Analysis of Excavator Productivity in Bore Pile Foundation Drilling Using the 5W + 1H Method

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ABSTRACT

The increasing traffic congestion has driven the development of the Solo–Yogyakarta–Yogyakarta International Airport toll road project, which involves drilling bore piles using heavy excavators. This study aims to evaluate excavator productivity by analyzing the percentage of value-added activities (VAA) and non-value-added activities (NVAA), using the Manufacturing Cycle Effectiveness (MCE) method combined with the 5W + 1H approach. The novelty of this research lies in integrating MCE and the 5W + 1H framework for analyzing construction equipment, providing a structured framework to identify the root causes of productivity losses beyond conventional time–motion studies. The results from three case samples reveal that NVAA dominates VAA, with idle time being the primary factor that reduces productivity. These findings underscore the importance of enhancing inter-team coordination, optimizing work sequencing, and minimizing standby periods to improve excavator efficiency in bore pile operations. Practically, the proposed analysis provides construction managers with actionable insights to minimize inefficiencies, reduce project costs, and improve scheduling reliability. However, the study is limited by its focus on a single project location and three observation samples, which may restrict generalizability. Future research should extend the method to larger datasets and diverse project settings to strengthen its applicability.

Keyword: Productivity, Excavator, MCE, 5W + 1H Method

1. INTRODUCTION

The increasing traffic congestion in Central and Southeastern Java has created significant risks to mobility, logistics, and regional development. To address this issue, the Indonesian government initiated the Solo–Yogyakarta–Yogyakarta International Airport (YIA) toll road project, which is expected to reduce travel time, improve connectivity, and stimulate economic growth. One of the critical construction tasks in this project is the installation of bore pile foundations, a process that requires precise drilling operations using heavy equipment such as excavators [1]. According to the Ministry of Public Works and Housing, the toll road is projected to accommodate more than 40,000 vehicles per day upon completion, underscoring the urgency of efficient construction practices [2]. High productivity in equipment operation is essential for ensuring timely project delivery and cost efficiency. In bore pile foundation drilling, excavator performance plays a central role in determining workflow effectiveness [3]. Productivity, defined as the ratio between output and input utilization, reflects not only machine capability but also coordination, sequencing, and resource management [4]. Previous studies emphasize that productivity losses often stem from excessive non-value-added activities (NVAA), including idle time and unnecessary movement, which do not contribute to the final output. To capture these inefficiencies, the Manufacturing Cycle Effectiveness (MCE) method is applied to measure the proportion of value-added activities (VAA) in excavator operations [5][6].

Recent studies also emphasize that performance optimization in construction and engineering requires analytical and systematic approaches that integrate quantitative data with field observations. For example, [7] demonstrated that productivity improvement depends on combining material performance testing with structured evaluation methods to achieve consistent field efficiency. Similarly, [8] showed that applying analytical frameworks such as the JONSWAP method can identify dominant performance variables through data-driven modeling, highlighting the role of quantitative precision in engineering optimization. Meanwhile, [9] revealed that even small variations in system components can significantly affect operational outcomes, underscoring the importance of controlled methodological assessment in engineering studies. In this context, the integration of MCE and 5W + 1H in the present study serves as a structured analytical tool to quantify excavator productivity and identify inefficiencies in bore pile drilling operations. Building on this, the present research employs the 5W + 1H method as an analytical framework to identify the root causes of low productivity and propose practical solutions. The distinction between Value-Added Activities (VAA) and Non-Value-Added Activities (NVAA) becomes central, as productivity in bore pile drilling is directly influenced by the proportion of effective working time devoted to VAA compared to NVAA. The analysis focuses on parameters such as equipment operating cycles, idle time, delays, and resource utilization, which are used to quantify excavator productivity and highlight inefficiencies. The objective is twofold:

first, to quantify the productivity of excavators in bore pile drilling, and second, to provide insights into improving operational efficiency by reducing NVAA. By combining MCE measurement with 5W + 1H analysis, this study offers a systematic approach that can support construction managers in decision-making, particularly in large-scale infrastructure projects such as toll roads.

