Journal of Social Research

P-ISSN:2827-9832
E-ISSN: 2828-335x
Vol. 5, No. 9, August 2026
http://ijsr.internationaljournallabs.com/index.php/ijsr

Analysis of Time Overrun and Alternative Solutions using The DMAIC Framework in The 8Th-Floor Electrical Installation Project at Mall X

Siti Nurul Afina*, Syamsir Abduh, Hakimul Batih
Institut Teknologi PLN, Indonesia
Email: siti2310050@itpln.ac.id*, syamsir@itpln.ac.id, hakimul.batih@itpln.ac.id

Keywords:
Time Overrun; Earned Value Management (EVM); Critical Path Method (CPM); Schedule Variance (SV); Standard Operating Procedure (SOP).

ABSTRACT

Time overrun is one of the most critical challenges affecting schedule performance in construction projects. This study aimed to identify the factors contributing to time overruns, evaluate schedule deviations using Earned Value Management (EVM), and propose improvement strategies through the Critical Path Method (CPM) within the DMAIC (Define, Measure, Analyze, Improve, Control) framework for the electrical installation project on the 8th floor of Mall X. A mixed-methods approach was employed by combining primary data obtained from interviews with the Project Manager, Site Engineer, Supervisor, and Quality Control personnel with secondary data from project schedules, S-curves, and progress reports. The analysis was conducted using Schedule Variance (SV), Fishbone Diagram analysis, CPM simulation, and the development of a Standard Operating Procedure (SOP). The results showed that time overrun factors included Design, Material, Management, Method, and Man, with Design, Material, and Management identified as the dominant factors (100% occurrence frequency), followed by Method (75%) and Man (50%). EVM analysis indicated that schedule deviation began in week 11, with an SV of −12.44% at the planned completion in week 17, indicating that actual progress reached only 87.56% of the planned progress and resulted in completion delays until week 20. The CPM simulation identified the critical path A–B–D–H–K–N–O with a total duration of 103 working days (approximately 15 weeks), compared with the existing 17-week schedule based on practical experience without structured scheduling methods, indicating a potential reduction of two weeks. This study proposed CPM implementation and an SOP for Project Schedule Performance Control to minimize time overruns in similar construction projects.

INTRODUCTION

The electrical installation industry has experienced rapid development and increasing complexity, reflected in the growing number of electrical installation projects and the continuous upgrading of installed electrical systems and equipment in both urban and rural areas. These developments have increased project complexity and the potential for schedule delays (Gutama & Ashari, 2023). Schedule delays remain a significant challenge in construction projects, including electrical and mechanical installation works (Aditia & Irwansyah, 2023). Such delays may increase project costs, reduce productivity, disrupt operational schedules, and negatively affect contractor reputation (Astuti & Nasution, 2014).

Mall X, one of the prominent shopping centers in Jakarta, is undergoing a complex renovation and development process, including the addition of an 8th-floor area intended for office functions. This development involves various engineering works, including electrical and mechanical system installations. During implementation, several challenges may affect project completion, including coordination among stakeholders (Widianto, 2020), material procurement delays, design changes, limited availability of skilled labor, and other external factors (Bohari Rahim R.A. & Aman, 2022). These challenges may contribute to schedule delays and increased resource requirements. Time overrun is a major concern in the construction industry because it can hinder project completion targets, reduce productivity, disrupt subsequent activities and project handover processes, increase the risk of cost escalation due to extended execution periods, and reduce the effectiveness of project control. Therefore, a systematic approach is required to identify the primary causes of time overrun and formulate appropriate improvement strategies. Schedule monitoring in the Mall X electrical installation project relied heavily on subjective assessments based on field experience (Frank Enkawa T. Schvaneveldt S.J. & Herbas Torrico, 2015). However, this approach provided limited quantitative information regarding work deviations, potentially affecting decision-making for both ongoing and future projects (Davis, 1989). Therefore, this study applied Schedule Variance (SV) as a performance measurement parameter using Earned Value Management (EVM) to quantitatively evaluate schedule performance. Through SV analysis, the gap between Planned Value and Earned Value, representing actual physical progress, could be identified. The resulting SV value served as an important input in the Measure and Analyze stages of the DMAIC (Define, Measure, Analyze, Improve, Control) methodology to evaluate the effectiveness of Critical Path Method (CPM) planning in reducing project delays (Chin & Ahmad, 2015).

