feasible under conditions of limited labor availability (EPRI, 2013; IEA, 2022; Kolisch, 1996).

To overcome this limitation, Resource-Constrained Scheduling (RCS) incorporates resource availability into the scheduling process to produce more realistic project schedules (EPRI, 2013; IEA, 2022; Kolisch, 1996). Previous studies have proposed various approaches for resolving resource conflicts, including heuristic priority rules, multi-objective optimization, stochastic scheduling, and Resource-Constrained Critical Path Method (RCPM)-based scheduling (Altuncan & Vanhoucke, 2025; EPRI, 2013; Kolisch, 1996; Larson & Gray, 2020; Mohamed et al., 2021; Nag, 2018; State Electricity Company [PLN], 2024). Among these approaches, resource leveling is widely applied because it adjusts the start times of non-critical activities by utilizing available total slack without increasing labor resources or working hours (Danfulani et al., 2023; Kerzner, 2021; Littler et al., 1991). Building upon this principle, RCPM integrates CPM with labor resource constraints through resource leveling to produce a resource-feasible schedule under fixed labor resource availability conditions (EPRI, 2013; Larson & Gray, 2020; Mohamed et al., 2021).

Although substantial progress has been made in resource-constrained project scheduling, previous studies have primarily focused on methodological development and applications in construction and manufacturing projects (Altuncan & Vanhoucke, 2025; EPRI, 2013; Kolisch, 1996; Larson & Gray, 2020; Mohamed et al., 2021; Nag, 2018; PLN, 2024). Empirical implementation of RCPM in Steam Power Plant overhaul projects remains limited, particularly for projects characterized by shutdown maintenance, limited specialist labor resources, and restricted outage windows. Therefore, further empirical evidence is required to evaluate the effectiveness of RCPM under actual overhaul project conditions.

The novelty of this study lies in providing empirical evidence regarding the effectiveness of the Resource-Constrained Critical Path Method (RCPM) for optimizing Steam Power Plant overhaul project durations by generating resource-feasible schedules under realistic labor resource constraints without increasing labor resources or working hours. Accordingly, this study aimed to identify critical and non-critical activities in the baseline Critical Path Method (CPM) schedule, implement the Resource-Constrained Critical Path Method (RCPM), analyze the characteristics of the resulting RCPM schedule, and evaluate project duration optimization in terms of achieving project duration targets, implications for estimated operational cost efficiency, and sensitivity to changes in labor resource availability.

To achieve these objectives, an applied quantitative approach was adopted using project scheduling modeling based on secondary data obtained from a Steam Power Plant overhaul project. A baseline schedule was initially developed using the Critical Path Method (CPM), followed by the implementation of the Resource-Constrained Critical Path Method (RCPM) through resource leveling using predefined priority rules under fixed labor resource availability conditions. The scheduling model was developed using Microsoft Project. This study is expected to provide empirical evidence regarding the application of the Resource-Constrained Critical Path Method (RCPM) for optimizing project duration in Steam Power Plant overhaul projects under realistic labor resource constraints.

METHOD

This study employed an applied quantitative research approach using project scheduling modeling to evaluate the implementation of the Resource-Constrained Critical Path Method (RCPM) for optimizing project duration in a Steam Power Plant (Pembangkit Listrik Tenaga Uap [PLTU]) overhaul project under labor resource constraints. Secondary data were obtained from a completed overhaul project conducted by PT XYZ as the project contractor. The project scope included the Boiler System, Turbine System, Generator System, and Auxiliary Equipment, while the Instrument and Control System, Electrical System, and Coal Handling System were excluded from the analysis. Microsoft Project was used as the scheduling platform. A baseline Critical Path Method (CPM) schedule was initially developed to establish the project schedule based on activity precedence relationships. The Resource-Constrained Critical Path Method (RCPM) was then implemented through resource leveling using predefined priority rules while maintaining fixed labor resource availability and working hours. The overall research procedure is presented in Figure 1.

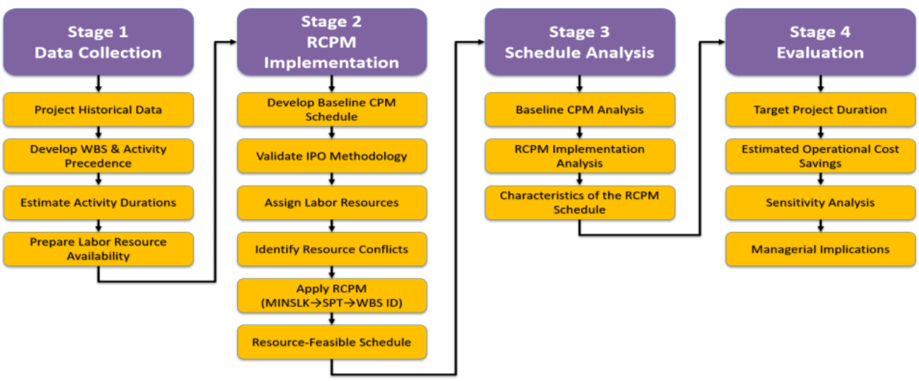


Figure 1. Research Methodology Flowchart

The research methodology consisted of four sequential stages.

The first stage involved collecting secondary data from project documentation, including the Work Breakdown Structure (WBS), activity precedence relationships, activity durations, labor resource availability, and other project planning documents. Historical project records were used to determine activity durations, while labor resource availability represented the maximum number of direct labor units available for each labor specialization during project execution.

The second stage involved developing the baseline CPM schedule. Project activities were modeled in Microsoft Project by constructing the WBS, defining activity precedence relationships, assigning activity durations, and establishing labor resource availability. Microsoft Project was used to calculate scheduling parameters, including Earliest Start (ES), Earliest Finish (EF), Latest Start (LS), Latest Finish (LF), and Total Slack. These parameters were then used to identify critical and non-critical activities and establish the baseline project schedule.

The third stage involved implementing the Resource-Constrained Critical Path Method (RCPM). Labor resources were assigned to each activity to identify resource conflicts caused by overlapping labor demands. The conflicts were resolved through resource leveling using predefined priority rules: Minimum Slack (MINSLK), Shortest Processing Time (SPT), and Work Breakdown Structure (WBS) ID as the tie-breaker. During the leveling process, activity precedence relationships, activity durations, labor resource availability, and working hours were maintained. This process generated a resource-feasible project schedule that reflected actual labor resource constraints.