2. METHODS

This research was conducted on the Solo–Yogyakarta Toll Project Package 1.2 (Klaten–Purwomartani) with a total length of approximately 20.08 km and located crossing Klaten (Central Java) and entering the DIY region in the Prambanan and Purwomartani areas. This research focuses on Pier Structure 1 of the STA. 35+882 Bridge. The focus was on the work cycle of bore pile foundation drilling using an excavator with a bore diameter of 1000 mm. The location of the Bore Pile points can be seen in Figure 1.

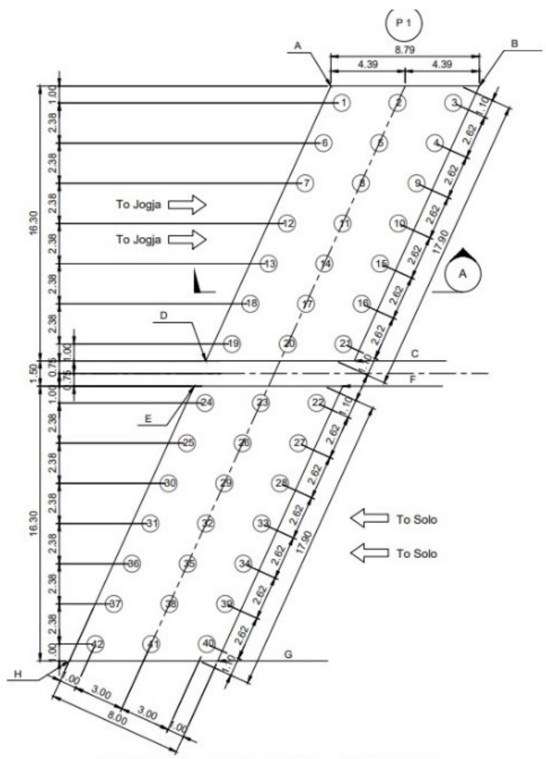

Figure 1 Layout of Bore Pile Foundation Pier P1

Direct field observations were carried out by a team of two trained observers to ensure reliability and minimize bias. The observers recorded each work cycle using digital timing instruments (stopwatches synchronized to ±0.01 seconds) and video documentation for validation. Observations were conducted across three samples during different shifts to capture variability in operational conditions. To maintain consistency, a standardized observation protocol was used, and inter-observer comparisons were performed at the end of each session to align recorded durations. The excavator's activities were classified into value-added activities (VAA) and non-value-added activities (NVAA). VAA included operations that directly contributed to bore pile drilling progress, while NVAA consisted of waiting, moving, or idle time. Cycle time was calculated as the sum of processing, inspection, transfer, waiting, and storage times. Manufacturing Cycle Effectiveness (MCE) was then determined by comparing VAA against total cycle time. In addition to descriptive calculations, significance testing was conducted to examine differences in NVAA proportions among the three samples. One-way ANOVA was applied to assess whether variations in NVAA were statistically significant, followed by post-hoc comparisons where necessary. This strengthened the validity of findings beyond simple percentage analysis. To explore potential improvements, the study also simulated alternative workflows using a task-parallelization approach. For example, scenarios where reinforcement preparation and material delivery were synchronized with drilling progress were modelled to estimate reductions in NVAA. These hypothetical scenarios were compared with actual observations to highlight the potential productivity gains achievable through improved coordination and workflow optimization.

In this study, the primary focus is on the work cycle of Bore Pile foundation drilling using an excavator, which is presented in Table 1. During the drilling process, the excavator performs several operations. Initially, it moves to the location of the steel plate, where the steel plate is picked up from its starting point. Next, the excavator loads the steel plate by placing it in the drilling area. Following this, a swing boom operation is performed. The swing boom is an integral component of the heavy equipment, the excavator, as it allows the excavator arm to rotate to the left or right, enabling the machine to work in various positions without having to reposition the entire unit [10]. Subsequently, the excavator moves to the designated location for placing the steel plate, thereby transferring the steel plate to its intended destination. This is followed by the unloading of the steel plate, which involves lowering the plate at the drilling location. Next, the excavator moves to the location of the red soil embankment to transfer the red soil from one location to another. It then waits for the drilling results to determine the appropriate handling of the excavated waste material. After this, the excavator performs another swing boom operation to collect the red soil. This is immediately followed by loading the red soil, which involves transporting the excavated waste to the excavator.