Based on this background, the Mall X electrical installation project was considered important to investigate because it not only identified the factors contributing to time overrun but also proposed alternative solutions through a structured project management approach integrating DMAIC, Schedule Variance (Kamolsook Badir Y.F. & Frank, 2019), and CPM. The research gap lies in the limited application of an integrated framework that combines the diagnostic capability of EVM for measuring schedule deviations, the root-cause analysis capability of DMAIC, and the optimization capability of CPM for developing improved schedules. Although project managers commonly apply these methods individually, their combined implementation remains limited, resulting in insufficient understanding of their synergistic contribution to improving project time performance. The novelty of this study lies in developing an integrated framework that sequentially applies DMAIC, EVM, and CPM to diagnose schedule delays, quantify performance deviations, and formulate structured solutions for future project execution (Sianturi & Suhadak, 2019). The findings are expected to contribute practically to construction practitioners by improving project time-control effectiveness and academically to the development of Six Sigma applications in construction project management, particularly for electrical installation activities that significantly influence overall project schedules (Kim & Han, 2010).

Based on this background, this study addressed three research questions: (1) what factors contributed to time overrun in the Mall X electrical installation project; (2) how did Schedule Variance in the Mall X electrical installation project differ between experience-

based planning and Critical Path Method (CPM)-based planning; and (3) what alternative solutions could be proposed to overcome time overrun in the Mall X electrical installation project. Accordingly, this study aimed to: (1) identify and analyze the factors contributing to time overrun in the Mall X electrical installation project; (2) evaluate the effectiveness of CPM planning compared with experience-based planning through Schedule Variance (SV) measurement within the DMAIC framework; and (3) formulate alternative solutions for addressing time overrun in the Mall X electrical installation project. The scope of this study was limited to the 8th-floor electrical installation work, covering the project schedule period from the fourth week of February to the fourth week of June. Data were collected through interviews with the Project Manager, Site Engineer, and Quality Control Engineer. The proposed improvement strategies were developed based on simulation results and conceptual recommendations, focusing specifically on project schedule performance (Mulyono, 2025).

METHOD

This study employed applied research using a case study approach conducted on the electrical installation project at Mall X. The study used a descriptive-analytical design to describe the project delay conditions, analyze the contributing factors, and formulate applicable improvement strategies. A quantitative approach was applied based on numerical data obtained from project documents, including execution schedules and work progress reports, while qualitative data were used to identify the factors contributing to project delays. The analytical framework followed the Six Sigma DMAIC (Define, Measure, Analyze, Improve, Control) approach. The Measure stage applied Schedule Variance (SV) to evaluate schedule deviations, while the Improve stage utilized the Critical Path Method (CPM) as an alternative approach for project time planning and control.

The study was conducted on the electrical and mechanical installation project of Mall X, which was selected due to the occurrence of time overrun relevant to the research objectives of analyzing schedule deviations and developing improvement strategies using the Six Sigma approach. The research period was from January to December 2025, covering data collection, processing, and analysis. The study used project execution data obtained during the implementation period. The Mall X electrical installation project involved activities supporting the building's electrical system, including cable installation, electrical panel installation, lighting installation, power distribution installation, and other related electrical works. During project execution, actual progress deviated from the planned schedule due to factors related to labor, materials, work methods, and project management. The existing scheduling process was primarily based on practical experience without the application of a structured scheduling method, resulting in suboptimal project time control.

The object of this study was project time performance, particularly the occurrence of time overrun in the electrical and mechanical installation work at Mall X. The study focused on analyzing schedule deviations, identifying their causal factors, and developing recommendations for future project improvement. The subjects of the study included project stakeholders involved in implementation and relevant project data sources, including project schedules, progress reports, planning data, and realization data, supported by information from field technicians and project implementers.

Two types of data were used in this study: primary and secondary data. Primary data were obtained through interviews with project personnel, including field technicians and implementers, to obtain information regarding work processes and project execution conditions. These data were used as the basis for developing the SIPOC diagram in the Define stage. Secondary data were collected from project documents, including time schedules, S-curves, and progress reports, which were used to analyze work sequences, planned durations, project progress, and (Aroline Outri A. Oei E. Verawati & Isnovian, 2021) between planned and actual implementation. Data collection was conducted through interviews and document reviews. Interview results provided qualitative information regarding project execution and delay factors, while document reviews supported the analysis of project time performance, particularly the calculation of Schedule Variance (SV) and CPM-based rescheduling simulations.

