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Productivity Analysis PC-300 and PC-400 in Earthworks at a Gold Mining Project in Indonesia

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ABSTRACT Material movement is a significant and costly aspect of gold or general mining projects. This involves the utilization of expensive heavy equipment, necessitating careful management to ensure optimal efficiency. Therefore, this study aimed to analyze the productivity of excavators PC-300 and PC-400 as well as compare theoretical calculation results with actual conditions. The basis was formed by real field data, collected by earthwork supervisors at a gold mine in Indonesia. This data encompassed daily heavy equipment usage, including the duration, the quantity of material moved, and the types of material involved in the relocation process. The calculations resulted in theoretical productivity of 121.45 m^3 $hour^{-1}$ and 99.56 m^3 $hour^{-1}$ for PC-400 and PC-300. Meanwhile, the calculations based on actual conditions resulted in an average productivity of 114.4 m^3 $hour^{-1}$ and 66.3 m^3 $hour^{-1}$ for PC-400 and PC-300 during a one-year project period. The difference between actual and theoretical productivity for PC-400 and PC-300 was relatively small and large at -7.05 m^3 $hour^{-1}$ and -33.26 m^3 $hour^{-1}$, with 0.94 and 0.64 match factors, respectively. The large difference in productivity for the PC-300 was because the equipment supported work projects, such as opening work area access, maintaining area of work, and serving as supporting equipment. Furthermore, it occurred in the total actual production of the material movement against the one-year target production, which was less than -31,921 m^3 (-2.5%) out of the 1,277,325 m^3 total. The production deficit was attributed to a construction failure that caused PC-400 and PC-300 to be temporarily relocated for reparation. Based on the simulation, target production was achieved by the actual condition at month 13 (additional 1-month duration) with a total production of 1,283,856 m^3, which obtained more than +6,531 m^3 (+0.51%).

KEYWORDS Earthwork Construction; Excavator Productivity; Heavy Equipment Simulation; Material Movement; Heavy Equipment Construction

1 INTRODUCTION

Indonesia is a country with numerous mining activities for copper, nickel, tin, and gold. Based on the data of the Ministry of Energy and Mineral Resources (ESDM), mineral ore reserves include 3.02, 5.24, 6.84, and 3.62 billion tons of copper, nickel, tin, and gold ore, respectively (Widhiyatna, 2021).

Earthmoving or material movement is a crucial process in most infrastructure projects. The operations represent a considerable portion of civil infrastructure projects such as highways, mines, and dams (Hassanien, 2002). Multiple factors have a direct and indirect influence on the optimal utilization of equipment, which can consequently result in a decline in productivity during earthmoving operations. Through the utilization of questionnaires directed towards experts and employing the fuzzy set theory method for analysis, the productivity of hauling equipment can be significantly impacted by excessive loads, adverse conditions of snowy hauling roads, and the age of equipment (Salem et al., 2017).

Open-pit mining is widely used for metallic (aluminum, bauxite, copper, iron), and nearly all nonmetallic ore bodies (coal, uranium, phosphate). The excavation typically follows a traditional cone-shaped design, although it can take on various shapes depending on the size and characteristics of the ore body, exhibiting pipe-shaped,

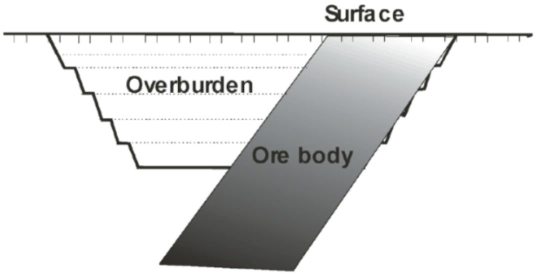


Figure 1 Dipping seam or bed, flat terrain by Awwad et al., (2020).

vein-type, steeply dipping stratified, or irregular features (Awwad et al., 2020).

Historical data from previous projects become valuable in simulation modeling to obtain the best arrangement of equipment for earthmoving operations. Utilizing empirical data, a model estimation is developed through Monte Carlo simulation to attain and optimize an appropriate fleet size. The primary fleet equipment comprises loaders and trucks. Through simulation analysis conducted during the project planning phase, substantial cost savings in project execution can be achieved, while simultaneously enhancing visibility into project performance. Consequently, it is recommended to incorporate additional project risk factors into the models to ensure a more reliable arrangement and mitigate uncertainties effectively (Arash et al., 2020).

Planning earthwork performance is a difficult and demanding task. Simple research framework (SRF) is used for estimates of excavator actual productivity and cycle time at a construction site during earthworks. The Site Productivity Research Framework (SRF) entails the utilization of a video camera to record excavator activities during earthworks at a construction site, followed by the analysis of the recorded videos using sophisticated computer software. By implementing SRF at a specific construction site in Rijeka, the maximum achievable productivity for an excavator equipped with a 0.9 m^3 bucket capacity was calculated to be 108 m^3 per hour (Šopíc et al., 2021).

The fleet management process in construction and earthwork activity is one of the most important factors in defining equipment assignment and optimization. Through theoretical analysis of fleet management, trucks with a capacity of 14 m^3 are more optimized compared to 10 and 18 m^3. In this analysis, the excavator bucket capacity was found to be 1.25 m^3. The calculated productivity using 5 and 4 haul units was 99.06 and 93.97 m^3 per hour (Sable and Waysal, 2020).

The method developed employs the Global Positioning System (GPS) and Google Earth to extract the necessary data for conducting near-real-time estimation of productivity in earthmoving operations to efficiently gather the required information for the estimation process. The method used a deterministic model during the planning phase and transitions to a probabilistic model in the tracking and control phase. To facilitate this process, computer simulation was employed to support the implementation of the models. Based on deterministic productivity using Volvo ECR235CL (excavator) and CAT725 (truck) the lower and upper limits were116.7 and 201.7 $y^3 hour^{-1}$ (Montaser et al., 2012).