The final stage involved evaluating the resulting RCPM schedule. The evaluation considered project duration achievement relative to the target duration, schedule characteristics, including critical activities, non-critical activities, and Total Slack distribution, estimated operational cost savings resulting from duration optimization, and schedule sensitivity under labor resource reduction scenarios of 10%, 15%, and 20%. This evaluation assessed the effectiveness of RCPM in generating resource-feasible schedules and its practical contribution to optimizing project duration under labor resource constraints.

RESULTS AND DISCUSSION

Project Overview

This study used a small-scale Steam Power Plant (SPP) overhaul project as the case study. The project data were obtained from an overhaul project executed by PT XYZ as the main contractor. The project was planned to be completed within 36 days and was carried out during a scheduled unit shutdown, requiring all maintenance activities to be completed within the designated outage period.

The main characteristics of the project are summarized in Table 1.

Table 1. Characteristics of the Steam Power Plant Overhaul Project

No.	Description	Information
1	Project Type	Steam Power Plant (PLTU) Overhaul Project
2	Project Contractor	PT XYZ

No.	Description	Information
3	Planned Project Duration	36 days
4	Project Scope	Boiler System, Turbine System, Generator System, and Auxiliary Equipment
5	Maintenance Type	Planned Unit Shutdown
6	Outage Window	Limited to the scheduled shutdown period
7	Resource Characteristics	Limited availability of specialized technicians
8	Activity Characteristics	Multidisciplinary activities with sequential and parallel execution

As shown in Table 1, the project involved maintenance activities on the primary generating systems and supporting auxiliary equipment. The combination of a fixed shutdown duration, a comprehensive maintenance scope, and limited labor resources created a complex scheduling environment in which both technical activity dependencies and labor availability had to be considered simultaneously. These project characteristics establish the basis for implementing the Resource-Constrained Critical Path Method (RCPM).

Baseline Critical Path Method (CPM) Schedule Analysis

The baseline schedule was developed using the Critical Path Method (CPM) to establish the logical project schedule prior to considering labor resource constraints. Microsoft Project was used to define activity sequences, calculate scheduling parameters, identify critical activities, and determine the baseline project duration. This schedule subsequently served as the reference for implementing the Resource-Constrained Critical Path Method (RCPM).

The project scope was decomposed into a Work Breakdown Structure (WBS) comprising seven major work packages: Preparation Stage, Scaffolding Erection, Boiler System and Auxiliary Equipment Inspection, Turbine Overhaul and Auxiliary Equipment Inspection, Generator Overhaul and Auxiliary Equipment Inspection, Scaffolding Dismantling, and Start-up Process and Commissioning Stage. The WBS established the basis for defining project activities, estimating durations, developing logical precedence relationships, and assigning labor resources.

Table 2. Work Breakdown Structure

WBS Code	Work Package	Description
1	Steam Power Plant Overhaul Project	Overall overhaul project scope
1.1	Preparation Stage	Unit shutdown and cooling-down activities
1.2	Scaffolding Erection	Scaffolding installation for all maintenance areas
1.3	Boiler System and Auxiliary Equipment Inspection	Inspection of pressure parts, combustion system, air and flue gas system, ash handling system, and boiler valves
1.4	Turbine Overhaul and Auxiliary Equipment Inspection	Turbine overhaul, lubrication system, condensate system, feedwater system, cooling water system, and auxiliary equipment inspection
1.5	Generator Overhaul and Auxiliary Equipment Inspection	Generator overhaul and auxiliary cooling system inspection
1.6	Scaffolding Dismantling	Removal of scaffolding after maintenance completion
1.7	Start-up Process and Commissioning Stage	Start-up, performance testing, synchronization, and project completion

The WBS was developed to Level 4 and comprised 172 scheduled activities, including summary tasks and milestones, providing the basis for CPM and RCPM scheduling analysis.

Based on the WBS, activity durations and logical precedence relationships were established using historical overhaul records and technical execution sequences. The resulting activity network is presented in Figure 2.

	WBS	Task Name	Duration	Predecessors
1	1	Overhaul Boiler, Turbine, Generator and Auxiliary Equipment		
2	1.1	Preparation Stage	2 days	
3	1.1.1	Unit Shutdown (Milestone)	0 days	
4	1.1.2	Cooling Down	2 days	3
5	1.2	Scaffolding Erection	3 days	
13	1.3	Boiler System and Auxiliary Equipment Inspection	19 days	
14	1.3.1	Boiler Pressure Parts System Inspection	10 days	
15	1.3.1.1	Steam Drum Inspection	4 days	4
16	1.3.1.2	Water Wall Tube Inspection	8 days	4;6
17	1.3.1.3	Superheater Inspection	9 days	4;6
18	1.3.1.4	Economizer Inspection	7 days	4;6
19	1.3.2	Combustion and Coal Feeding System Inspection	19 days	
23	1.3.3	Boiler Air and Flue Gas Auxiliary System Inspection	17 days	
31	1.3.4	Flue Gas Particulate and Ash Handling System Inspection	17 days	
34	1.3.5	Boiler Valve and Safety System Inspection	11 days	
40	1.3.6	Boiler and Auxiliary Equipment Inspection Completed (Milestone)	0 days	15;16;17;18;20;21;22;24;26;28;
41	1.4	Turbine Overhaul and Auxiliary Equipment Inspection	30 days	
42	1.4.1	Turning Mechanism Shutdown	0,5 days	3
43	1.4.2	Turbine Main Unit Overhaul	28 days	
44	1.4.2.1	Turbine Enclosure and Insulation Disassembly	1,5 days	4;10;42
45	1.4.2.2	Main Steam Piping System Disassembly	1 day	4;10;42
46	1.4.2.3	Turning Mechanism Disassembly	0,5 days	45
47	1.4.2.4	Pre-Disassembly Inspection and Measurement Checks	1 day	44;45
48	1.4.2.5	Turbine-Generator Coupling Disassembly	1 day	47;130
49	1.4.2.6	Bearing Pedestal Cover Disassembly	0,5 days	47
50	1.4.2.7	Bearing Clearance Measurement	0,5 days	49
51	1.4.2.8	Upper Bearing Assembly Disassembly	1 day	50

TASK SHEET

Figure 2. Activity Precedence Relationships and Activity Durations

Figure 2 illustrates that the overhaul project contains extensive interdependencies among activities. Most relationships are represented by Finish-to-Start (FS) dependencies, whereas several Start-to-Start (SS) relationships enable selected inspection activities to be executed in parallel. The network indicates that major turbine and generator overhaul activities must follow sequential dismantling, inspection, reassembly, and testing processes, while several auxiliary equipment inspections can proceed concurrently. This combination of serial and parallel activities forms the logical basis for the baseline CPM schedule.