Data analysis was conducted systematically based on the DMAIC framework. In the Measure stage, Planned Value (PV) was determined from planned S-curve data, representing the expected progress according to the project schedule, while Earned Value (EV) was obtained from actual progress data in the S-curve and project reports. Schedule Variance was calculated using the formula $SV = EV - PV$, where negative values indicated schedule delays, positive values indicated progress ahead of schedule, and zero values indicated completion according to plan. The calculated SV values were used to evaluate project schedule performance and served as the basis for the Analyze stage.

The Analyze stage was conducted to identify the factors contributing to time overrun by integrating quantitative findings from SV analysis with qualitative information from interviews and document reviews. The identified factors were categorized into labor, material, work method, project management, and external factors. The relationships among these factors were analyzed using a Fishbone Diagram to systematically identify the root causes of delays. Based on the findings that existing scheduling practices were primarily experience-based and lacked structured scheduling analysis, the Critical Path Method (CPM) was applied as an improvement approach in the Improve stage. CPM analysis involved arranging project activities based on available work data, determining activity durations, establishing activity dependencies through a network diagram, and identifying the critical path. The resulting project duration and critical path were compared with the original schedule to evaluate potential improvements in project time performance.

The overall research procedure followed the DMAIC framework. The Define stage identified the initial project conditions and problems using a Project Charter and SIPOC analysis. The Measure stage evaluated project schedule performance using EVM through SV calculation. The Analyze stage identified root causes of time overrun using a Fishbone Diagram based on quantitative and qualitative findings. The Improve stage applied CPM as a proposed scheduling improvement method. The Control stage developed a Standard Operating Procedure (SOP) as a guideline for improving project schedule control. Each stage was implemented sequentially, with the output of each phase serving as the basis for subsequent analysis and improvement activities.

RESULT AND DISCUSSION

Define Stage

The Define stage is the initial stage of the DMAIC methodology, aimed at defining the research problem, determining the research scope, and establishing the research objectives. In this stage, an initial identification was carried out of the condition of the Mall X electrical installation project, which experienced time overrun based on the difference between the planned schedule and the actual project execution (Garrett et al., 2014). Primary data were collected through interviews with the Project Manager, Site Engineer, Project Supervisor, and Project QC regarding the condition of project execution, the scheduling system used, the workflow, and the obstacles encountered during execution (Hanifah & Mukhlis, 2022). A semi-structured interview approach was used, guided by the information needs for preparing the Project Charter, SIPOC, and understanding the existing scheduling system (Brahmanta & Wardhani, 2021). The interview questions and their objectives, together with a summary of the interview results, are presented in Table 1.

Tabel 1. Define-Stage Interview Questions and Summary of Findings

No	Interview Question	Summary of Findings
1	What is the general condition of the Mall X construction project execution?	The project generally proceeded according to the planned stages, but several obstacles occurred during execution that caused delays in work completion.
2	What scheduling method has been used for the project so far?	Project scheduling was carried out using an S-curve and Gantt Chart as the reference for monitoring work progress.
3	Was the schedule developed using a specific method or based on experience from previous projects?	Scheduling was developed based on a combination of experience from previous projects and the company's scheduling practices.
4	How is progress monitoring carried out?	Monitoring was carried out through daily reports, weekly evaluations, S-curve updates, and periodic coordination meetings.
5	What common obstacles occur during project execution?	Common obstacles included changes in design or working drawings, rework, delays in material procurement, and coordination among parties that had not been optimal.
6	Which parties are involved in schedule control?	Schedule control involved the Project Manager, Site Engineer, Project Supervisor, the implementation team, the supervising consultant, and the Owner.
7	How is coordination among activities carried out in the field?	Coordination was carried out through coordination meetings, communication among implementation teams, and progress evaluation.

A Project Charter was prepared based on the interview results to summarize the project background, research problems, objectives, scope, and DMAIC stages, together with the target, stakeholders, and Critical to Quality (CTQ) elements of the study, namely the timeliness of project completion, the effectiveness of schedule control, the smoothness of project coordination, and the availability of materials according to the execution schedule. Based on the Project Charter, it is known that the main focus of this study is to analyze the time-overrun

problem in the Mall X electrical installation project (Hanafizadeh et al., 2014), identify the causal factors of the delay, and formulate alternative schedule improvements through the application of CPM. After the Project Charter was prepared, the Define stage continued with process mapping using a SIPOC diagram to identify the relationships among suppliers, inputs, processes, outputs, and customers involved in the execution of the electrical installation project, as presented in Table 2.