The excavators were frequently used for supporting work projects such as opening work area access, maintaining the area of work, and serving as supporting equipment. This intensive use for supporting work projects resulted in a lower overall productivity compared to using the excavators for material movement (Hidayat et al., 2019). The impact of construction failures was found to have reduced productivity and caused delays in construction operations. Cases of construction failures included design errors, material shortages, and unexpected ground conditions. These factors resulted in various negative consequences, such as rework, schedule disruptions, increased costs, and compromised project quality (Gascuena et al., 2011). Various approaches to measuring productivity were developed in academic circles, including deterministic model-based, simulation-based, queuing theory-based, and actual measurements (Halpin, 1992; Han, 2010). These methods have been frequently used to evaluate construction performance. However, the applicability in real-world scenarios is challenging, highlighting the importance of conducting investigations that compare the effectiveness of these four methods and analyze different types of construction operations in practice (Han, 2008, 2010).

Based on the aforementioned background, this study analyzed the productivity of PC-300 and PC-400 excavators. Study on heavy equipment productivity primarily originated from the road or civil work projects, with limited emphasis on mining projects. Furthermore, there was a lack of extensive studies focused on excavators, such as the PC-400 and PC-300 models. It was also intriguing to conduct a study using field data and evaluate productivity over a one-year project period. This allowed for the identification of different factors that caused disparities between planned and actual productivity.

Overall, this study contributed to the knowledge and understanding of excavator productivity in material movement activities in gold mining projects, particularly concerning the difference between theoretical and actual productivity. By analyzing real field data from a gold mine, this study identified factors, accounting for this discrepancy and provided practical insights for improving future mining operations.

Material movement was the main activity in mining projects, requiring significant costs and the utilization of heavy equipment. By identifying the factors that affected excavator productivity, this study provided valuable information for optimizing mining operations and reducing costs. The comparison between theoretical and actual productivity underscored the importance of using real-world data to inform estimates and enhance planning in mining projects.

This study contribution explained the operation of heavy equipment in mining work with a unique character. In a mining project, heavy equipment was allocated to specific projects but was used to support other endeavors. In addition to analyzing productivity, project risk factors that influenced productivity in earthwork were considered. The results were intended to serve as an overview for engineers, estimators, and project managers involved in the planning of earthmoving construction for mining projects.

2 METHOD

To analyze the productivity of heavy equipment, this study was conducted using a series of processes in material movement activities within the gold mining projects as a research method. This entailed the collection of genuine daily construction data from the ”equipment record report” and the ”timesheet of heavy equipment,” diligently gathered by field supervisors. Table 1 showed the summary of daily reports which represented the production volume of each heavy equipment with the total hours used each month. Figure 2 reported the flow of the analysis process used in this study.

The variables employed were the excavator models PC-300 and PC-400, the type of material transported, supporting work projects, and construction failures. The indicators comprised the productivity in cubic meters per hour, the daily duration of heavy equipment usage, the quantity of material relocated between locations, the total actual production of material movement relative to the one-year production target, and the production deficit. The analysis was conducted by computing the productivity of the heavy equipment and comparing the theoretical values to the actual measurements. The calculations for heavy equipment productivity were based on theoretical considerations (Richardson, 2002; Iseley and Gokhale, 2003; Sable and Waysal, 2020), as presented in Table 5.

2.1 Data Collection

The data used were obtained from daily equipment load reports (m^3) and time sheets of heavy equipment as daily forms filled in by supervisors in the field. The data was entered into each internal database for material movement from equipment load records and a database of timesheets of heavy equipment in Microsoft Excel from July 2021 to June 2022.

The data in the material movement from the equipment load record database includes loading and dumping points, the type of material transported, the number of times taken per hour, the ID of the transport truck, the shift schedule, and the type or class of heavy equipment. Meanwhile, the output of productivity was $m^3 hour^{-1}$ as the total volume of material moved.

The timesheet database of heavy equipment contains information such as the duration of heavy equipment operation during a single shift, reasons for non-functioning heavy equipment, transport truck identification, shift schedule, and the type or class of heavy equipment. This data serves as the foundation for calculating productivity inputs,