Table 3. Direct Labor Resource Availability

Resource Group	Labor Resource	Abbreviation	Maximum Units	Role Level
Boiler Mechanical Team	Boiler Mechanical Technician	BMT	4	Skilled Boiler Mechanical Technician
	Boiler Mechanical Assistant Technician	BMAT	11	Semi-Skilled Boiler Mechanical Assistant
	Boiler Helper	BH	16	General Boiler Support Worker
Turbine Mechanical Team	Turbine Mechanical Technician	TMT	5	Skilled Turbine Mechanical Technician
	Turbine Mechanical Assistant Technician	TMAT	10	Semi-Skilled Turbine Mechanical Assistant
	Turbine Helper	TH	4	General Turbine Support Worker
Electrical and Generator Team	Electrical and Generator Technician	EGT	4	Skilled Electrical and Generator Technician
	Electrical and Generator Assistant Technician	EGAT	5	Semi-Skilled Electrical and Generator Assistant

Resource Group	Labor Resource	Abbreviation	Maximum Units	Role Level
	Electrical and Generator Helper	EGH	2	General Electrical and Generator Support Worker
Scaffolding Crew	Scaffolder	SCF	8	Skilled Scaffolding Technician
	Scaffolding Helper	SCFH	2	General Scaffolding Support Worker
Mechanical Cleaning Crew	Water Jet Operator	WJO	2	Skilled Mechanical Cleaning Technician
	Water Jet Helper	WJH	4	General Mechanical Cleaning Support Worker
Valve Inspection Team	Valve Inspection Technician	VIT	3	Skilled Valve Inspection Technician
	Valve Inspection Assistant Technician	VIAT	3	Semi-Skilled Valve Inspection Assistant
Condenser Inspection Team	Condenser Technician	CT	2	Skilled Condenser Inspection Technician
	Condenser Helper	CH	2	General Condenser Support Worker

Table 3 shows that different maintenance systems require different categories of specialized personnel. Boiler and turbine works rely primarily on mechanical technicians and assistant technicians, whereas generator maintenance requires more specialized personnel. Supporting activities, such as scaffolding, mechanical cleaning, valve inspection, and condenser inspection, are performed by dedicated work crews. Consequently, mechanical personnel represent the most critical labor resources because they are simultaneously required by multiple project activities.

Using the established activity network and available labor resources, the baseline CPM produced a planned project duration of 33 days, which is three days shorter than the project duration target of 36 days. This result indicates that the overhaul project can theoretically be completed within the required outage period when only activity precedence relationships are considered. To illustrate the baseline schedule, an overview of the CPM network diagram and an excerpt of the baseline Gantt chart are presented in Figures 3 and 4.

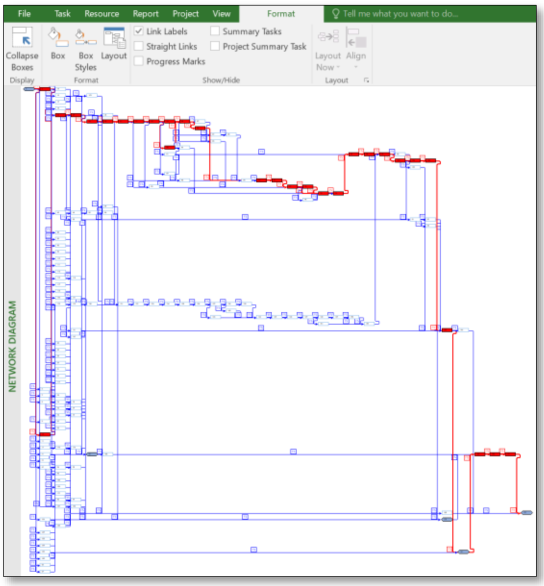


Figure 3. Overview of the Baseline CPM Network Diagram

Figure 3 presents an overview of the baseline CPM network diagram. The overview highlights the project's critical path, which is formed by activities with zero Total Slack. The critical path is dominated by the turbine and generator overhaul sequence, beginning with Cooling Down, followed by Turbine and Generator Area Scaffolding Erection, dismantling and inspection of the main turbine components, Turbine Rotor Inspection, rotor installation, Turbine–Generator Alignment and Coupling, generator reassembly, Bearing Lubrication System Flushing, Final Inspection and Electrical Reconnection, and concluding with the commissioning sequence comprising Turbine Run-up, Overspeed Protection System Testing, and Unit Synchronization. Because these activities have no scheduling flexibility, delays in any of them directly extend the overall project duration.

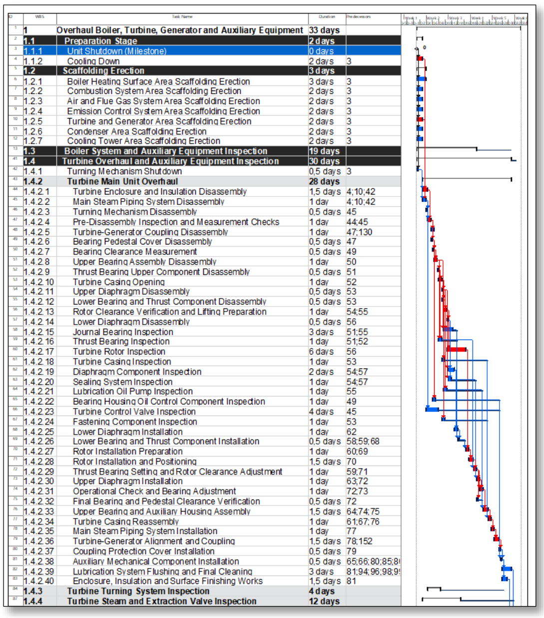


Figure 4. Excerpt of the Baseline CPM Gantt Chart Showing Critical and Non-Critical Activities

Figure 4 presents an excerpt of the baseline CPM Gantt chart, highlighting the execution sequence of representative critical and non-critical activities. Critical activities are represented by red bars, enabling them to be easily distinguished within the schedule. The chart illustrates that critical activities are scheduled sequentially with no available scheduling flexibility, whereas several non-critical activities, particularly boiler inspections and auxiliary equipment inspections, are performed in parallel. This scheduling pattern demonstrates that the baseline schedule combines sequential and concurrent activities to maximize utilization of the available outage period while maintaining the planned project duration.

