Evaluating Cost Efficiency in SMO Earthwork Service Contracts Using CPI, BV, and Variance-Based Approach

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ABSTRACT

This study examines the implementation of unit price contracts with hypothetical volumes in Surface Maintenance Operation (SMO) Earthwork service projects, where quantity uncertainty may significantly affect project cost performance. The objective of this study is to evaluate cost efficiency and analyze the financial impact of quantity realization under unit price contract schemes. **A quantitative approach** was employed using completed contract data from Package X and Package X Mitigation. Cost efficiency was assessed through Cost Performance Index (CPI), Budget Variance (BV), and variance-based analysis using Budget Plan (RAB) and Final Budget Plan (RAPP) data. The **results** indicate that CPI and BV effectively measure cost efficiency and identify deviations between planned and actual expenditures. The analysis further reveals that quantity realization and changes in work volumes are major factors influencing contractor profitability and project cost performance. The mitigation package demonstrated a more balanced operational distribution and improved cost control compared with the original package. **The study concludes** that integrating CPI, BV, and variance based analysis provides a practical framework for evaluating post execution cost efficiency in unit price contracts with hypothetical quantities. These findings support evidence-based cost management and contribute to SDG 9 and SDG 12 through improved resource efficiency and sustainable infrastructure project management.

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1. INTRODUCTION

The oil and gas sector remains a strategic contributor to Indonesia's national economy through its significant role in non-tax state revenue generation and energy supply sustainability. One of the largest upstream operational areas is the Rokan Block, which has historically been one of the most productive oil fields in Indonesia. Following the transition of operatorship in [1], operational continuity, cost efficiency, and effective contract management have become critical priorities to sustain production levels across extensive operational areas. The Rokan Block covers a wide geographical region in Riau Province, consisting of multiple production fields and surface facilities that require continuous maintenance, civil works, and earthwork activities to support drilling, production, and logistics operations. Due to the scale and uncertainty of field conditions, SMO Earthwork services are commonly executed under unit price contracts with hypothetical volumes, where estimated quantities are used for tendering purposes, while actual payments are determined based on measured quantities during project execution. This study aligns with SDG 9 (Industry, Innovation, and Infrastructure) by improving cost efficiency and operational continuity in infrastructure projects, and supports SDG 12 (Responsible Consumption and Production) through more efficient resource management in large-scale construction activities.

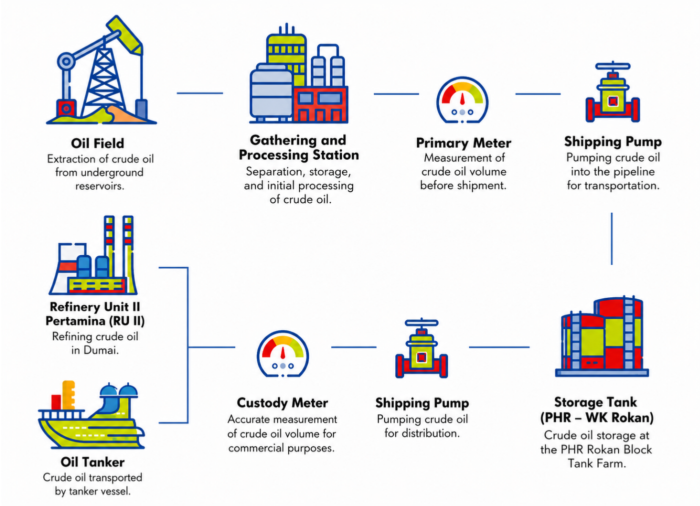

Figure 1. Operational Cycle of the Rokan Block

The Figure 1 unit price contract with hypothetical volume structure provides flexibility for project owners but introduces significant financial risks for contractors. Contractors must submit competitive unit rates without certainty regarding actual volume distribution, and inaccurate assumptions may lead to cost overruns, reduced profit margins, or financial losses. Therefore, robust cost control and performance evaluation are essential to assess financial efficiency.

Cost efficiency in construction and service contracts is commonly evaluated using the Cost Performance Index (CPI) and Budget Variance (BV). However, in unit price contracts with hypothetical volumes, these indicators require variance based analysis at the level of total cost, work items, and executed quantities. This study evaluates cost efficiency in SMO Earthwork service contracts using CPI, BV, and variance-based analysis based on completed contract data.

2. LITERATURE REVIEW

2.1. Unit Price Contracts and Hypothetical Volume in Construction Projects

Unit price contracts are widely applied in construction projects characterized by uncertainty in work scope and quantity, particularly in infrastructure and oil and gas service projects. However, this flexibility comes with financial risks for contractors, especially when estimated quantities used during tendering differ significantly from realized quantities in the field. The concept of hypothetical volume is inherently linked to unit price contracts, where initial quantities serve as a pricing reference rather than a guaranteed workload. Consequently, contractors must develop adaptive pricing and cost control strategies to maintain profitability under fluctuating work volumes.

