
Analysis of Alloy Piping Operations in the Muara Tawar PLTGU Project

Rendy Yoel, Muhammad Abduh, Ima Fatima

Intitut Teknologi Bandung, Indonesia

Email: 24022102@mahasiswa.itb.ac.id

Abstract

Productivity in construction work is one of the important factors in managing the expenses of a project. One way to assess work productivity is by conducting simulations. This study specifically focuses on the productivity of alloy piping work in the Muara Tawar PLTGU project, considering that this work requires a significant amount of resources and lies on the critical path of the project completion schedule. The Muara Tawar PLTGU Project involves substantial alloy piping operations, which are critical to project scheduling and resource management due to their high resource demands and placement on the critical path. This study aims to analyze and optimize the productivity of alloy piping construction through simulation. Using CYCLONE modeling and EZSTROBE software, the research simulates existing operational processes based on field data, including work stages, durations, and resource allocations. The simulation revealed an initial productivity rate of 10.66 dia-inch/day per team. Further sensitivity analysis identified bottlenecks in the fit-up stage, leading to recommendations for resource augmentation. By increasing the number of fitters and helpers, productivity improved to 15.99 dia-inch/day. These findings underscore the value of simulation-based planning in enhancing construction efficiency and resource utilization, offering practical implications for project managers in similar large-scale mechanical installations.

Keywords: Construction Operations, Productivity, Piping, Simulation, CYCLONE, EZSTROBE.

Corresponding: Rendy Yoel

E-mail: 24022102@mahasiswa.itb.ac.id



INTRODUCTION

Power plant construction is a multidisciplinary project that requires not only civil works but also mechanical, electrical, and instrumentation expertise (Kartika Sari et al., 2023). Among mechanical tasks, piping—particularly alloy piping—is one of the most resource- and time-intensive activities, which makes careful planning and preparation essential for achieving project goals (Hunt, 2024). Studies highlight that pipe spool productivity is influenced by factors such as spool attributes, crew characteristics, and environmental conditions, all of which significantly impact man-hours, especially in alloy piping (Fayek & Oduba, 2008). In industrial construction, productivity control and schedule tracking are usually carried out periodically using productivity profiles and progress curves, which enable early detection of deviations from planned schedules (Construction Industry Institute, 2020). To strengthen this process, project organizations often apply Earned Value Management (EVM), using metrics such as the Schedule Performance Index (SPI) and Cost Performance Index (CPI) to measure schedule and cost efficiency quantitatively (Dozzi et al., 1985). Integrated cost and schedule control systems have also been implemented in nuclear power plant projects, where project numbering systems combined with EVM provide owners and EPC firms with strategic advantages in managing risks and efficiency (Jung et al., 2014). Moreover, synchronizing cost plans with the timing of actual expenditure records is considered vital to ensure accurate and timely cost monitoring and control in construction projects (SlideShare, n.d.). Finally, research emphasizes that power

plant projects involve complex interactions between piping systems, rotating equipment, and overall plant design, where productivity and cost control mechanisms must be rigorously combined to meet schedule and budget targets (Sánchez Colmenarejo, 2022).

Construction productivity simulation has become increasingly important in complex infrastructure projects, particularly in power plant construction, where schedule adherence and cost control are critical (Abduh, 2022). Previous studies have demonstrated the effectiveness of CYCLONE modeling in analyzing construction operations and identifying bottlenecks in work processes (Halpin & Riggs, 1992; Cheng et al., 2000). As a source of research data, the author selected one of the power plant projects currently under construction, namely the 650 MW Muara Tawar Add-On PLTGU. In this project, pipe construction involves a large volume—approximately 201,202 Dia.Inch of piping that must be connected. This work lies on the project's critical path for completion.