Tabel 2. SIPOC (Supplier, Input, Process, Output, Customer)

Supplier	Input	Process	Output	Customer
Project Owner	Working drawings and technical specifications	Preparation of electrical installation work	Work area ready for installation	Main contractor
Planning consultant	Project execution schedule (time schedule)	Procurement of materials and equipment	Materials and equipment available	Project implementation team
Material vendor/supplier	Cables, panels, conduits, lamps, and electrical accessories	Pulling of electrical installation cables	Cable installation completed	Project supervisor
Contractor	Labor and work equipment	Installation of electrical panels	Electrical panels installed	Project owner
Engineering team	Shop drawings and work methods	Installation of lighting system	Lighting system installed	Building users
Quality Control team	Quality standards and work procedures	Testing and inspection of electrical installation	Installation meets standard	Supervising consultant
PLN/power source	Electrical power source	Energizing and commissioning	Electrical system ready to operate	Owner and building users
Project management	Work progress data	Monitoring and control of work	Project progress report	Project management

The SIPOC mapping shows that the execution of the electrical installation project involves various interacting parties, from the planning stage, material procurement, and work execution, through to testing and commissioning, and that project success is strongly influenced by the availability of inputs, coordination among the parties involved, and the effectiveness of process control. To obtain an initial picture of the most dominant factors emerging from the Define-stage interviews, the frequency of occurrence of each factor mentioned by informants was tabulated, as presented in Table 3.

Tabel 3. Frequency of Causal Factors from the Define-Stage Interviews

No	Factor	Number of Informants Mentioning	Percentage
1	Design (design changes, shop drawing, rework)	4	100%
2	Material (material waste, material procurement, lead time)	4	100%
3	Management (coordination, monitoring, supervision)	4	100%
4	Method (experience-based scheduling, S-curve, CPM)	3	75%
5	Man (labor, manpower cost, labor coordination)	2	50%

The frequency recapitulation from the Define stage shows that the Design, Material, and Management factors were the ones most frequently mentioned by informants, followed by the Method and Man factors, indicating that the project delay was not caused by a single factor but was influenced by various interrelated aspects during project execution. Although this frequency analysis provided an initial picture of the potential causes of time overrun, the information obtained was still general in nature and had not yet explained the root causes of the delay in depth, so further exploration was required in the Analyze stage (Mowen & Minor, 2002).

Measure Stage

The Measure stage aims to measure project time performance and to determine the level of schedule deviation that occurred during project execution, based on secondary data in the form of the time schedule, S-curve, and progress reports. The electrical installation work accounts for 50.72% of the total weight of the overall project, so its progress could be observed specifically; however, the EVM calculation was still prepared based on the overall project S-curve, because the electrical installation work has dependency relationships with several other disciplines of work, such that delays in those activities could affect the execution of the electrical installation work. The results of the EVM calculation, comprising the Planned Value (PV), Earned Value (EV), and Schedule Variance (SV) for each week of project execution, are presented in Table 4.

Tabel 4. Earned Value Management (EVM) Results

Week	Month	PV (%)	EV (%)	SV (%)
1	February	9.28	18.02	8.73
2	March	14.84	25.96	11.12
3	March	20.78	37.81	17.03
4	March	27.35	52.53	25.18
5	March	34.22	53.49	19.27
6	April	34.22	53.49	19.27
7	April	41.09	57.87	16.78
8	April	47.96	59.51	11.55
9	April	54.81	59.66	4.85

Week	Month	PV (%)	EV (%)	SV (%)
10	May	61.66	62.27	0.61
11	May	68.48	65.91	-2.57
12	May	74.84	67.52	-7.33
13	May	80.18	73.87	-6.30
14	June	85.42	78.15	-7.27
15	June	90.43	82.96	-7.46
16	June	95.39	84.68	-10.71
17	June	100.00	87.56	-12.44
18	July	100.00	89.53	-10.47
19	July	100.00	95.75	-4.25
20	July	100.00	100.00	0.00

The EVM calculation shows variation in the Schedule Variance (SV) value throughout the execution of the electrical installation work. A summary of the schedule-performance measurement results is presented in Table 5.