Table 1 Cycle and duration of the excavator for Bore Pile foundation drilling work

No	Sub Task	Sample 1		Sample 2		Sample 3	
		Repetition	Total Duration (min)	Repetition	Total Duration (min)	Repetition	Total Duration (min)
	Preparation of Drilling Location (Relocation of Bore Pile Machine Base Plate)						
1	Moving to the steel plate location	3	0.57	3	0.52	3	0.57
2	Loading the steel plate	3	2.70	3	3.70	3	2.70
3	Swing boom	3	0.05	1	0.05	3	0.05
4	Moving to the steel plate placement location	3	1.12	3	0.51	3	0.51
5	Unloading the steel plate	3	5.10	3	4.20	3	5.10
6	Moving to the red soil stockpile location	1	0.30	1	0.50	1	0.30
	Drilling Process						
7	Waiting for drilling results	3	70.56	3	57.22	3	63,08
8	Swing boom	35	1.75	30	1.50	33	1,65
9	Loading red soil	5	0.50	7	0.70	5	0,5
10	Moving to the drilling waste disposal location	13	3.97	9	2.75	12	3,67
11	Moving to the drilling material storage location	12	3.56	10	2.91	13	3,63
12	Moving to the drilling location	9	3.05	11	5.10	9	3,05
13	Moving to the red soil stockpile location	4	1.10	6	1.65	4	1,1
14	Moving to the fabrication site	5	1.05	5	1.05	5	1,05
15	Loading red soil	5	0.50	7	0.70	5	0,5
16	Loading drilling material	13	1.57	9	1.13	13	1,47
17	Loading reinforcement bars	3	3.00	3	4.80	3	2,2
18	Loading the welding machine	1	1.00	1	2.00	1	1
19	Unloading red soil	5	0.50	7	0.70	5	0,5
20	Unloading drilling material	13	6.90	9	4.40	12	5,7
21	Unloading reinforcement bars	3	3.00	3	5.00	3	2,9
22	Unloading the welding machine	1	1.00	1	3.00	1	1
	Total		112.85		104.09		102.23

The excavator moves to the disposal site to transfer the drilling waste, which consists of debris generated from the drilling process. The excavator then moves to the material stockpile location to transport the extracted drilling materials. Following this, the excavator moves back to the drilling location to resume the drilling process. Subsequently, the excavator moves to the red soil stockpile location to collect more red soil. The next step involves moving to the fabrication site to retrieve the reinforcement bars. The excavator then performs the loading of red soil, which entails transporting the red soil into the excavator. After that, it loads the extracted drilling materials and reinforcement bars from the fabrication site. Additionally, the excavator loads the welding machine for transport to the drilling site. The subsequent step is unloading the red soil at the drilling location. Afterward, the excavator performs the unloading of the extracted drilling materials at the material stockpile site. It then proceeds with unloading the reinforcement bars at the drilling location. Lastly, the excavator unloads the welding machine at the drilling site. Following the loading process, the excavator moves to the waste disposal area to transfer the drilling waste. Thereafter, it moves to the material storage area to transfer the material excavated from the drilling process. The excavator then returns to the drilling location to resume drilling. It proceeds by moving again to the red soil embankment to retrieve additional red soil, then moves to the fabrication area to collect reinforcement bars. The excavator then loads the red soil once more, transporting it back to the machine. This is followed by loading the excavated material into the excavator. Furthermore, it loads the reinforcement bars from the fabrication area onto the excavator. The machine also loads the welding machine, transporting it to the excavator. In this study, the excavator's value-added activities (VAA) include swing boom operations, loading and unloading of steel plates for the Bore Pile machine base, and loading/unloading red soil, rebar, and welding machines. Non-value-added activities (NVAA) primarily consist of moving and waiting during the drilling process.