The global push for energy security and infrastructure development has significantly accelerated the construction of gas turbine power plants (PLTGU), yet the industry continues to be plagued by pervasive project delays and cost overruns that often stem from managerial and operational inefficiencies. Recent analysis of industrial EPC (Engineering, Procurement, and Construction) projects—especially in the refining, gas, and electricity sectors—reveals that construction-phase inefficiencies alone account for up to 60% of delay and cost overrun causes, highlighting the critical need to better manage complex mechanical operations (Álvarez-Pozo et al., 2024). Moreover, a systematic scientometric and social network analysis of construction cost escalations identifies core drivers such as planning and scheduling issues, design inefficiencies, scope ambiguities, and inaccuracies in estimation—each of which can severely impede mechanical productivity (Abdelalim, 2024). Compounding these challenges, the recent surge in gas-fired power generation has triggered a turbine supply crunch and a sharp rise in unit construction costs—from about USD 1,000 to USD 2,000–2,500 per kilowatt—due to limited manufacturing capacity and contractor shortages (Reuters, 2025). Such bottlenecks in procurement and resource allocation inevitably disrupt execution timelines and escalate budgets, undermining the commercial viability of power infrastructure. From a broader cost-performance perspective, mapping 66 interrelated cost-overrun factors across high-impact studies further underscores that unresolved planning, contractual ambiguity, and unforeseeable site conditions are among the most influential threats to both schedule adherence and financial control (Abdelalim, 2024). As a result, optimizing highly specialized and resource-intensive construction processes—through robust planning, strategic supply chain management, and streamlined operational flows—is not only a commercial imperative but also a vital enabler of energy resilience and sustainable economic development.

Within power plant construction, mechanical works—specifically piping installation—represent some of the most demanding and schedule-critical activities. Piping networks act as the circulatory system of a plant, and their installation often dictates the project's critical path. Alloy piping introduces a layer of complexity due to stringent welding and heat treatment procedures required to ensure integrity under high pressure and temperature. The Muara Tawar PLTGU Add-On project, with a massive scope of approximately 201,202 Dia.Inch of piping, exemplifies this challenge. The sheer volume of work, coupled with the technical precision

required, makes the productivity of these operations a primary determinant of the project's overall success or failure, directly influencing its final cost and completion date.

Productivity in construction has long been a subject of academic inquiry, with simulation emerging as a powerful tool for analysis and optimization. Pioneering work by Halpin & Riggs (1992) established the foundation for modeling construction operations using systems like CYCLONE (Cyclic Operation Network). Subsequent researchers, such as Cheng, Wu, & Tseng (2000), developed advanced digital tools like COST to enhance these simulation capabilities. More recently, studies have applied these methodologies to various construction scenarios, demonstrating their efficacy in identifying bottlenecks and testing resource allocation strategies before physical work commences. This body of research confirms that simulation-based planning is a robust approach for improving operational efficiency in complex projects.

Despite the established value of simulation modeling, a specific research gap exists in its application to the precise, high-stakes context of alloy piping installation in Indonesian power plant projects. Many previous studies offer theoretical models or apply simulations to broader construction phases, but few provide a granular, step-by-step analysis of the specialized workflow involving fit-up, preheating, welding, post-heat treatment, and testing. There is a lack of empirical, data-driven studies that begin with actual field data from an ongoing mega-project to build a realistic model, identify a precise bottleneck (e.g., the "ready to fit-up" node), and propose a quantified, optimized resource mix to address it. This gap between general simulation theory and its targeted application to this specific mechanical trade forms the core problem this research addresses.

The urgency of this research is directly tied to the strategic importance of the Muara Tawar PLTGU project itself. As a key infrastructure project aimed at boosting Indonesia's electricity capacity, any delay incurs significant financial penalties for the contracting company and, more broadly, can impede national energy provision goals. The alloy piping work is on the project's critical path, meaning any inefficiency here has a direct and multiplicative effect on the overall completion date. Therefore, finding ways to accelerate this specific operation without compromising quality or safety is not just an academic exercise but an urgent operational necessity to safeguard the project's economic viability and its contribution to the public good.

The novelty of this study lies in its targeted and integrated approach. It moves beyond generic productivity analysis by creating a highly specific CYCLONE model tailored to the intricate, sequential process of alloy piping installation. Its originality is demonstrated by using actual resource data and durations from the live project to create a realistic baseline simulation. Furthermore, the research introduces novelty by conducting a sensitivity analysis focused exclusively on optimizing the fit-up crew composition (fitters and helpers), revealing a non-linear relationship where adding resources beyond an optimal point becomes counterproductive. This provides a precise, evidence-based recommendation rather than a general suggestion to "add more manpower."

The primary purpose of this research is to rigorously analyze the productivity of alloy piping operations within the Muara Tawar PLTGU project through discrete-event simulation. It seeks to move from anecdotal evidence or simplistic calculations to a sophisticated systems-

based understanding of the entire operation. The goal is to accurately diagnose the root causes of productivity constraints within the simulated workflow and to scientifically test and validate potential solutions through scenario analysis. Ultimately, the aim is to translate quantitative simulation outputs into actionable managerial insights that can be implemented on the ground to improve performance.