Tabel 5. Summary of Project Schedule Performance Measurement Results

No	Parameter	Result
1	Maximum SV value	+25.18% (Week 4)
2	Minimum SV value	-12.44% (Week 17)
3	Period ahead of schedule	Weeks 1-10
4	Period when delay began	Week 11
5	Period of greatest delay	Weeks 16-17
6	SV value at the planned completion target (Week 17)	-12.44%
7	Planned completion target	Week 17 (4th week of June)
8	Actual work completion	Week 20 (July)
9	SV value at project completion	0.00%
10	Final project status	Work completed 100% in Week 20

Based on the summary of the Schedule Variance analysis, the electrical installation work was ahead of schedule from Week 1 through Week 10, as indicated by a positive SV, with the highest SV occurring in Week 4 at 25.18%, showing that actual progress substantially exceeded the planned progress. However, starting from Week 11, the SV turned negative, indicating that actual progress could no longer keep up with the planned target. The greatest delay occurred in Week 17, with an SV of -12.44%; at that point the project should have reached 100% progress, but actual progress had only reached 87.56%. According to the planned schedule, the electrical installation work was targeted for completion in Week 17 (the 4th week of June), but the work was only fully completed in Week 20 (July), indicating a schedule deviation (time

overrun) during project execution that required further analysis in the Analyze stage to identify its contributing factors.

Analyze Stage

The Analyze stage was carried out to identify the root causes of the time overrun in the Mall X electrical installation project. Based on the Measure-stage results, which showed a negative Schedule Variance in several periods, further analysis was required to determine the contributing factors, carried out using a Fishbone Diagram based on interviews with the parties involved in project execution. Building on the initial indications from the Define stage, a more in-depth set of interview questions was developed for the Analyze stage, covering the Design, Material, Man, Method, and Management aspects, with each question designed to support the preparation of the Fishbone Diagram. The Analyze-stage interview questions and a summary of the findings are presented in Table 6.

Tabel 6. Analyze-Stage Interview Questions and Summary of Findings

No	Interview Question	Summary of Findings
1	What factors cause delays in the electrical installation project?	Main factors include design changes (shop drawing), additional work outside the initial scope, clashes among MEP disciplines, material delays, and rework.
2	Have material delays occurred during the project?	All informants confirmed that material delays occurred; some materials were indent items, and design changes altered material requirements, lengthening the procurement process.
3	Does the number of workers affect project delay?	Labor levels affect project performance; workforce shortages caused delays, while unplanned additions to the workforce reduced productivity due to crowded work areas.
4	How does coordination among teams affect project work?	Good coordination accelerated work completion, while ineffective coordination caused work clashes, miscommunication, rework, and delays.
5	Did change orders occur during the project?	Most informants confirmed that change orders occurred, ranging from working-drawing changes to changes in the scope of work that affected the schedule.
6	Has the scheduling method used been effective?	The scheduling method was considered not fully effective in anticipating dynamic design changes; informants suggested applying CPM, EVM, and rolling wave planning.
7	What obstacles most often occur in field electrical installation work?	The most common obstacles were rework, clashes among disciplines, material delays, installation errors, and design changes during execution.
8	How does the delay of previous work affect subsequent work?	A delay in one activity affects subsequent activities because project activities are interdependent, creating a domino effect on the overall schedule.
9	Were there any supervision or communication obstacles during the project?	Communication obstacles occurred related to work changes, material requests, and coordination among parties; suboptimal supervision caused some problems to be identified late.

No	Interview Question	Summary of Findings
10	In your opinion, what is the main factor causing the time overrun in this project?	The main factors are design changes (shop drawing), material delay, rework, suboptimal coordination, and a scheduling method not yet able to effectively anticipate project changes.

The interview results indicate that design changes (change orders) were mentioned most frequently, as they led to changes in material requirements, rework, and schedule adjustments; material delays, workforce levels, inter-team coordination, the scheduling method, and communication and supervision constraints also contributed to delay. These factors are interrelated: design changes can trigger rework and material changes, while material delays hinder activities with dependency relationships, producing the deviation between the planned schedule and actual realization. Each response was reduced and grouped by causal-factor category, and a frequency analysis was performed to determine the dominant factors, as presented in Table 7.