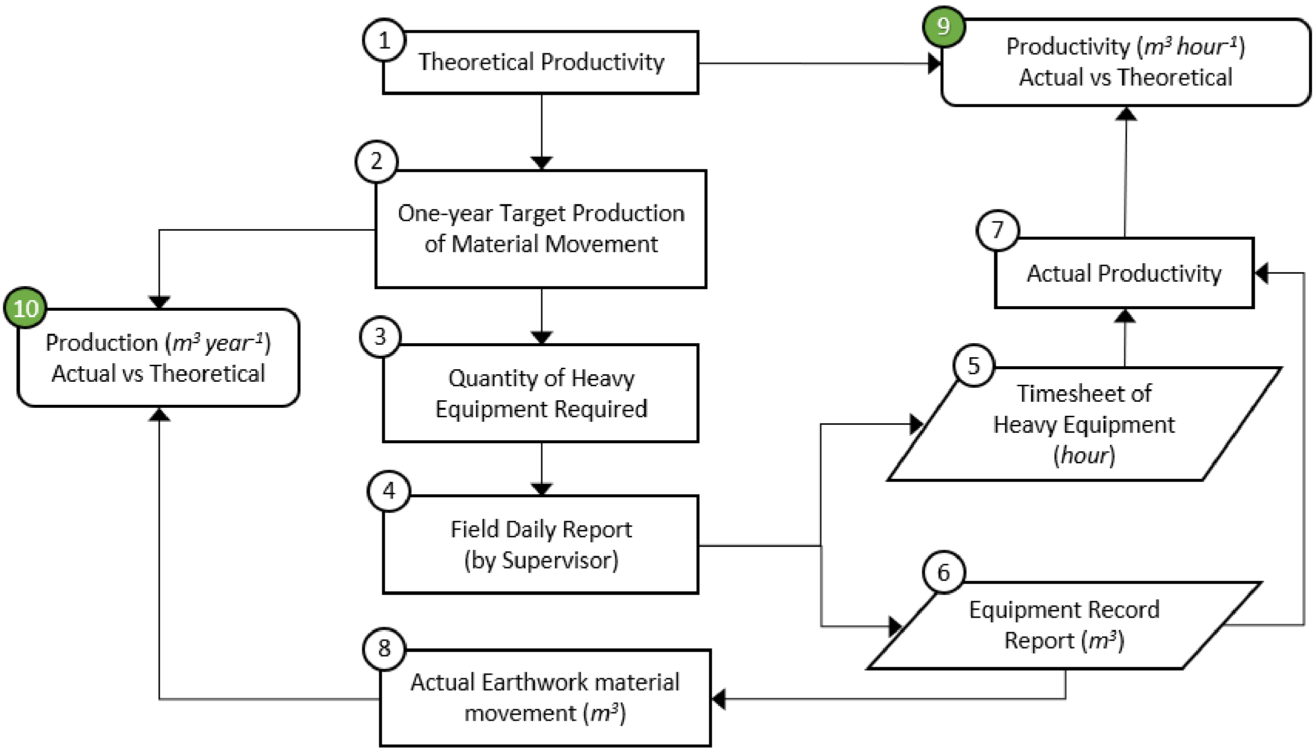


Figure 2 Flow of research method

measuring the output in cubic meters per hour based on the total hours of heavy equipment utilization. This daily data is used as a reference for monthly heavy equipment rental payments. The number of hours of equipment usage serves as the fundamental factor for calculating the total amount of heavy equipment utilized each month, as shown in Figure 3.

2.2 Theoretical Productivity of Heavy Equipment

Construction productivity can be simply illustrated by a comparison between output and input (Panas and Pantouvakis, 2010). According to Glen and Christopher (2022), productivity is the quantity of work produced for a certain amount of labor hours or costs and is defined as a relative measure of labor efficiency. A productivity analysis is commonly performed to determine the impact of certain constraints. After the impact is calculated, it is necessary to link the lost productivity to the impact event or action. For general calculation of productivity analysis, Equation 1 can be used as follows (Panas and Pantouvakis, 2010).

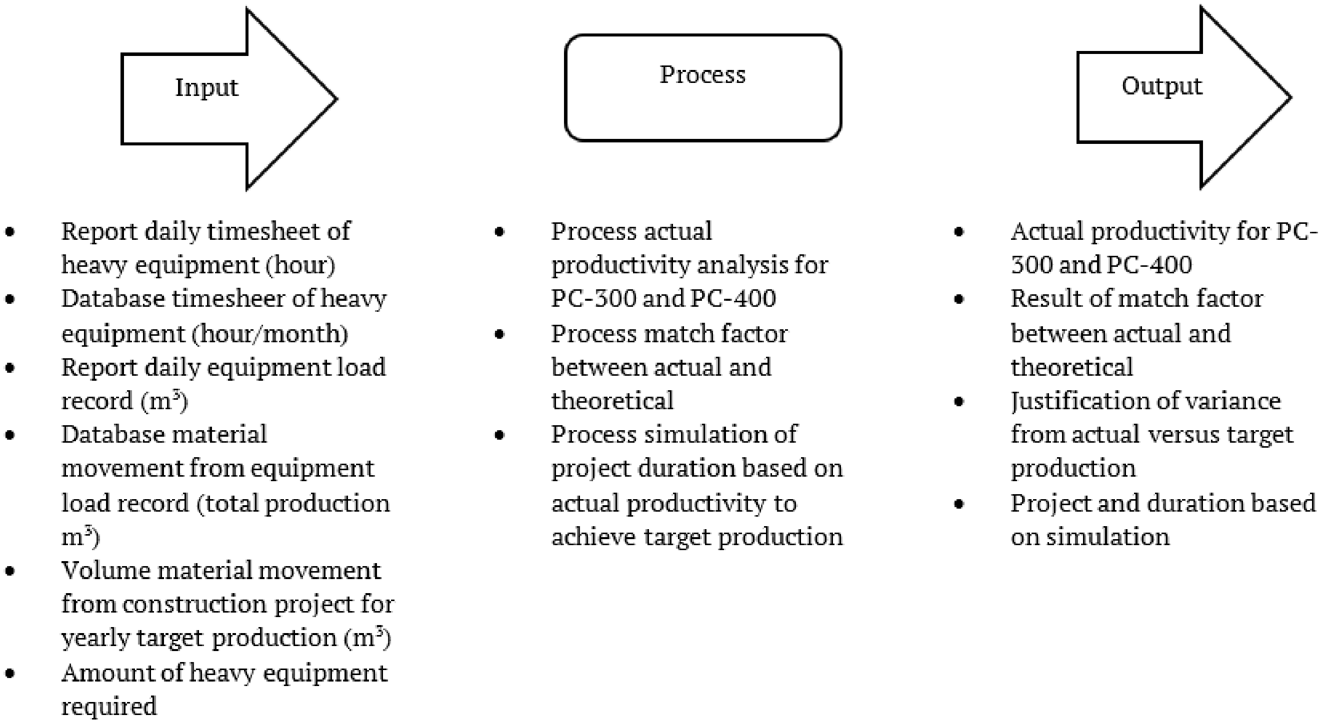
$$productivity = \frac{\sum_{output}}{\sum_{input}} \tag{1}$$

2.3 Actual Production of Heavy Equipment

The calculation of actual productivity was based on the measurement of material movement from July 1, 2021, to June 30, 2022. The data covered daily heavy equipment use in day and night shifts within a 24-hour cycle, which included hourly heavy equipment travel cycle and the type of material hauled. Material movement in construction projects was limited to two main projects outside the planning target.