Overall, the baseline CPM schedule demonstrates that the project can be logically completed within 33 days, thereby achieving the established project duration target of 36 days. However, because the schedule assumes sufficient labor availability, it does not yet reflect the impact of labor resource constraints on concurrent activities. Therefore, further analysis using the Resource-Constrained Critical Path Method (RCPM) is required to determine whether the same project duration can be maintained under actual labor resource constraints.

Resource-Constrained Critical Path Method (RCPM) Implementation

Following the development of the baseline CPM schedule, the Resource-Constrained Critical Path Method (RCPM) was implemented to evaluate whether the planned schedule remained feasible under actual labor resource limitations. Before resource adjustments were performed, the implementation procedure was validated using an Input–Process–Output (IPO) framework and predefined success indicators to ensure that the RCPM application followed a systematic and reproducible process.

Table 4. Input–Process–Output Matrix for RCPM Implementation

Stage	Component	Description
Input	Work Breakdown Structure (WBS)	Hierarchical breakdown of the steam power plant overhaul project used as the basis for developing the baseline CPM schedule.
Input	Activity Precedence Relationships	Logical dependencies among project activities, including Finish-to-Start (FS) and Start-to-Start (SS) relationships, used to construct the baseline CPM network.
Input	Activity Durations	Planned duration of each activity in the baseline CPM schedule based on historical data from the steam power plant overhaul project.
Input	Resource Availability	Availability of labor resources in the baseline CPM schedule serving as the resource constraint for the RCPM implementation.
Process	Identification of Resource-Constrained Conditions	Identification of resource-constrained conditions to detect conflicts arising from concurrent activities competing for the same limited labor resources in the baseline CPM schedule.
Process	Priority Rule Determination	Establishment of activity priorities using Minimum Slack (MINSLK), Shortest Processing Time (SPT), and WBS ID as the tie-breaker for schedule adjustment decisions.
Process	Resource Leveling	Adjustment of activity schedules to eliminate resource conflicts based on the established priority rules while preserving all logical precedence relationships.
Output	Resource-Constrained CPM Schedule	Resource-feasible project schedule generated through the RCPM implementation, including the resulting project duration, critical and non-critical activities, and schedule feasibility based on the predefined success indicators.

As presented in Table 4, the implementation process began with project activities, activity durations, precedence relationships, and available labor resources as the primary inputs. These inputs were subsequently processed through resource assignment, identification of resource-constrained conditions, resource conflict analysis, and resource leveling using the established priority rules. The expected outcome was a resource-feasible schedule that maintained all technical precedence relationships while eliminating labor resource conflicts.

The effectiveness of the implementation procedure was further evaluated using several predefined success indicators.

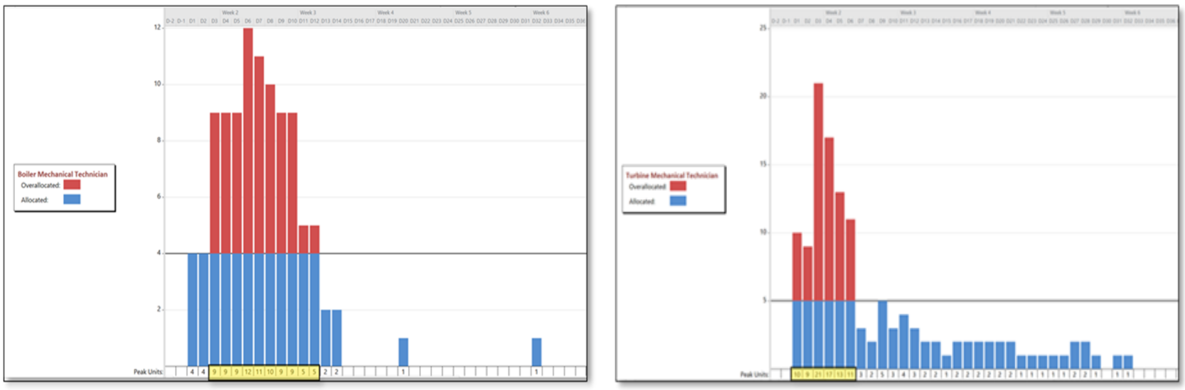
Table 5. Success Indicators of the RCPM Implementation

No.	Indicator	Evaluation Criteria
1	Schedule Feasibility	No activities compete for the same labor resources during the same time period, allowing all activities to be scheduled within the available resource capacity.
2	Consistency of Activity Precedence Relationships	All predecessor–successor relationships are maintained in accordance with the original project scheduling network.
3	Characteristics of the RCPM Schedule	Critical activities, non-critical activities, and the distribution of Total Slack are clearly identified in the RCPM schedule.
4	Achievement of the Project Duration Target	The project duration produced by the RCPM schedule is equal to or shorter than the established project duration target of 36 days.
5	Project Duration Efficiency	A positive reduction is achieved between the established project duration target and the project duration produced by the RCPM schedule.
6	Operational Cost Saving Implications	The reduction in project duration provides potential savings in operational costs during the overhaul period.
7	Schedule Stability under Resource Availability Changes	The RCPM schedule continues to satisfy the project duration target within the limits of workforce availability evaluated through sensitivity analysis.

As shown in Table 5, the implementation was considered successful when four conditions were achieved: all activities received appropriate labor assignments, resource conflicts were correctly identified, overallocation was eliminated through resource leveling, and all precedence relationships remained unchanged. These indicators provided objective criteria for assessing the effectiveness of the proposed scheduling approach.

After the implementation framework had been validated, labor resources were assigned to every activity according to the required technical competencies. The resource assignment showed that the boiler, turbine, and generator work packages relied heavily on the same categories of mechanical personnel. Consequently, simultaneous execution of these activities created competition for limited labor resources, indicating the potential existence of resource-constrained conditions within the baseline schedule.

The resource availability was subsequently evaluated using Microsoft Project Resource Graphs.