Tabel 7. Recapitulation of Causal Factor Frequency (Analyze Stage)

No	Factor	Indicators from the Interviews	Frequency	Percentage (%)
1	Design	Shop-drawing changes, design changes, change orders, working drawings not yet finalized, rework	4	100
2	Material	Indent materials, material delays, incorrect material orders, procurement of new materials	4	100
3	Management	Suboptimal stakeholder coordination, suboptimal supervision, ineffective project monitoring	4	100
4	Method	Experience-based scheduling, ineffective scheduling method, suboptimal schedule control	3	75
5	Man	Insufficient labor, labor coordination, miscommunication among teams	3	50

The recapitulation shows that Design, Material, and Management were the factors most frequently mentioned by informants, each with a 100% occurrence rate, while Method and Man showed occurrence rates of 75% and 50% respectively, indicating that the delay resulted from a combination of interrelated factors rather than a single cause. The Design factor comprises changes in owner requirements, shop-drawing changes, and design revisions; Material comprises delayed procurement, indent materials, and new material requests; Man comprises insufficient labor, ineffective labor coordination, and miscommunication among teams; Method comprises experience-based scheduling, unidentified critical activities, and suboptimal schedule control; and Management comprises suboptimal stakeholder coordination, supervision, and progress monitoring (Arif et al., 2024). These factors were visualized in a Fishbone Diagram to systematically illustrate their relationship to the time-overrun problem: repeated design changes led to fieldwork adjustments, changed material requirements, and a

longer work duration than planned; indent materials and unplanned new material requests delayed procurement; ineffective labor coordination and understaffing reduced productivity; experience-based scheduling left critical activities unidentified so delays could not be anticipated early; and suboptimal stakeholder coordination, supervision, and monitoring delayed information flow, decision-making, and the identification of field problems. Overall, the Fishbone analysis shows that the time overrun originated from five main factors, with Design, Material, and Method identified as the most dominant because of their direct relationship to work changes, material availability, and the effectiveness of schedule planning and control; accordingly, the Improve stage applied a CPM scheduling simulation to produce a more structured schedule and reduce the potential for further delay.

Improve Stage

The Improve stage was carried out to formulate alternative improvements for the time-overrun causal factors identified in the Analyze stage. Since the interviews indicated that critical activities had not been systematically identified, the Critical Path Method (CPM) was selected as the alternative to the existing scheduling method (Priambodo & Prabawani, 2016). The application of CPM in this study was intended to simulate project scheduling as if CPM had been used from the planning stage, so that the results could be compared with the experience-based schedule actually used. CPM was chosen for its ability to identify the dependency relationships among project activities, determine the critical path, and identify activities with zero float (no tolerance for delay). Although this study focuses on electrical installation work, the CPM table also considers several activities from other work disciplines, because the electrical installation work has predecessor-successor dependency relationships with non-electrical activities, so that delays in those activities can affect the timing of the electrical installation work. The resulting activity data and dependency relationships used for the CPM calculation are presented in Table 8.

Tabel 8. Activity Data and Work Dependency Relationships for the CPM Calculation

No	Activity	Work	Predecessor	Optimistic (days)	Most Likely (days)	Pessimistic (days)	Expected Time (days)
1	A	Dismantling of existing M&E utilities	-	7	9	12	9
2	B	Cable tray installation	A	10	12	15	12
3	C	Hydrant installation	A	14	16	19	16
4	D	Cable pulling	B	35	37	40	37
5	E	Lamp installation	B	9	11	14	11
6	F	Sprinkler installation	C	4	6	9	6
7	G	Panel installation	D, E	8	10	13	10
8	H	Switch and outlet installation	D, E	11	13	16	13
9	I	Fire alarm installation	F	4	6	9	6
10	J	Sound system installation	G	4	6	9	6
11	K	Telephone installation	H	5	7	10	7
12	L	Clean water installation	I	14	16	19	16
13	M	Waste, sewage, and vent installation	I	14	16	19	16
14	N	Installation and testing	J, K	7	9	12	9
15	O	Testing and commissioning	L, M, N	14	16	19	16

Based on the network diagram developed from this activity data, the CPM calculation identified the critical path A-B-D-H-K-N-O, with a total minimum project completion duration of 103 working days, or approximately 15 weeks. This critical path identifies the activities with a direct influence on total project duration, which become the primary focus of schedule control. The CPM results were then used as the basis for developing a proposed project S-curve and were compared with the existing schedule, which had been developed based on experience without a structured scheduling method, by comparing the cumulative Planned Value (PV) at each period of project execution, as presented in Table 9.