2.4 Comparison of Theory vs Actual Productivity of Heavy Equipment

The theoretical and actual productivity of heavy equipment was compared with Equation 2 below. Actual productivity is under theoretical calculation when the match factor value = 1, but when the value is < 1, the variable is lower than in theoretical calculation.



- Report daily timesheet of heavy equipment (hour)
- Database timesheer of heavy equipment (hour/month)
- Report daily equipment load record (m^3)
- Database material movement from equipment load record (total production m^3)
- Volume material movement from construction project for yearly target production (m^3)
- Amount of heavy equipment required

- Process actual productivity analysis for PC-300 and PC-400
- Process match factor between actual and theoretical
- Process simulation of project duration based on actual productivity to achieve target production

- Actual productivity for PC-300 and PC-400
- Result of match factor between actual and theoretical
- Justification of variance from actual versus target production
- Project and duration based on simulation

Figure 3 Input, process, and output of productivity

$$MatchFactor = \frac{actual}{theoretical}(productivity) \qquad (2)$$

2.5 Material Movement Production Target for One-year Period

The production target of a material movement project is determined by the owner of the mine area. The owner will involve an earthwork/geotech consultant and contractor to determine the realistic and achievable nature of the production target. Table 2 shows the one-year production target of the material movement project.

2.6 Validation

The output results from the calculations were in the form of actual material movement production (m^3), actual heavy equipment hour use (hour), actual productivity ($m^3 hour^{-1}$), match factor, difference from actual and theoretical analysis during the planning stage, and project duration simulation. Validation was conducted on initial data for match factors and production targets. The match factor was the comparison of actual productivity to theoretical productivity. Validation was carried out by comparing the two data to determine the differences between the actual and theoretical analysis. Furthermore, the difference was described in the match factor and justification.

3 RESULTS

3.1 Project Overview

In general, the main activities of earthworks in construction projects include land clearing, area preparation, tree cutting, excavation, backfilling, spreading, and compacting. However, the scope of this study is limited to excavation and fill work or material movement.

The raw data used for analysis were daily reports obtained from supervisors, including daily timesheet monitoring reports and activity unit hour equipment forms. From these two sets of data, productivity analysis was calculated by comparing the total materials number moved from the daily timesheet equipment monitoring to the equipment use (number of hours the equipment operates in one shift).

Table 1. Heavy equipment earthwork actual production and unit hour used

		Production (m^3)		HE (hour)		HE (unit)	
Month	Year	PC-300	PC-400	PC-300	PC-400	PC-300	PC-400
July	2021	653	76,108	557	541.5	1	1
August	2021	15,835	61,849	595	442	1	2
September	2021	47,259	150,442	649	944.5	2	2
October	2021	41,740	119,406	548	1009	1	2
November	2021	39,287	66,821	398.5	648.5	1	2
December	2021	45,940	58,169	925	548.5	2	2
January	2022	70,582	62,285	1051.5	483.5	2	1
February	2022	45,080	48,815	421	439.5	1	1
March	2022	53,817	45,256	428.5	392.5	1	1
April	2022	46,824	52,653	493.5	463.5	1	1
May	2022	28,657	39,789	1056.5	390	2	1
June	2022	11,653	16,486	888.5	476	2	1
1,245,404 m^3		447,328	798,077	8,012	6,779	17	17

Table 2. One-year target production of material movement project

Description	Unit	Heap Leach Pad	Hauling Road
Cut and Haul	m^3	896,976	202,798
Fill	m^3	1,074,527	67,932
Bulk Earthwork	m^3	1,074,527	202,798
Total	m^3	1,277,325	

Figure 4 Main equipment types (Articulated dump truck and excavator). Source: products.unitedtractors.com

3.2 Types of Heavy Equipment Used

Heavy equipment used in material movement is diverse, but only PC-400 and PC-300 excavators with articulated dump trucks (ADT-40 Ton) followed by the fleet needs. Figure 4 shows two pieces of main heavy equipment used in the material movement project.

Table 3. Capacity of main heavy equipments

Equipment	Capacity	
40T-ADT	24	m^3
PC-400	2.8	m^3
PC-300	1.8	m^3

The bucket capacity of the main heavy equipment (ADT-40, PC-300, and PC-400) in earthworks at construction projects can be seen in Table 3 (Komatsu, 2017). The specifications included good condition with a maximum in-manufacture production of 3 years from the year of the project and heavy equipment physical availability grade of more than 85% each month.

3.3 Types of Material Movement

The types of material being moved differ in characteristics, which are divided into soil, stone, sand, and wood/plants. Each type of material has a different swell factor as shown in Table 4 (Richardson, 2002; U.S, 2018).

The majority of hauling material types from the project were Zone-C (silt clay), topsoil, and F2 (gravel/base course). This was based on the majority of the material type being moved (topsoil) and the specifications used in the project (Zone-C and F2).