This research is poised to contribute significantly to both theory and practice. From a theoretical standpoint, it adds to the body of knowledge in construction management by providing a detailed case study on the application of CYCLONE modeling and EZSTROBE simulation to a specialized mechanical process, validating and extending frameworks proposed by earlier scholars. For practitioners, the contribution is immensely practical: it offers a validated model and a clear, quantified strategy for project managers and mechanical supervisors at the Muara Tawar site to enhance their productivity, potentially saving considerable time and cost.

The specific objectives of this study are fourfold: first, to develop an accurate CYCLONE model of the alloy piping construction process based on real-world project data; second, to calculate the current productivity rate (in Dia.Inch/day) using the EZSTROBE simulation software; third, to perform a sensitivity analysis by experimenting with different combinations of key resources (fitters and helpers) to identify an optimal crew size; and finally, to provide data-driven recommendations for improving the site's operational implementation based on the simulation's findings.

The benefits of this research are multifaceted. For project stakeholders, the direct benefit is the potential for achieving schedule compression and cost savings on a critical activity, enhancing the project's profitability and timely delivery. For the academic community, it provides a replicable methodology and a rich dataset for future research into construction operation optimization. For the wider industry, it serves as a compelling demonstration of how modern simulation tools can be leveraged for pre-emptive problem-solving, promoting a culture of data-driven decision-making and planning in complex construction environments.

RESEARCH METHOD

This research employed a quantitative approach using discrete-event simulation methodology. The first stage is to conduct a literature review on cyclone modeling, and the simulation application that will be used. Then information will be identified regarding the Muara tawar PLTGU Project and specifically identify the sub-work of Alloy piping construction. The data collected includes an overview of the project, information on the method of the alloy piping work such as the stages of work, the duration of operation and the resources used. The data is then processed and simulated on the EZSTROBE application to find out what the productivity value is, and conduct a productivity analysis. After that, recommendations, conclusions, and suggestions will be prepared based on the research that has been conducted. This research started from collecting actual data from the field. It is divided into 3 parts, starting from general project information, an explanation of the piping construction method and finally the resources used in the piping construction.

RESULTS AND DISCUSSION

Piping Construction Method

Pipe construction work generally starts from the process of sending materials from laydown to the site, doing fit up, preheating process, then welding and then sent to post heat, the results of postheat will be tested, where if the test results are good they will be accepted, but if the results are not good, they will be repaired and return to the preheat stage again. Broadly speaking, the work can be seen in the picture.

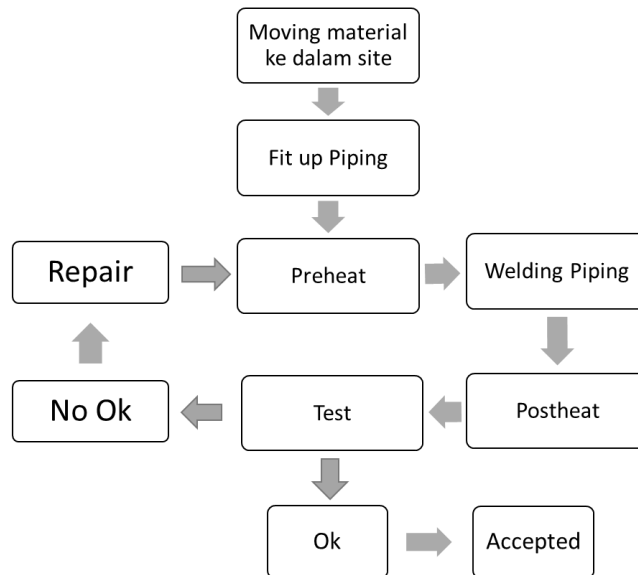


Figure 1. Pipe construction work

Resources

Based on actual data in the field, the resources needed and the duration required to do per section on the alloy piping work can be seen in the following table:

Table 1. Resource Requirements and Duration for Alloy Piping Operations

No	Activity	Duration per section(hour)	Resources required to run					
			Welder	Fitter	Rigger	Helper	Crane	PWHT tool
1	Moving material in site	10			3		1	
2	Fitup Welding	15		4		2		
3	Pre Heat	3						1
4	Welding Pipe	7	2			2		
5	Post heat	3						1
6	Testing	15						
7	Repair	7	1	2		1		