2.2. Cost Efficiency and Performance Measurement in Construction Projects

Cost efficiency is a fundamental indicator of project success, particularly in service contracts where profit margins are sensitive to cost deviations. In construction management literature, cost efficiency is commonly assessed through the comparison of planned budgets and actual expenditures, enabling stakeholders to evaluate how effectively financial resources are utilized [2]. In unit price contracts, cost efficiency assessment becomes more complex due to the interaction between unit rates, volume realization, and execution strategy. Therefore, performance indicators must be complemented by detailed variance analysis to explain not only whether inefficiency occurs, but also why it occurs.

2.3. Cost Performance Index (CPI) as a Cost Efficiency Indicator

The Cost Performance Index (CPI) is a widely used metric for evaluating project cost efficiency by comparing earned value with actual cost. A CPI value greater than one indicates favorable cost performance, whereas a value below one reflects cost inefficiency. In unit price contracts, CPI is particularly useful for assessing how effectively contractors convert incurred costs into measurable work output. However, CPI should be interpreted alongside volume variability and complementary indicators such as Budget Variance (BV) and variance based analysis to provide a comprehensive evaluation of cost efficiency.

2.4. Budget Variance (BV) and Financial Deviation Analysis

Budget Variance (BV) measures the difference between planned and actual costs, providing a direct indication of cost deviation. BV is widely applied in post project evaluation to assess whether a project exceeds or remains within its budget constraints. In the context of SMO Earthwork service contracts, BV analysis is critical due to the cumulative effect of small deviations across multiple work orders issued through call-out mechanisms. This multi level approach is particularly relevant for hypothetical volume contracts, where deviations are often driven by changes in executed quantities rather than price escalation alone.

2.5. Variance Based Analysis in Unit Price Contracts

Variance based analysis provides a detailed examination of cost deviations by isolating the effects of price, quantity, and execution differences. Recent studies suggest that variance analysis is essential for understanding cost behavior in unit price contracts, as it enables project stakeholders to distinguish between controllable and uncontrollable cost factors [3]. Recent literature highlights that integrating variance analysis with CPI and BV creates a comprehensive framework for evaluating cost efficiency in complex service contracts [4].

2.6. Research Gap and Conceptual Positioning

Recent studies have explored various aspects of construction cost performance and contract management. For example, [5] examined cost efficiency measurement using CPI and earned value indicators, while [6] emphasized the integration of variance analysis in project financial evaluation. Other studies published [7], and [8], primarily focused on tender pricing strategies, contractor competitiveness, risk allocation, and project cost control during planning stages. However, limited research has investigated post execution cost efficiency using completed realization data under unit price contracts with hypothetical quantities. Unlike previous studies, this research integrates CPI, Budget Variance (BV), and variance based analysis using actual contract realization data from SMO Earthwork service contracts, thereby providing empirical evidence on how quantity realization influences contractor profitability and cost efficiency [9].

Despite extensive research on bidding strategies, markup optimization, and contractor competition models, limited empirical studies evaluate cost efficiency using actual post execution data from unit price contracts in the oil and gas sector, as most studies focus on tender stage decisions rather than realized contract outcomes [10]. This study addresses that gap by evaluating actual post execution cost efficiency using completed contract realization data from SMO Earthwork service contracts. The proposed framework integrates Cost Performance Index (CPI), Budget Variance (BV), and variance based analysis to assess financial performance under hypothetical volume conditions. By examining the relationship between quantity realization, contractor profitability, and cost efficiency, this study provides empirical evidence and a structured framework to support evidence based tender evaluation and cost management strategies in unit price contracts.

3. RESEARCH METHODOLOGY

3.1. Research Design and Approach

This study adopts a quantitative post project evaluation design to assess cost efficiency in Surface Maintenance Operation (SMO) Earthwork service contracts using realized data from completed projects. The approach aligns with the objective of evaluating cost efficiency rather than predicting future performance. The methodology is designed for unit price contracts with hypothetical volumes, where initial tender quantities are not guaranteed workloads and cost efficiency depends on the realization of work quantities through Work Assignment Proposals (WAP) and Work Order (WO). Therefore, this study applies a structured framework combining Cost Performance Index (CPI), Budget Variance (BV), and variance-based analysis to compare planned and realized costs and identify dominant contributors to cost deviation.

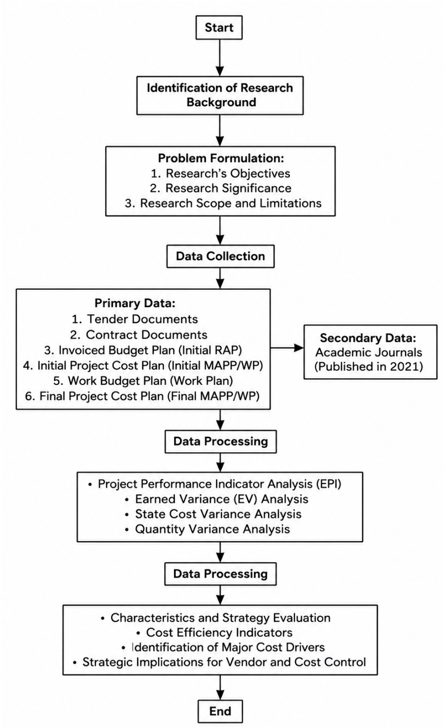

Figure 2. Research Flow Diagram for Evaluating Cost Efficiency in SMO Earthwork Service Contracts

Figure 2 shows the research process, starting from problem identification on cost efficiency in unit price contracts with hypothetical quantities. Data were collected from RAB, RAPP, and contract realization records for Package X and Package X Mitigation, then analyzed using CPI, BV, and variance based analysis. The results were used to evaluate contractor cost performance and provide recommendations for improving cost management and decision making.