Table 4. Material swell factor

Material	Factor	Material	Factor	Material	Factor
Log	55%	Waste	88%	Sub Base	85%
Sand	90%	Zone C	80%	Rip Rap	85%
Rock	61%	Boulder	85%	Mining Rock	90%
Gravel	70%	F2	88%	Base Course	88%
Clay	70%	Mud	88%	Gabion	70%
Top-Soil	75%	Stone Dust	90%		

3.4 Theoretical Productivity Calculation

Theoretical productivity calculation steps for PC-300 and PC-400 are shown in Table 5. From the calculation, the resulting productivity is 99.5 m^3hour^{-1} and 121.4 m^3hour^{-1} for the PC-300 and PC-400, with each excavator supported by two units of ADT-40T.

3.5 One-year Production Target of Material Movement

Theoretical productivity value is used to determine the number of heavy equipment units used for the one-year target production set by the owner, as shown in Table 2. From the calculation with SF=1.5, the total theoretical production value is 1,980,281 m^3 against a production target of 1,277,325 m^3.

- Work effective duration for 1 shift: 10 hours
- Total number of shifts in one day: 2 shifts
- Total number of effective days in one month: 28 days
- Total number of working hours in one month: 560 hours/month
- Safety factor (SF): 1.5

3.6 Actual Productivity Analysis

From the actual analysis of field data, the average, maximum, and minimum productivity for PC-300 is 63.3 m^3hour^{-1}, 125.6 m^3hour^{-1}, and 1.17 m^3hour^{-1}. Meanwhile, PC-400 has an average, maximum, and minimum productivity of 114.4 m^3hour^{-1}, 159.3 m^3hour^{-1}, and 34.6 m^3hour^{-1}. The overall results of the productivity analysis for one year are presented in Figure 5.

3.7 Deviation of Calculation and Analysis

3.7.1 Deviation of Productivity

From the analysis, the average value of actual productivity was lower than the theoretical for PC-300, while for PC-400 the value was close to the theoretical productivity, as presented in Tables 7 and 8.

3.7.2 Deviation of Actual Material Movement Agains One-year Target Production

From the actual field production data, the total volume production was below the one-year production target, production volume deficiency of approximately -2.5% or -31,921 m^3. The comparison of actual production and one-year production target can be seen in Table 9 and Figure 6.

4 DISCUSSION

Using historical data from a previous project was one of the valuable and common methods for making simulation modeling or productivity analysis to obtain the best output of heavy equipment (Arash et al., 2020). Table 9 and Figure 6 showed that the actual field production volume reported a sharp fluctuation each month. The actual production volume (197,701 m^3 on Sep 2021) was higher than the theoretical (191,779 m^3 on Sep 2021). Meanwhile, the actual production volume was also lower than the one-year production target. During the 7 months of the study period, the volumes were less than the production target (Jul 2021, Aug 2021, Nov 2021, Dec 2021, Feb 2022, May 2022, Jun 2022).

To examine the low production volumes, analysis, and justification were conducted to observe the differences between actual and one-year production targets. Different factors affected directly and indirectly the efficient utilization of equipment and led to a productivity decline in earthmoving operations (Salem et al., 2017). The factors that affected lower production volumes were unexpected conditions in the field. In this study, two conditions caused the heavy equipment to be used for other prioritized activities. First, at the beginning of the project, it coincided with the access ramp, which required PC-300 to support the activities. Second, at the end of the project, construction failure occurred at the access road, which

Table 5. Theoretical and engineering calculation productivity of excavator

No	Description	Symbol	Unit	PC-300	PC-400
1	Distance of stockpile to excavation		km	1	1
2	Bucket capacity	BC	m^3	1.8	2.8
3	Bucket fill factor	bf		0.7	0.7
4	Cycle time	CT	s	21	22
5	Correction factor (excavator)	CFe			
	Machine availability	ma		0.85	0.80
	Time efficiency	te		0.85	0.80
	Operator skills	os		0.85	0.80
	$CF_e = ma.te.os$			0.614	0.512
6	1-hour production capacity (Maximum)	Vb			
	$V_b = (BC.bf.3600.CF_e)CT^{-1}$		$m^3 hour^{-1}$	132.7	164.2
	ADT 40T – Input Factor				
7	Vessel capacity	VC	m^3	24	24
8	Material factor (clay/gravel)	Sf	0.68	0.68	
9	Correction factor (truck)	CF_t			
	Machine availability	ma		0.85	0.85
	Time efficiency	te		0.85	0.85
	Operator skills	os		0.85	0.85
	$CF_t = ma.te.os$			0.614	0.614
10	Bucket loading to truck				
	$BL = VC(BC.bf.CF_t)^{-1}$		bucket	31	20
11	Loading time				
	$LT = (BL.CT)/60$		minute	10.8	7.3
12	Vessel positioning	Vp	minute	1.2	1.2
13	Loading point preparation	lpp	minute	1.5	1.5
14	Dumping and positioning	dap	minute	2	2
15	Total cycle time	TCT			
	$TCT = LT + Vp + lpp$		minute	13.6	10
16	Vessel speed with full capacity	VS_f	$kmhour^{-1}$	25	25
17	Full vessel bucket time				
	$fvbt = DistanceVS_f^{-1}$		minute	2.4	2.4
18	Vessel speed with empty capacity	VS_e	$kmhour^{-1}$	35	35
19	Empty vessel bucket time				
	$evbt = DistanceVS_e^{-1}$		minute	1.7	1.7
20	$CycleTime1Ritunit^{-1}$				
	$CTR1unit^{-1} = LT + dap + Vp + lpp + evbt + fvbt$		minute	19.7	16.2
21	Unit Compatibility	UC			
	$UC = (CTRunit^{-1})/TCT$		unit	1.4 ≈ 2	1.6 ≈ 2
22	$1hourunit^{-1} = 60(CTR1unit^{-1})^{-1}$		$Rithour^{-1}unit^{-1}$	3	3.7
23	Total Ritase=[21] .[22]			6.1	7.4
24	Productivity with 1 unit of ADT				
	$Productivity = [22].VC.Sf$		$m^3 hour^{-1} unit^{-1}$	49.8	60.7
25	Productivity with 2 units of ADT		$m^3 hour^{-1}$	99.5	121.4