Tabel 9. Comparison of Planned Schedules With and Without CPM

Week	Month	PV (%) without CPM	PV (%) with CPM
1	February	9.28	14.62
2	March	14.84	21.89
3	March	20.78	30.09
4	March	27.35	55.24
5	March	34.22	64.25
6	April	34.22	64.25
7	April	41.09	65.96
8	April	47.96	67.67
9	April	54.81	76.65
10	May	61.66	83.92
11	May	68.48	94.82
12	May	74.84	97.41
13	May	80.18	100.00
14	June	85.42	100.00
15	June	90.43	100.00
16	June	95.39	100.00
17	June	100.00	100.00
18	July	100.00	100.00
19	July	100.00	100.00
20	July	100.00	100.00

The comparison shows that the CPM-based schedule produces a higher cumulative planned progress than the existing schedule in most periods; for example, in Week 4 the CPM-based cumulative progress reached 55.24%, compared with only 27.35% for the schedule without CPM, and by Week 13 the CPM-based cumulative progress had already reached 100%, whereas the existing schedule only reached 80.18% at that point and did not reach its 100% target until Week 17. This indicates that the application of CPM was able to optimize the sequence of work execution through the identification of activity dependencies and the determination of the project's critical path. Overall, compared with the existing schedule, which had a planned duration of 17 weeks, the CPM simulation, with a total duration of 103 working

days (approximately 15 weeks), demonstrates the potential to shorten the planned project duration by approximately 2 weeks, indicating that CPM enables a more systematic and effective approach to project time planning and control than experience-based scheduling.

Improvement of project time performance depends not only on the scheduling method applied but also on addressing the causal factors identified in the Analyze stage. Accordingly, a set of proposed improvements was formulated by integrating the Fishbone Diagram results, the CPM results, the interview findings, and the relevant literature on construction project control, as presented in Table 10.

Tabel 10. Proposed Improvements Based on the Fishbone Diagram and CPM Results

No	Factor	Root Cause	Basis of Finding	Proposed Improvement
1	Design	Changes in owner requirements	Interview and Fishbone results	Coordinate owner requirements from the planning stage and finalize the design before work begins
2	Material	Changes in material procurement requests	Interview and Fishbone results	Improve coordination between the design team and the procurement team
3	Man	Insufficient labor	Interview and Fishbone results	Adjust labor requirements for critical project activities
4	Method	Experience-based scheduling	Interview and Fishbone results	Apply the CPM method in preparing the project schedule
5	Management	Suboptimal stakeholder coordination	Interview and Fishbone results	Hold periodic project coordination meetings

Each time-overrun causal factor identified in the Analyze stage was assigned a corresponding improvement alternative based on its root cause: the Design factor focuses on controlling design changes and shop drawings to minimize rework; the Material factor focuses on improving material-procurement planning and control so that material availability supports activities according to schedule; the Man and Management factors are directed at improving coordination, communication, supervision, and progress monitoring; and the Method factor focuses on applying CPM as a scheduling method capable of systematically identifying critical activities and supporting more structured schedule control than the existing experience-based method. These proposed improvements are intended not only to address the problems within each causal factor but also to support the control of activities on the project's critical path, so that supervision, resource allocation, and material procurement can be prioritized for the activities with a direct influence on project duration, thereby reducing the potential for time overrun in the Mall X electrical installation project and improving the effectiveness of project schedule planning and control (Nuriana et al., 2019).

Control Stage

The Control stage was carried out to ensure that the improvements formulated in the Improve stage can be applied consistently and sustainably, so that the potential for time overrun can be minimized in similar future projects. In this study, the Control stage is embodied in a Standard Operating Procedure (SOP) for Project Schedule Performance Control, developed

based on the interview results, the Fishbone Diagram analysis, the CPM results, and relevant literature on construction project control, with the factors prioritized for control determined based on the frequency of occurrence obtained in the Analyze stage. Through this triangulation of data, each control action was formulated based on the relationship between the identified root causes of delay from the Fishbone Diagram and the critical activities obtained from the CPM results, so that the resulting control mechanism functions not only to resolve problems that have already occurred but also as a preventive measure against potential delay in subsequent project execution. The proposed Standard Operating Procedure for Project Schedule Performance Control is presented in Table 12.