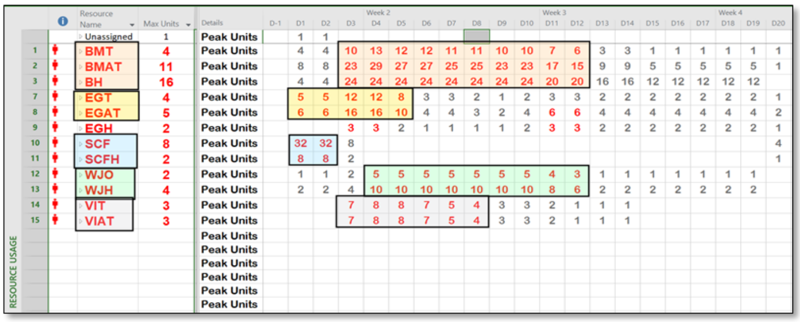


(a) (b)

Figure 5. Resource Graphs of Critical Mechanical Resources in the Baseline CPM Schedule

The resource graphs shown in Figure 5 confirm that labor demand exceeded the available labor capacity during several periods of project execution. As illustrated in Figure 5(a), the demand for Boiler Mechanical Technicians (BMT) reached approximately 9–12 technicians, whereas only four technicians were available. A more severe condition occurred for the Turbine Mechanical Technician (TMT) group, where labor demand increased to approximately 9–21 technicians despite an available capacity of only five technicians, as shown in Figure 5(b). These findings indicate that, although the baseline CPM schedule satisfied logical activity sequencing, it could not be implemented under the actual labor availability without resource adjustment.

To identify the activities responsible for these conflicts, further analysis was conducted using the Resource Usage view and Microsoft Project's resource overallocation indicators.



	Resource Name	Max Units	Details	D-1	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11	D12	D13	D14	D15	D16	D17	D18	D19	D20
	Unassigned	1	Peak Units		1	1																		
1	BMT	4	Peak Units		4	4	10	13	12	12	11	11	10	10	7	6	3	3	1	1	1	1	1	1
2	BMAT	11	Peak Units		8	8	23	29	27	27	25	25	23	23	17	15	9	9	5	5	5	5	5	1
3	BH	16	Peak Units		4	4	24	24	24	24	24	24	24	24	20	20	16	16	12	12	12	12	12	
7	EGT	4	Peak Units		5	5	12	12	8	3	3	2	1	2	3	3	2	2	2	2	2	2	2	1
8	EGAT	5	Peak Units		6	6	16	16	10	4	4	3	2	4	6	6	4	4	4	4	4	4	4	2
9	EGH	2	Peak Units				3	3	2	1	1	1	1	2	3	3	2	2	2	2	2	2	2	1
10	SCF	8	Peak Units		32	32	8																	4
11	SCFH	2	Peak Units		8	8	2																	1
12	WJO	2	Peak Units		1	1	2	5	5	5	5	5	5	5	4	3	1	1	1	1	1	1	1	
13	WJH	4	Peak Units		2	2	4	10	10	10	10	10	10	10	8	6	2	2	2	2	2	2	2	
14	VIT	3	Peak Units				7	8	8	7	5	4	3	3	2	1	1	1						
15	VIAT	3	Peak Units				7	8	8	7	5	4	3	3	2	1	1	1						
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Figure 6. Resource Graphs of Critical Mechanical Resources in the Baseline CPM Schedule

As illustrated in Figure 6, several labor groups were simultaneously assigned to parallel activities, particularly during scaffolding erection, boiler inspection, and supporting maintenance work, resulting in cumulative labor demand exceeding the available labor capacity.

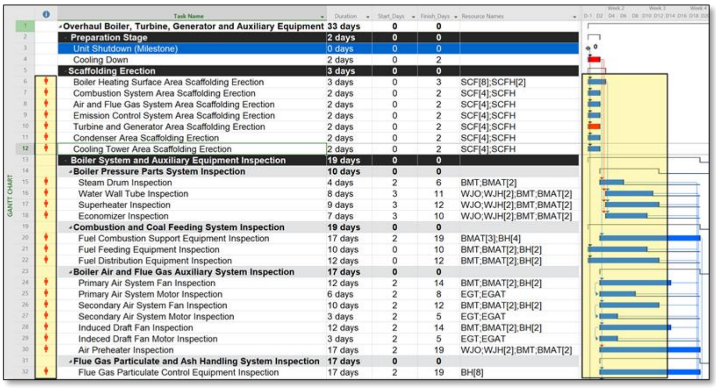


Figure 7. Resource Overallocation Indicators for Scaffolding Erection and Boiler and Auxiliary Equipment Inspection Activities in the Baseline CPM Schedule

The overallocation indicators presented in Figure 7 further confirm the occurrence of labor resource conflicts within the baseline schedule. The most significant conflicts involved the Scaffolding Crew, Boiler Mechanical Team, and several specialist teams, including the Electrical and Generator Team, Mechanical Cleaning Crew, and Valve Inspection Team. These findings demonstrate that the baseline CPM schedule was logically feasible but not resource-feasible, thereby justifying the application of the Resource-Constrained Critical Path Method (RCPM).

To eliminate these conflicts, resource leveling was applied as the core scheduling mechanism of the RCPM approach. Schedule adjustments were performed without modifying activity precedence relationships by utilizing the scheduling flexibility of non-critical activities according to the predefined priority rules: Minimum Slack (MINSLK), Shortest Processing Time (SPT), and WBS ID as the final tie-breaker.

The implementation of resource leveling is illustrated using the Boiler System and Auxiliary Equipment Inspection work package.