Table 6. Planning of fleet and production heavy equipment

Description	Unit	2021						2022					
		Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Heap Leach Pad													
PC-400	unit	1	1	1	1	1	1	1	1	1	1	1	1
PC-400	m^3	68.012	68.012	68.012	68.012	68.012	68.012	68.012	68.012	68.012	68.012	68.012	68.012
PC-300	unit	1	1	1	1	1	1	1	1	1	1	1	1
PC-300	m^3	55.756	55.756	55.756	55.756	55.756	55.756	55.756	55.756	55.756	55.756	55.756	55.756
Hauling Rod													
PC-400	unit	-	-	1	1	1	1	-	-	-	-	-	-
PC-400	m^3			68.012	68.012	68.012	68.012						
PC-300	unit	-	-	-	-	-	1	1	-	-	-	1	1
PC-300	m^3						55.756	55.756				55.756	55.756
Total													
PC-400 (unit)	16	1	1	2	2	2	2	1	1	1	1	1	1
Pc-300 (unit)	16	1	1	1	1	1	2	2	1	1	1	2	2
Production	m^3	123.76	123.768	191.779	191.779	191.779	247.535	179.523	123.768	123.768	123.768	179.523	179.523

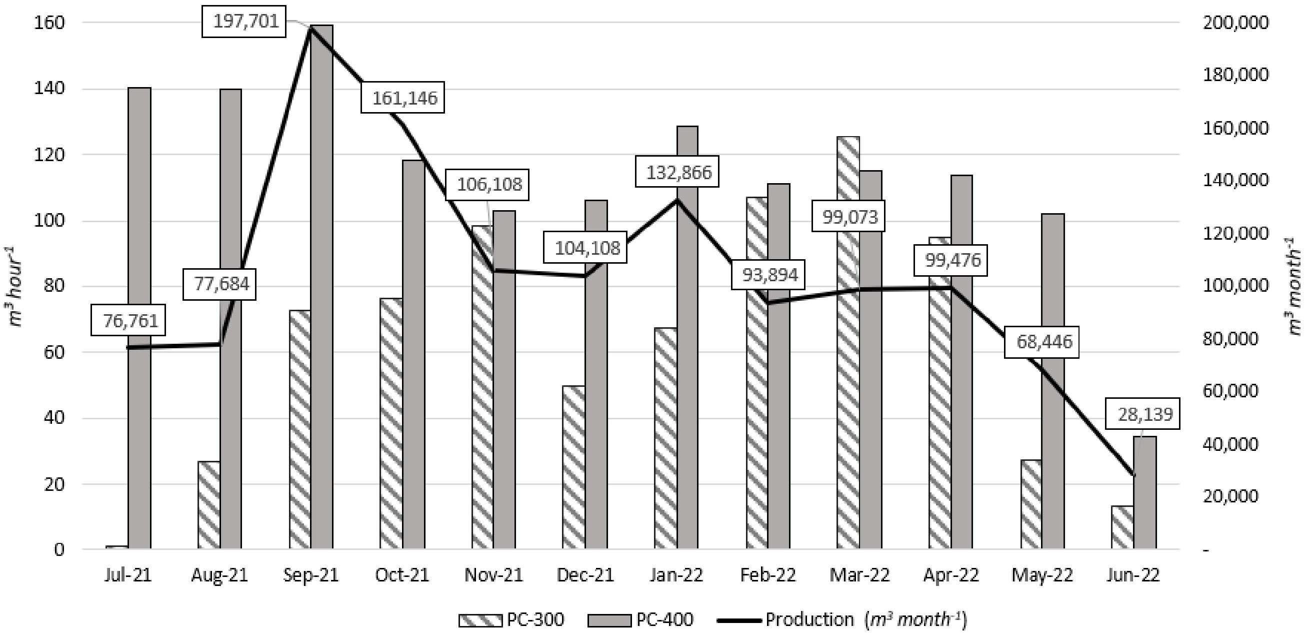


Figure 5 Heavy Construction Equipment Actual Productivity

Table 7. Heavy Construction Equipment Productivity and Match Factor

Productivity	Unit	2021						2022					
		Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
PC-300	$m^3 hour^{-1}$	1.2	26.6	72.8	76.2	98.6	49.7	67.1	107.1	125.6	94.9	27.1	13.1
Match Factor		0.01	0.27	0.73	0.77	0.99	0.50	0.67	1.08	1.26	0.95	0.27	0.13
PC-400	$m^3 hour^{-1}$	140,6	140	159	118	103	106	123	111	115	113	102	34.6
Match Factor		1.16	1.15	1.31	0.97	0.85	0.87	1.06	0.91	0.95	0.94	0.84	0.29