For each section (20 dm inch) the amount of resources available is:

1. Welder = 3 orang
 2. Fitter = 6 people
 3. Rigger = 3 orang
 4. Helper = 5 people
 5. Crane = 1 set
- PWHT tool = 2 set

Operation Modeling with Cyclone

CYCLONE modeling is made based on the work activity; the resources needed for the alloy piping work. Then priority determination is carried out for each work where in this modeling the researcher takes priority in the following order:

1. Fitup
2. Preheat
3. Welding
4. Postheat
5. Fitup

(the greatest value has the greatest priority to work on first)

In this model, it is assumed that the probability of an acceptable test result is 8:10.

CYCLONE modelling for alloy piping work activities.

Cyclone Simulation Results With Ezstrobe

The CYCLONE simulation that has been created is then operated using EZstrobe software. With the target setting of the stop simulation is with an acceptable value (ACCEPTED) of 10000 sections. The output of the EZstrobe can be seen in the following image:

Table 2. Statistics report at simulation time 150053

Queue	Res	Cur	Tot	AvWait	AvCont	SDCont	MinCont	MaxCont
Crane	ezs	0.00	15006.00	0.00	0.00	0.00	0.00	1.00
Fitter	ezs	2.00	45026.00	5.89	1.77	0.64	0.00	6.00
Fitup_Ready	ezs	5002.00	15005.00	25006.00	2500.55	1443.89	0.00	5002.00
Helper	ezs	1.00	47529.00	5.42	1.72	1.02	0.00	5.00
PWHT	ezs	2.00	25017.00	9.00	1.50	0.55	0.00	2.00
PostWHT_Ready	ezs	0.00	12507.00	0.00	0.00	0.00	0.00	1.00
PreWHT_Ready	ezs	0.00	12508.00	0.00	0.00	0.01	0.00	2.00
ReadyRepair	ezs	0.00	2506.00	0.00	0.00	0.00	0.00	1.00
Rigger	ezs	0.00	45018.00	0.00	0.00	0.00	0.00	3.00
Welder	ezs	1.00	27523.00	9.36	1.72	1.02	0.00	3.00
WeldingReady	ezs	0.00	12508.00	0.59	0.05	0.22	0.00	3.00

Table 3. Activity Statistics

Activity	Cur	Tot	IstSt	LstSt	AvDur	SDDur	MinD	MaxD	AvInt	SDInt	MinI	MaxI
Accepted	0	10000	53.00	150053.00	0.00	0.00	0.00	0.00	15.00	7.86	7.00	75.00
Fitup	1	10003	10.00	150040.00	15.00	0.00	15.00	15.00	0.00	0.00	15.00	15.00
PostWHT	0	12507	35.00	150047.00	3.00	0.00	3.00	3.00	12.00	3.62	0.00	15.00
PreWHT	0	12508	25.00	150048.00	3.00	0.00	3.00	3.00	11.99	4.18	0.00	15.00
Reject	0	2506	278.00	150038.00	0.00	0.00	0.00	0.00	59.78	62.75	7.00	615.00
Repair	0	2506	278.00	150038.00	7.00	0.00	7.00	7.00	59.78	62.75	7.00	615.00
Testing	1	12507	38.00	150050.00	15.00	0.00	15.00	15.00	12.00	3.62	7.00	15.00
TransPipe	1	15006	0.00	150050.00	10.00	0.00	10.00	10.00	10.00	0.00	10.00	10.00
WELDING	1	12508	28.00	150047.00	7.00	0.00	7.00	7.00	11.99	3.62	7.00	15.00

Based on the above results, 10000 sections can be completed by the system in 150053 hours, or the equivalent in 18756.62 working days, if in 1 day the working time is calculated to be 8 hours.

1 section is as much as 20 dia inches, then 10000 sections is as much as 200000 dia inches.

The productivity of the work is:

$$\text{Work Productivity} = 200000/18756.62 = 10.66 \text{ dia inch/day}$$

CYCLONE Simulation Optimization

Analysis of the simulation results revealed significant bottlenecks in the system

Based on the results of the CYCLONE simulation that can be seen in the image above, some resources can be optimized by reducing the average waiting time for resources. From the simulation above, it can be seen that the largest waiting time is in the node ready to fit up. This may be due to a lack of resources to work on fitups.