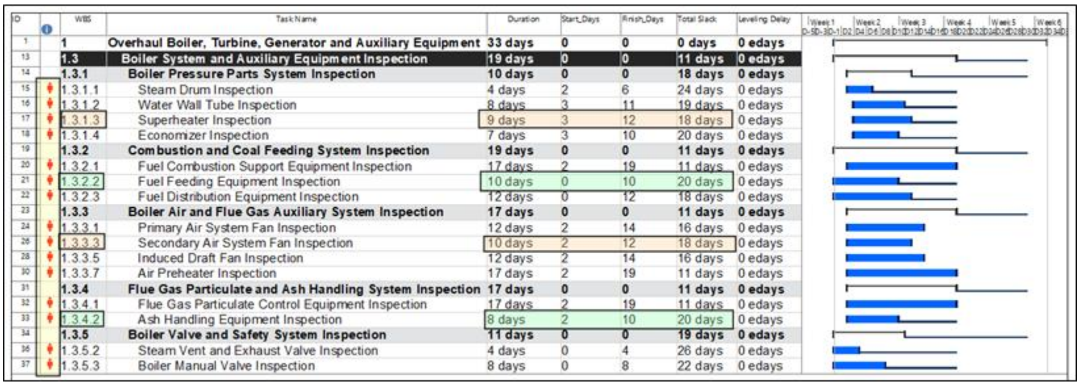
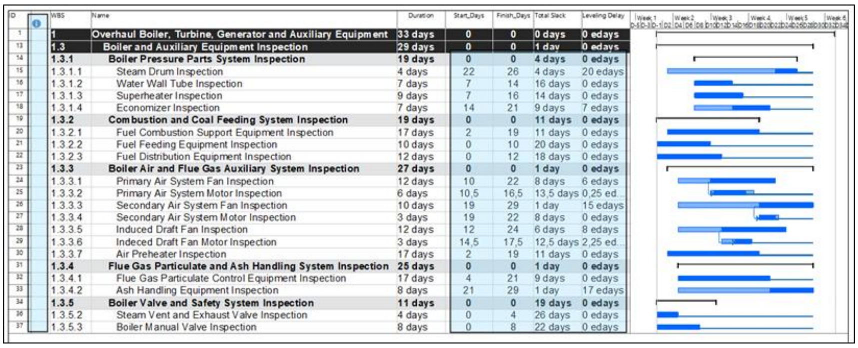


Figure 8. Boiler System and Auxiliary Equipment Inspection Before Resource Leveling



ID	WBS	Name	Duration	Start_Days	Finish_Days	Total Slack	Leveling Delay
1	**1**	**Overhaul Boiler, Turbine, Generator and Auxiliary Equipment**	**33 days**	**0**	**0**	**0 days**	**0 edays**
13	**1.3**	**Boiler and Auxiliary Equipment Inspection**	**29 days**	**0**	**0**	**1 day**	**0 edays**
14	**1.3.1**	**Boiler Pressure Parts System Inspection**	**19 days**	**0**	**0**	**4 days**	**0 edays**
15	1.3.1.1	Steam Drum Inspection	4 days	22	26	4 days	20 edays
16	1.3.1.2	Water Wall Tube Inspection	7 days	7	14	16 days	0 edays
17	1.3.1.3	Superheater Inspection	9 days	7	16	14 days	0 edays
18	1.3.1.4	Economizer Inspection	7 days	14	21	9 days	7 edays
19	**1.3.2**	**Combustion and Coal Feeding System Inspection**	**19 days**	**0**	**0**	**11 days**	**0 edays**
20	1.3.2.1	Fuel Combustion Support Equipment Inspection	17 days	2	19	11 days	0 edays
21	1.3.2.2	Fuel Feeding Equipment Inspection	10 days	0	10	20 days	0 edays
22	1.3.2.3	Fuel Distribution Equipment Inspection	12 days	0	12	18 days	0 edays
23	**1.3.3**	**Boiler Air and Flue Gas Auxiliary System Inspection**	**27 days**	**0**	**0**	**1 day**	**0 edays**
24	1.3.3.1	Primary Air System Fan Inspection	12 days	10	22	8 days	6 edays
25	1.3.3.2	Primary Air System Motor Inspection	6 days	10,5	16,5	13,5 days	0,25 ed...
26	1.3.3.3	Secondary Air System Fan Inspection	10 days	19	29	1 day	15 edays
27	1.3.3.4	Secondary Air System Motor Inspection	3 days	19	22	8 days	0 edays
28	1.3.3.5	Induced Draft Fan Inspection	12 days	12	24	6 days	8 edays
29	1.3.3.6	Indeced Draft Fan Motor Inspection	3 days	14,5	17,5	12,5 days	2,25 ed...
30	1.3.3.7	Air Preheater Inspection	17 days	2	19	11 days	0 edays
31	**1.3.4**	**Flue Gas Particulate and Ash Handling System Inspection**	**25 days**	**0**	**0**	**1 day**	**0 edays**
32	1.3.4.1	Flue Gas Particulate Control Equipment Inspection	17 days	4	21	9 days	0 edays
33	1.3.4.2	Ash Handling Equipment Inspection	8 days	21	29	1 day	17 edays
34	**1.3.5**	**Boiler Valve and Safety System Inspection**	**11 days**	**0**	**0**	**19 days**	**0 edays**
36	1.3.5.2	Steam Vent and Exhaust Valve Inspection	4 days	0	4	26 days	0 edays
37	1.3.5.3	Boiler Manual Valve Inspection	8 days	0	8	22 days	0 edays

Figure 9. Boiler System and Auxiliary Equipment Inspection After Resource Leveling

The comparison between Figures 8 and 9 shows that activities with higher scheduling priority retained their original execution periods, whereas activities with greater available slack experienced leveling delays to eliminate labor resource conflicts. For example, Superheater Inspection maintained its original schedule because it had a higher priority, while Secondary Air System Fan Inspection was rescheduled according to the Shortest Processing Time (SPT) rule. When activities had identical slack values and durations, WBS ID was applied as the final priority criterion. As a result, resource overallocation was successfully eliminated without modifying activity durations or technical precedence relationships.

Overall, the implementation results demonstrate that RCPM successfully transformed the logically feasible CPM schedule into a resource-feasible schedule by systematically reallocating the execution timing of non-critical activities while preserving the original project network structure. These findings confirm that RCPM provides an effective scheduling approach for steam power plant overhaul projects with limited labor resources and establish the basis for evaluating the characteristics of the RCPM schedule in the subsequent section.

Characteristics of the Resource-Constrained Critical Path Method (RCPM) Schedule

Following the completion of the resource leveling process, the Resource-Constrained Critical Path Method (RCPM) produced a project schedule that satisfied labor resource constraints while preserving all activity precedence relationships. The resulting schedule achieved a total project duration of 33 days. Its characteristics are reflected in the distribution of Total Slack, the composition of critical and non-critical activities, and the changes in activity status resulting from the resource leveling process. These scheduling characteristics are interpreted through the RCPM network diagram and Gantt chart.