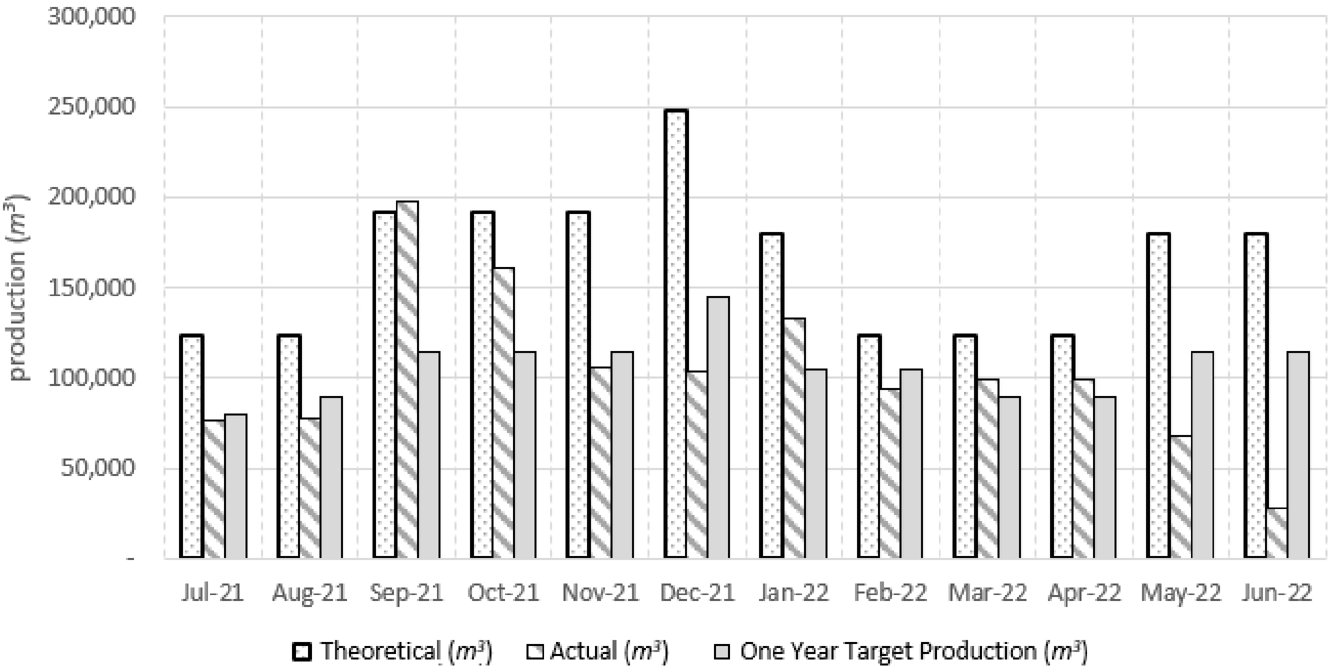


Figure 6 Comparison of Material Movement Production

Table 8. Average Productivity and Match Factor

Description	Unit	PC-300	PC-400
Average Productivity	$m^3 hour^{-1}$	63.3	114.4
Average Match Factor		0.64	0.94

required PC-300 and PC-400 to support the failure management activities. Table 10 showed the justification for the low actual production volumes compared to the one-year target.

The result analysis discovered that a productivity plan for heavy equipment construction was an important aspect of project management to be reviewed from the beginning of the project up to the end. Task-level productivity in a construction project was measured, analyzed, and improved in every project. Furthermore, better product management produced significant improvement in meeting predetermined targets with considerating project risks (Kulkarni and Saharkar, 2020).

4.1 Simulation-Based on Actual Productivity to Achieve Target Production

Analysis from Table 10 found that actual production was below the target. Simulation with real data productivity as an input was calculated to obtain the optimized heavy equipment unit and achieve target production. The simulation used a two-month average method for forecasting or predicting the best value generated from a planning/estimating model against the next target from actual basis data (Furniss and Nichols, 2022). Figure 7 showed the result of the simulation based on actual production and productivity. Meanwhile, Table 11 reported the total production of simulation to achieve the target in month-13 (July 2022). Table 12 also showed that from simulation to actual productivity, an almost similar result was reported with a match factor.

The focus on analyzing the productivity of the PC-300 and PC-400 excavators in material movement in the context of a gold mine was unique since study on this specific topic in this geographical area was limited. The use of real field data collected by earthwork supervisors was also novel and the concept provided a more accurate picture of actual conditions and productivity than theoretical calculations.

Identification of the impact of support work projects on PC-300 productivity was a new finding with practical implications for optimizing the use of heavy equipment in mining projects. In terms

Table 9. Material Movement Production Comparison

Description	Unit	2021						2022					
		Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Theoretical	m^3	123.76	123.768	191.779	191.779	191.779	247.535	179.523	123.768	123.768	123.768	179.523	179.523
Target	m^3	79.544	89.544	114.894	114.894	114.894	144.894	104.894	104.894	89.544	89.544	114.894	114.894
Actual	m^3	76.761	77.684	197.701	161.146	106.108	104.108	132.866	93.894	99.073	99.476	68.446	28.139

Table 10. Justification of Variance from Actual vs One-Year Target Production

Month	Production	PC-400		PC-300		Justification
	(m^3)	(unit)	(m^3hr^{-1})	(unit)	(m^3/hr)	
July	-2.783	0	140.55	0	1.17	PC-300 was used to support access ramp activities
August	-11.860	+1	139.93	0	26.61	1 unit PC-400 was on standby and PC-300 was still used to support access ramp activities
September	82.808	0	159.28	+1	72.82	Additional unit PC-300 was on-site on September 17, 2021
October	46.252	0	118.34	0	76.17	
November	-8.786	0	103.04	0	98.6	1 unit of PC-400 had PA (physical availability) < 85%
December	-40.785	0	106.05	0	49.66	1 unit of PC-400 operated only for 10 days
January	27.973	0	128.82	0	67.12	
February	-10.999	0	111.07	0	107.08	PC-400 was demobilized in December 2021
March	9.530	0	115.3	0	125.6	
April	9.932	0	113.6	0	94.88	
May	-16.323	0	102.02	0	27.12	PC-300 was used to support failure management activities
June	-86.755	0	34.63	0	13.12	PC-300 and PC-400 were used to support failure management activities
Total	-31.921	+1	114.4	+1	63.3	