The optimization strategy focused on addressing the identified bottleneck

For this reason, the optimization that can be done is to increase resources to work on fitups such as fitters. By adding fitters and helpers, productivity values are increasing. However, the increase in the number is only maximum for the number of resource fitters of 8 people and helpers of 6 people. The addition of the number of resources above does not increase productivity but instead increases the waiting time of the resource.

The following are the results of the simulation with the optimization of the addition of resource fitter and helper to 8 and 6 people.

Table 4. Queue and Resource Statistics

Queue	Res	Cur	Tot	AvWait	AvCont	SDCont	MinCont	MaxCont
Crane	ezs	0.00	10006.00	0.00	0.00	0.00	0.00	1.00
Fitter	ezs	4.00	45070.00	3.66	1.65	1.78	0.00	8.00
Fitup Ready	ezs	0.00	10005.00	0.89	0.09	0.29	0.00	2.00
Helper	ezs	2.00	47587.00	2.25	1.07	1.30	0.00	6.00
PWHT	ezs	0.00	25052.00	4.99	1.25	0.78	0.00	2.00
PostWHT Ready	ezs	0.00	12525.00	0.00	0.00	0.02	0.00	1.00
PreWHT Ready	ezs	0.00	12527.00	0.05	0.01	0.08	0.00	2.00
ReadyRepair	ezs	0.00	2523.00	1.68	0.04	0.20	0.00	2.00
Rigger	ezs	0.00	30018.00	0.00	0.00	0.00	0.00	3.00
Welder	ezs	1.00	27556.00	3.89	1.07	0.75	0.00	3.00
WeldingReady	ezs	0.00	12526.00	3.49	0.44	0.78	0.00	7.00

Table 5. Activity Statistics

Activity	Cur	Tot	1stSt	LstSt	AvDur	SDDur	MinD	MaxD	AvInt	SDInt	MinI	MaxI
Accepted	0	10000	63.00	100057.00	0.00	0.00	0.00	0.00	10.00	4.81	5.00	54.00
Fitup	1	10005	10.00	100052.00	15.00	0.00	15.00	15.00	10.00	2.43	0.00	16.00
PostWHT	1	12525	35.00	100055.00	3.00	0.00	3.00	3.00	7.99	1.31	5.00	14.00
PreWHT	1	12527	25.00	100055.00	3.00	0.00	3.00	3.00	7.99	3.27	0.00	15.00
Reject	0	2523	53.00	100043.00	0.00	0.00	0.00	0.00	39.65	36.93	6.00	355.00
Repair	0	2523	55.00	100045.00	7.00	0.00	7.00	7.00	39.65	36.88	0.00	357.00
Testing	1	12524	38.00	100050.00	15.00	0.00	15.00	15.00	7.99	1.31	5.00	14.00
TransPipe	1	10006	0.00	100050.00	10.00	0.00	10.00	10.00	10.00	0.00	10.00	10.00
WELDING	1	12526	28.00	100055.00	7.00	0.00	7.00	7.00	7.99	1.31	7.00	14.00

Compared to the previous results with this optimization, productivity increased to

$$\text{Productivity} = 200000 / (100057/8) = 15.99 \text{ Diainch/day}$$

This represents a 50% improvement in productivity through strategic resource reallocation, demonstrating the effectiveness of simulation-based optimization in construction operations.

CONCLUSION

Based on the EZSTROBE simulation using actual field data from the Muara Tawar PLTGU project, the productivity of alloy piping operations was precisely measured at 10.66

Dia inch/day, revealing a bottleneck at the 'ready to fit-up' stage caused by resource imbalance. Optimizing the crew to 8 fitters and 6 helpers improved productivity by approximately 50%, increasing the rate to 15.99 Dia inch/day without additional welding or crane resources, highlighting the importance of targeted resource allocation over simply increasing manpower. For future research, it is recommended to extend the simulation model to include a detailed cost-benefit analysis of resource augmentation relative to productivity and schedule improvements. Additionally, exploring the effects of prefabrication, advanced welding technologies, and applying this simulation approach to other critical disciplines in power plant construction—such as turbine installation and electrical commissioning—could further optimize large-scale, multi-disciplinary infrastructure projects.

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