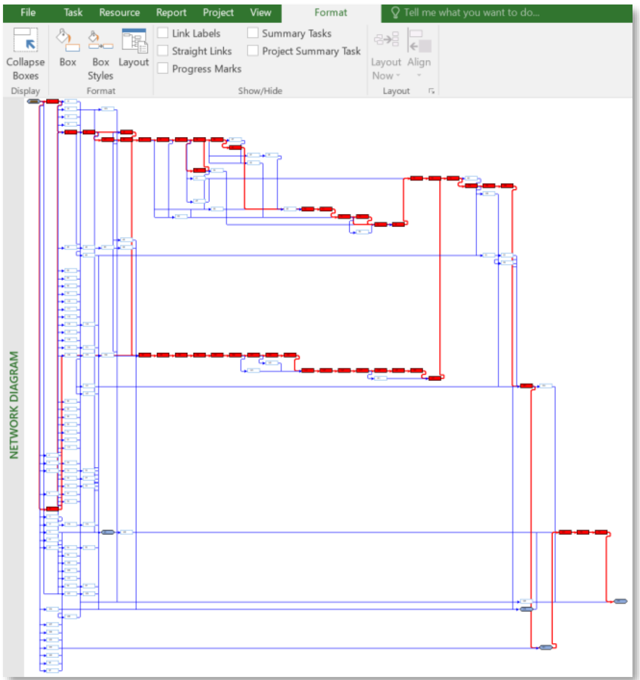


Figure 10. Overview of the RCPM Network Diagram

Figure 10 presents an overview of the RCPM network diagram. The figure illustrates that all activity precedence relationships were preserved, indicating that the technical execution sequence remained unchanged throughout the scheduling process. The primary characteristic of the resulting schedule is reflected in the distribution of Total Slack, where non-critical activities retain scheduling flexibility, whereas critical activities maintain a Total Slack value of zero. Consequently, the resulting critical path represents the sequence of activities that directly determines project completion while remaining feasible under the available labor resource capacity.

The identified critical path continued to be dominated by the turbine and generator overhaul sequence, beginning with Cooling Down, followed by Turbine and Generator Area Scaffolding Erection, dismantling and inspection of major turbine components, Turbine Rotor Inspection, Rotor Installation and Positioning, Turbine–Generator Alignment and Coupling, Generator Housing Clearance Verification and Assembly, Bearing Lubrication System Flushing, Final Inspection and Electrical Reconnection, and concluding with the commissioning sequence comprising Turbine Run-up, Overspeed Protection System Testing, and Unit Synchronization. All activities on this path have zero Total Slack; therefore, delays in any of these activities directly extend the overall project duration.

The RCPM schedule contains 47 critical activities, while the remaining activities are classified as non-critical out of a total of 172 modeled activities, including summary tasks and milestones. Compared with the baseline CPM schedule, 18 additional activities became critical after resource leveling because part of the available Total Slack was consumed to eliminate labor resource conflicts. These changes indicate that labor resource constraints influence schedule characteristics by redistributing scheduling flexibility without modifying activity precedence relationships. Consequently, project monitoring should be extended to a larger number of critical activities that directly affect project completion.

In contrast, non-critical activities are primarily associated with inspections of the Boiler System, Auxiliary Equipment, Condensate System, Feedwater System, Cooling Water System, and several supporting activities within the Generator System. These activities retain positive Total Slack, providing limited scheduling flexibility without affecting the overall project duration, provided that delays remain within the available slack.

To further illustrate the characteristics of the resulting schedule, the distribution of critical and non-critical activities is visualized in the Gantt chart shown in Figure 11.

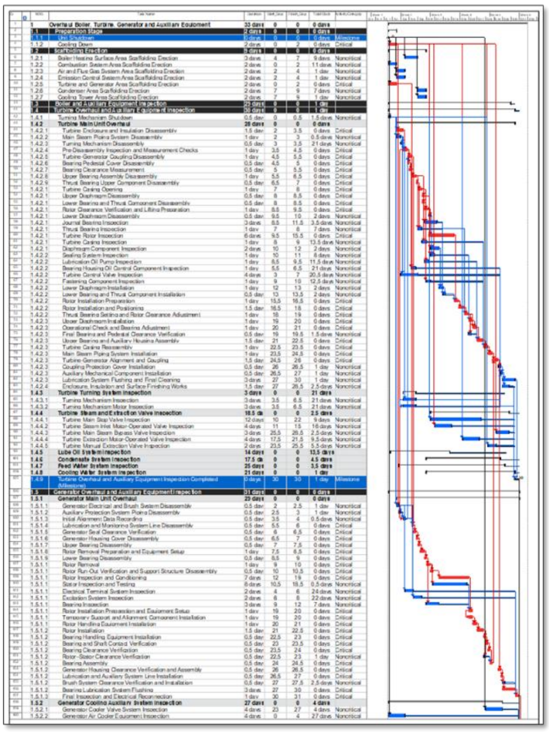


Figure 11. Excerpt of the RCPM Gantt Chart

Figure 11 presents an excerpt of the RCPM Gantt chart, highlighting the execution sequence of representative critical and non-critical activities. The figure shows that critical activities retained their scheduled execution periods because no scheduling flexibility was available, whereas non-critical activities experienced scheduling adjustments according to their available Total Slack. These adjustments produced a more balanced distribution of labor utilization throughout the project without modifying activity durations or technical precedence relationships. This scheduling pattern indicates that the available scheduling flexibility was selectively utilized to optimize labor allocation while maintaining the planned project completion target.

Overall, the characteristics of the RCPM schedule demonstrate that the resulting project schedule satisfies labor resource constraints while preserving the original project network structure and activity precedence relationships. The redistribution of Total Slack, the transition of several activities to the critical path, and the scheduling adjustments applied to non-critical activities indicate that the resource leveling process successfully produced a schedule that is more practical and feasible for implementation in steam power plant overhaul projects.

Evaluation of Project Duration Optimization

Following the implementation of the Resource-Constrained Critical Path Method (RCPM), the resulting schedule was evaluated to assess its ability to achieve the project duration target, improve scheduling efficiency, generate potential operational cost savings, and maintain schedule performance under different labor availability scenarios. This evaluation provides quantitative evidence of the practical benefits obtained from applying RCPM to steam power plant overhaul scheduling.