*Red = lower than production target / average theoretical productivity

*Green = higher than production target / average theoretical productivity

Table 11. Production of Simulation vs Target

Description	2021						2022						
	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul
Target (m^3)	79.544	89.544	114.894	114.894	114.894	144.894	104.894	104.894	89.544	89.544	114.894	114.894	-
Cum	79.544	169.088	283.982	398.875	513.769	658.663	763.556	868.450	957.994	1.047.538	1.162.431	1.277.325	
Actual (m^3)	76.761	77.684	197.701	161.146	106.108	104.108	132.866	93.894	99.073	99.476	68.446	28.139	38.452
Cum	76.761	154.446	352.147	513.293	619.400	723.509	856.375	950.270	1.049.343	1.148.819	1.217.265	1.245.404	1.283.856

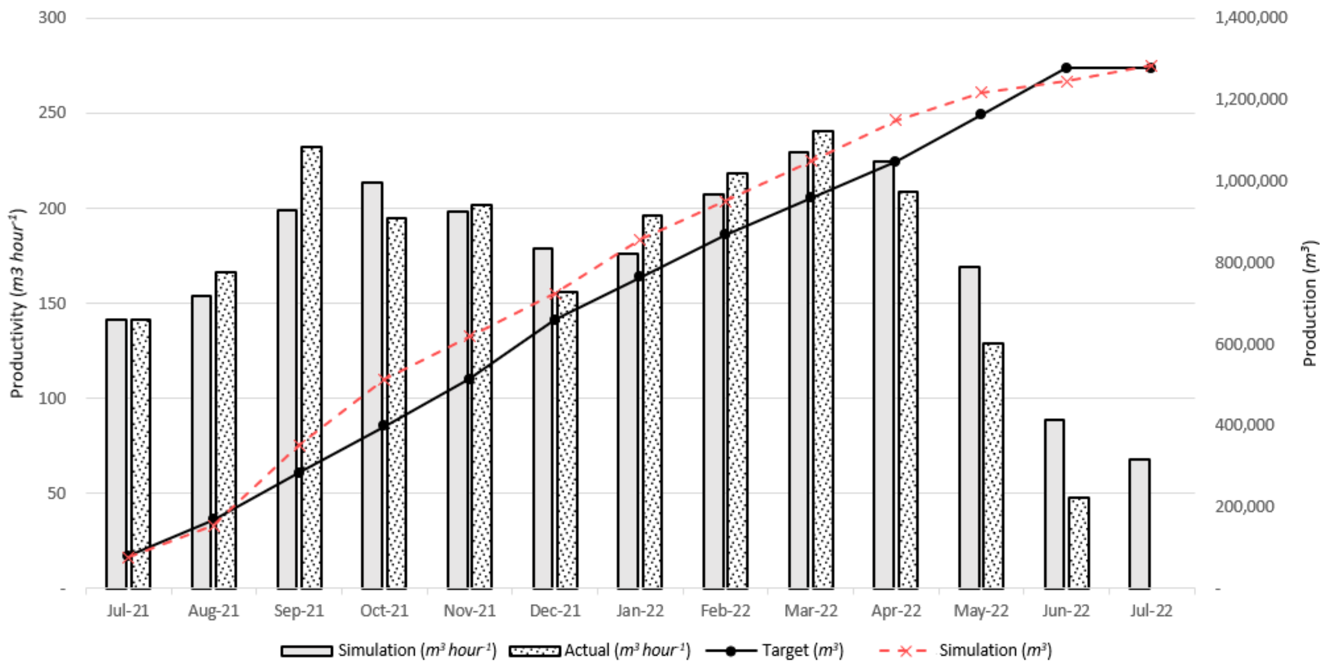


Figure 7 Comparison of Simulation Based on Data Actual and Target Production

Table 12. Average Productivity and Match Factor of Simulation vs Actual

Description	Unit	PC-300	PC-400
Average Actual Productivity	m^3hour^{-1}	63.3	114.4
Average Simulation Productivity		62.8	118.8
Average Match Factor Simulation vs Actual		0.99	1.04

of sophistication, this study was based on existing study on material movement in mining projects, particularly in the use of heavy equipment such as excavators.

This study presented a new approach to analyzing heavy equipment productivity using real field data and identifying new insights on the impact of supporting works projects on productivity. The result contributed to the state of the art in mining project management and had practical implications for increasing the efficiency and effectiveness of the material movement in mining projects.

5 CONCLUSION

In conclusion, the theoretical productivity of the PC-400 was higher than PC-300, and the actual productivity of the two heavy equipment was lower than theoretical calculations. The productivity deficit of PC-300 was largely due to its use to support work projects. The study also identified construction failures as the main cause of the production deficit, which resulted in the temporary relocation of excavators for repairs. Simulation analysis showed that the production target was achieved in the 13th month with an additional one-month duration. The results had practical implications for improving material movement management in mining projects, particularly in terms of optimizing the use of heavy equipment and addressing construction-related issues. Further studies should be conducted to explore ways of increasing excavator productivity and minimizing the impact of support work projects on material movement efficiency.

6 LIMITATION OF THE STUDY

The study focused on the productivity of two types of excavators, the PC-300 and PC-400, and did not investigate other heavy equipment impacting productivity on material movement in the mining project. Furthermore, it was conducted at only one gold mine in Indonesia, which limited the generalizability of the findings to other mining projects in different locations. The study relied on real field data collected by earthwork supervisors, which might be subjected to errors or inconsistencies in the recording. The accuracy of the data was improved by using automated monitoring systems or conducting more rigorous quality control checks. This study had a limited timeframe and analyzed the productivity of the excavators over a one-year period, which might not be sufficient to fully capture the variability in productivity occurring over longer periods.

DISCLAIMER

The authors declare no conflict of interest.

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