2.1 *Manufacturing Cycle Effectiveness* (MCE)

Manufacturing Cycle Effectiveness (MCE) is measured by comparing processing time to cycle time, which results in the percentage of value-added activities [11]. MCE is determined based on cycle time data for the production process. Cycle time refers to the time required to complete a task obtained from direct observations [12]. Value-added activities (VAA) represent processing time, whereas non-value-added activities (NVAA) consist of inspection time, transfer time, waiting time, and storage time. Based on work duration data from each work stage at three sample points, cycle time is calculated using the cycle time formula, as shown in Equation (1). Cycle time is used to calculate Manufacturing Cycle Effectiveness (MCE) using the MCE formula in Equation (2). Furthermore, Manufacturing Cycle Effectiveness (MCE) can also be expressed as VAA, can be determined using Equation (3).

$$\text{Cycle Time} = \text{Process Time} + \text{Inspection Time} + \text{Transfer Time} + \text{Waiting/Storage Time} \quad (1)$$

$$MCE = \frac{= Process\ Time}{Cycle\ Time} \text{ x } 100\% \quad (2)$$

$$\text{NVAA} = 100\% - \text{Value Added Activities (VAA)} \quad (3)$$

2.2 5W + 1H Method

The 5W + 1H method is an analytical approach used to identify root causes in depth by applying detailed question-based analysis. This method consists of six key questions: What, Where, When, Why, Who, and How, each of which provides specific insights into a given problem [13]. "What" is used to determine what is happening regarding the main topic, while "Where" helps identify the location of an event. "When" is used to establish the timing of an incident, and "Why" helps understand the underlying causes of a problem. "Who" identifies the subjects related to the issue, whereas "How" gathers information about potential solutions or recommendations for addressing the identified problem. By systematically answering these questions, a deeper understanding of the problem and its root causes can be achieved, enabling effective decision-making and problem resolution [14].

3. RESULTS AND DISCUSSION

3.1 Calculation of *Manufacturing Cycle Effectiveness* (MCE)

The data on the excavator's cycle and duration in Bore Pile foundation drilling work, shown in Table 1, are used to calculate the percentage of Manufacturing Cycle Effectiveness (MCE), Value Added Activities (VAA), and Non-Value-Added Activities (NVAA). The results of the MCE calculation for the excavator from the three samples are presented in Table 2.

Table 2 MCE Calculation Results for the Excavator in the Three Samples

No	Sample	MCE	VAA	NVAA
1	Sample 1	24,43%	24,43%	75,57%
2	Sample 2	30,63%	30,63%	69,37%
3	Sample 3	24,72%	24,72%	75,28%

The findings of this study successfully address the research objectives by quantifying the proportions of value-added activities (VAA) and non-value-added activities (NVAA) in excavator operations during bore pile drilling. Across the three observed samples, the results consistently indicate that NVAA dominates VAA, with NVAA values exceeding 69%. This imbalance highlights significant inefficiencies, confirming the need for productivity improvement strategies. The analysis further reveals that the two primary causes of high NVAA are the fixed work method and inadequate coordination among work teams. The fixed sequence of tasks requires the excavator to remain on standby during certain stages, leading to extended idle times. At the same time, weak coordination—such as delays in reinforcement cage preparation or material delivery—exacerbates waiting periods, further reducing overall effectiveness.

While these internal factors are critical, external influences also play a role. Site-specific conditions such as soil variability, weather interruptions, and logistical constraints in material transport contribute to fluctuating idle times. For instance, unexpected rainfall or late delivery of reinforcement steel can extend NVAA well beyond the values predicted by cycle time analysis. Recognizing these external factors provides a more comprehensive understanding of productivity barriers. To address these issues, several improvement strategies are proposed. First, strengthening coordination through integrated scheduling systems can minimize idle periods. This includes aligning reinforcement preparation, drilling, and material handling activities to reduce task dependency bottlenecks. Second, adopting more flexible work methods, such as task parallelization where possible, can lower standby time by overlapping non-sequential activities. For example, simultaneous reinforcement preparation during drilling can shorten waiting periods. Implementing these solutions would require not only procedural adjustments but also managerial commitment to workflow optimization.