Table 6. Comparison of the Baseline CPM Schedule, RCPM Schedule, and Project Duration Target

No.	Scheduling Scenario	Project Duration (Days)	Description
1	Baseline CPM Schedule	33	Project duration generated using the Critical Path Method (CPM), considering only activity precedence relationships without accounting for labor resource constraints.
2	RCPM Schedule	33	Project duration obtained after applying resource leveling while considering limited labor resource availability.
3	Project Duration Target	36	Maximum project duration established as the target for completing the overhaul project.

As presented in Table 6, the RCPM schedule achieved a project duration of 33 days, successfully meeting the project duration target of 36 days. This represents a reduction of three days (8.33%) while eliminating labor resource conflicts and preserving all activity precedence relationships. These findings demonstrate that the proposed scheduling approach is capable of producing a resource-feasible schedule without compromising the required project completion target.

Project duration optimization also has implications for improving project cost efficiency during the overhaul period. A shorter execution period is expected to reduce time-dependent project costs, particularly labor costs and project operational overhead costs. Although the magnitude of the resulting cost savings depends on the cost structure of each project, the findings indicate that implementing the Resource-Constrained Critical Path Method (RCPM) has the potential to improve project cost efficiency while maintaining a resource-feasible schedule under labor resource constraints.

To evaluate the robustness of the resulting schedule, a sensitivity analysis was conducted by reducing the available direct labor resources by 10%, 15%, and 20%.

Table 7. Direct Labor Composition under the Labor Reduction Scenarios

Direct Labor Group	Existing Condition (Personnel)	10% Reduction (Personnel)	15% Reduction (Personnel)	20% Reduction (Personnel)
Boiler Mechanical Team	31	29	28	25
Turbine Mechanical Team	19	17	15	14
Electrical and Generator Team	11	11	9	8
Scaffolding Crew	10	8	8	8
Mechanical Cleaning Crew	6	6	6	6
Valve Inspection Team	6	6	6	6
Condenser Inspection Team	4	2	2	2
Total Personnel	**87**	**79**	**74**	**69**

Table 8. Sensitivity Analysis Results of the RCPM Schedule under Different Labor Reduction Scenarios

Parameter	Existing Condition	10% Reduction	15% Reduction	20% Reduction
Total Personnel	87	79	74	69
Project Duration (Days)	33	42.5	48.5	51

The sensitivity analysis results presented in Table 8 indicate that project duration is highly sensitive to labor availability. A 10% reduction in available labor increased the project duration to 44 days, while reductions of 15% and 20% extended the duration to 48.5 days and 50 days, respectively. All three scenarios exceeded the project duration target of 36 days, demonstrating that the labor allocation adopted in the RCPM schedule was already close to the minimum level required to achieve the planned completion time.

These findings indicate that further reductions in labor availability cannot be fully compensated through schedule adjustments or resource leveling. Once the available scheduling flexibility has been exhausted, insufficient labor capacity delays critical activities and consequently extends the overall project duration.

Overall, the results demonstrate that the RCPM schedule successfully achieved the project duration target while satisfying labor resource constraints. In addition to improving scheduling performance, the optimized schedule has implications for enhancing project cost efficiency through a shorter execution period. The sensitivity analysis further confirms that adequate labor availability is essential for maintaining schedule performance, highlighting the practicality of RCPM as a scheduling approach for Steam Power Plant overhaul projects under realistic labor resource constraints.

Managerial Implications

The findings demonstrate that the implementation of the Resource-Constrained Critical Path Method (RCPM) provides practical implications for optimizing the duration of Steam Power Plant overhaul projects by integrating activity precedence relationships with labor resource constraints during project planning. The resulting resource-feasible schedule achieved the established project duration target without requiring additional labor resources or extended working hours, indicating that RCPM can serve as a more realistic scheduling approach for Steam Power Plant overhaul projects.

In addition to supporting project duration optimization, RCPM provides information on critical activities, non-critical activities, and Total Slack distribution that can assist project managers in establishing work priorities, allocating labor resources, and controlling project execution. These scheduling characteristics enable resource leveling to improve labor utilization while preserving activity precedence relationships.

Project duration optimization also has implications for improving project cost efficiency through a shorter execution period, which is expected to reduce time-dependent project costs, particularly labor and project operational overhead costs. Furthermore, the sensitivity analysis demonstrates that project duration performance is highly dependent on labor resource availability, highlighting the importance of considering labor resource constraints during the planning stage. Overall, these findings indicate that RCPM functions not only as a scheduling method but also as a practical decision-support tool for developing realistic and resource-feasible schedules for Steam Power Plant overhaul projects.

CONCLUSION

This study identified critical and non-critical activities in the baseline Critical Path Method (CPM) schedule of a Steam Power Plant (Pembangkit Listrik Tenaga Uap [PLTU]) overhaul project. The baseline schedule successfully established the logical project sequence based on activity precedence relationships, with the critical path primarily dominated by Turbine System and Generator System overhaul activities. Meanwhile, activities within the Boiler System and several supporting systems retained positive Total Slack values, providing scheduling flexibility without affecting the planned project duration.

The implementation of the Resource-Constrained Critical Path Method (RCPM) through resource leveling using the Minimum Slack (MINSLK), Shortest Processing Time (SPT), and Work Breakdown Structure (WBS) ID priority rules successfully eliminated all labor resource conflicts without modifying activity precedence relationships, activity durations, available labor resources, or working hours. As a result, a resource-feasible schedule was generated that accurately represented labor resource constraints within the assumptions of this study.

The resulting RCPM schedule maintained a project duration of 33 days and consisted of 47 critical activities, while the remaining non-critical activities retained Total Slack values ranging from 0.5 to 27 days. These findings indicated that RCPM was able to preserve the planned project duration while producing a schedule that more realistically reflected labor resource availability and supported practical project execution.

The RCPM schedule achieved the established project duration target by completing the project in 33 days, representing a reduction of 3 days (8.33%). This improvement indicated potential enhancement of project cost efficiency through a shorter execution period. Furthermore, the sensitivity analysis showed that reductions in labor resource availability of 10%, 15%, and 20% increased the project duration to 42.5, 48.5, and 51 days, respectively, preventing the project from achieving the target duration. These findings provided empirical evidence that RCPM was an effective scheduling approach for Steam Power Plant overhaul projects characterized by shutdown maintenance, limited specialist labor resources, and strict outage windows.

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