Tabel 11. Standard Operating Procedure (SOP) for Project Schedule Performance Control

No	Control Activity	Objective	Frequency	Responsible Party	Control Action
1	Review and approval of shop drawings before work execution	Minimize design changes and rework	Before work begins	Project Manager and Site Engineer	Verify and approve shop drawings before work execution
2	Monitoring of changes in owner requirements	Control changes in the scope of work	As needed	Project Manager	Evaluate the impact of changes on the project schedule
3	Monitoring of material procurement	Ensure material availability according to schedule	Weekly	Procurement and Site Engineer	Check procurement status and follow up on delays
4	Monitoring of critical and indent materials	Avoid delay due to limited material availability	Weekly	Procurement	Procure long-lead-time materials earlier
5	Evaluation of labor requirements	Ensure the workforce matches project needs	Weekly	Project Manager and Supervisor	Adjust the workforce for critical activities
6	Work briefing and coordination	Reduce miscommunication among teams	Daily	Supervisor	Communicate work targets and field obstacles before work begins
7	Monitoring of critical-path activities based on CPM	Control activities with a direct influence on project duration	Weekly	Site Engineer and Project Manager	Compare actual progress with the CPM schedule
8	Monitoring of work progress against the project schedule	Identify schedule deviation early	Weekly	Project Control and Project Manager	Evaluate progress and take corrective action if delay occurs
9	Project stakeholder coordination meetings	Improve coordination and decision-making	Weekly	Project Manager	Discuss progress, obstacles, and follow-up plans

No	Control Activity	Objective	Frequency	Responsible Party	Control Action
10	Evaluation of project time performance using Schedule Variance (SV)	Regularly measure project time performance	Weekly/Monthly	Project Manager	Analyze SV and formulate corrective action if a negative deviation occurs

The developed SOP shows that each control procedure is designed to manage the time-overrun causal factors identified in the Analyze stage while also supporting supervision of the critical activities identified through CPM. The application of this SOP is expected to improve the effectiveness of monitoring, coordination, and schedule control, so that the potential for delay can be minimized, and to serve as a guideline for maintaining project time performance and sustaining the improvements formulated in the Improve stage.

CONCLUSION

Based on interviews, frequency analysis, and Fishbone Diagram analysis, five factors contributing to time overrun were identified in the Mall X 8th-floor electrical installation project: Design, Material, Management, Method, and Man. Design, Material, and Management were identified as the dominant factors, each with an occurrence frequency of 100%, followed by Method (75%) and Man (50%). The identified root causes included owner-driven design changes, delayed material procurement, inadequate stakeholder coordination, experience-based scheduling that failed to identify critical activities, and limited labor availability and field coordination. Earned Value Management (EVM) analysis showed that schedule deviation began in Week 11, with a Schedule Variance (SV) of −12.44% at the planned completion in Week 17, indicating that actual progress had reached only 87.56% of the planned progress. Consequently, the project was completed in Week 20. A Critical Path Method (CPM) simulation identified the critical path A–B–D–H–K–N–O with a total duration of 103 working days (approximately 15 weeks). Compared with the existing 17-week schedule, this result indicated the potential to reduce completion time by approximately two weeks through systematic sequencing and control of critical activities.

The proposed improvement strategies included the implementation of CPM as a structured scheduling method, recommendations developed from Fishbone Diagram and CPM analyses, and a Standard Operating Procedure (SOP) for Project Schedule Performance Control. The proposed SOP covered Planned Value (PV), Earned Value (EV), and Schedule Variance (SV) monitoring, critical activity control, and stakeholder coordination mechanisms. Overall, the integration of DMAIC (Define, Measure, Analyze, Improve, Control) with EVM, Fishbone Diagram analysis, CPM, and SOP development provided a comprehensive framework for improving schedule control in electrical installation projects. Contractors are recommended to adopt CPM during the early planning phase and establish stronger controls for design changes before significant field execution progresses. Project management teams and stakeholders are encouraged to institutionalize the proposed SOP to improve schedule monitoring and coordination. Future research should evaluate the direct implementation of CPM and the proposed SOP in ongoing projects and expand the analysis to include cost and

risk dimensions, as this study was limited to a single case study based on simulation results and conceptual recommendations without direct field implementation.

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