From an academic perspective, the present findings are sufficient to demonstrate the applicability of MCE and 5W + 1H methods in identifying inefficiencies and proposing general improvements. However, for industrial applications, additional steps are required. Specifically, technical simulations of alternative workflows should be conducted to estimate quantitative reductions in NVAA, while pilot testing in real projects would validate the feasibility of proposed solutions. Expanding the dataset to include more samples and varied project conditions would also improve generalizability and strengthen the reliability of the conclusions.

3.2 Productivity Analysis Using the 5W + 1H Method

Based on the work cycle of bore pile foundation drilling, a productivity analysis was conducted to eliminate inefficiencies and increase the percentage of value-added activities. Several factors influence the productivity of the excavator in the bore pile foundation drilling process, primarily the high percentage of non-value-added activities due to idle time. In the bore pile drilling process, idle time is observed when waiting for the next stage of work. This waiting period can be caused by either internal factors or a lack of coordination in scheduling the excavator's work. The excavator's working method follows a sequential work order. In the bore pile drilling process, the work order determines the drilling stage that must be completed before the next stage can proceed. Each stage must be completed before the next one can begin. As a result, the excavator often experiences waiting periods before starting the next phase. For instance, after completing the drilling phase, the excavator must remain on standby until the reinforcement cage installation is completed. This waiting time contributes to idle time, as the excavator cannot continue working until the current stage is completed. Thus, an incorrect work sequence increases the risk of errors and affects the final construction quality.

Table 3 Productivity Analysis of the Excavator in Bore Pile Foundation Drilling

What	Why	When	Where	Who	How
Higher NVAA value compared to VAA	Caused by standby activities due to the fixed work method	Idle time mostly occurs while waiting for the completion of other tasks	At the Bore Pile foundation drilling location	All parties involved in the work process.	Improve coordination between teams, and use work methods that reduce standby time.
Fixed work method	The method requires the excavator to always be on standby due to technical requirements.	Waiting for materials to be placed and other tasks to be completed	At the Bore Pile foundation drilling location	All parties involved in the work process.	Increase operational efficiency and optimize workflow.

Several key factors influence and manage idle time for the excavator. First, the excavator operator plays a crucial role in ensuring that the machine operates according to the designated work procedures. The operator must efficiently operate the excavator throughout each work phase and adhere to the set schedule. Additionally, coordination among the entire drilling team is essential. Each team member must coordinate their tasks to ensure that each process is completed on time and in sequence. Poor coordination, such as delays in material delivery, can cause the excavator to experience unnecessary idle time. An effective method to reduce idle time in the excavator operation during bore pile drilling is to improve inter-team coordination. This can be achieved by creating a structured and synchronized work schedule. A well-organized schedule ensures that each stage is executed on time, eliminating unnecessary waiting time. Furthermore, optimizing the work schedule by carefully planning the necessary tasks at each stage can reduce waiting time. Prioritizing material procurement at the right time before each stage begins can help minimize unnecessary idle time.

4. CONCLUSION

Based on the cycle data and duration of the excavator during Bore Pile foundation drilling work, the results from all three research samples show that the percentage of Non-Value-Added Activities (NVAA) is higher than the percentage of Value-Added Activities (VAA). Consequently, productivity analysis of the excavator was conducted using the 5W + 1H method. The primary factors contributing to the low productivity of the excavator are the high NVAA values compared to VAA values and the fixed work method. The research findings suggest that the high NVAA is due to excessive idle time, particularly during waiting periods. This waiting time arises from the fixed work method, which requires the excavator to remain on standby and follow the set sequence of tasks. Therefore, several measures can be implemented to increase the productivity of the excavator, including improving coordination between teams, using work methods that reduce standby time, increasing operational efficiency, and optimizing workflow.

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