3.2. Research Object and Data Sources

This research examines SMO Earthwork contracts in the upstream oil and gas sector using a unit price and hypothetical volume scheme. Package X and Package X Mitigation were selected based on similar characteristics and data completeness. Data were obtained from contractor records, including contracts, WAP, SPK, cost reports, and RAB/RAPP documents, supported by recent literature after [11].

Table 1. Research Object and Data Sources

Component	Description
Research Object	SMO Earthwork Service Contracts
Contract Scheme	Unit Price Contract with Hypothetical Volume
Contract Packages	Package X and Package X Mitigation
Primary Data	Contracts, WAP, SPK, RAB, RAPP
Secondary Data	Academic journals ($\geq$ 2021)

Table 1 presents the research object and data sources used in this study. The study focuses on SMO Earthwork Service Contracts under a unit price contract with hypothetical volume scheme, covering Package X and Package X Mitigation. Primary data were obtained from contract documents, WAP, SPK, RAB, and RAPP, while secondary data were taken from recent academic journals published after [12].

3.3. Research Variables and Operational Definitions

The research variables are derived directly from project cost management practices applied in the analyzed contracts [13]. Planned and actual cost data form the basis for performance evaluation, while derived indicators are used to assess cost efficiency and deviation.

Table 2. Research Variables and Operational Definitions

Variable	Operational Definition	Measurement Basis
Planned Cost	Budgeted project cost established during project planning	Initial RAB and RAPP
Actual Cost	Actual project expenditure incurred during execution	Final RAB and RAPP
Earned Value	Value of completed work based on approved quantities	Approved WO quantities
Cost Performance Index (CPI)	Indicator used to evaluate project cost efficiency	Earned Value / Actual Cost
Budget Variance (BV)	Indicator measuring deviation between planned and actual costs	Planned Cost – Actual Cost
Cost Variance	Cost deviation identified at individual work-item level	Item-level cost comparison
Quantity Variance	Difference between planned and realized work quantities	Planned vs. actual quantities

Table 2 presents the research variables, operational definitions, and measurement basis used in this study. Planned Cost, Actual Cost, and Earned Value are derived from Initial and Final RAB/RAPP documents and approved WO quantities. Key indicators such as CPI, BV, Cost Variance, and Quantity Variance are used to evaluate cost efficiency and identify deviations between planned and actual project performance [14].

3.4. Cost Performance Index (CPI)

In simple terms, CPI shows the comparison between the value of work that has been completed (earned value) and the actual cost that has been incurred to complete the work. CPI can be calculated using the following equation:

$$CPI = \frac{\text{Earned Value (EV)}}{\text{Actual Cost (AC)}} \tag{1}$$

Description:

- EV (Earned Value) or BCWP (Budgeted Cost for Work Performed), the value of the work that has been completed.
- AC (Actual Cost) or ACWP (Actual Cost for Work Performed), the actual cost that has been incurred up to the present time.

3.5. Budget Variance (BV)

Budget Variance (BV) is used to measure the difference between the Earned Value (EV) and the actual cost. BV is applied to track expenditures in a project. Budget Variance can be calculated using the following equation:

$$BV = \text{(EV)} - \text{(AC)} \tag{2}$$

Description:

- BV : Budget Variance (Rp)
- EV : Budgeted cost up to the completion of the work (Rp)
- AC : Actual cost incurred (Rp)

3.6. Total Cost Variance Analysis

Total cost variance analysis examines and compares the Initial RAPP and the Final RAPP [15]. Indirect variables represent fixed costs that have been budgeted and incurred. Therefore, this analysis focuses on the condition of direct costs at the initial stage and at the final stage.

- Cost Variance (Amount): Cost variance is calculated by subtracting the final cost amount from the initial cost amount.

$$\text{Cost Variance} = \text{Final Cost Amount} - \text{Initial Cost Amount} \tag{3}$$

- Weight Variance (Percentage): Weight variance is calculated by subtracting the final percentage weight from the initial percentage weight.

$$\text{Weight Variance} = \text{Final Weight (\%)} - \text{Initial Weight (\%)} \tag{4}$$

Cost variance and weight variance identify changes in project cost performance between the initial and final RAPP. Cost variance shows cost increases or decreases, while weight variance reflects changes in each work item's contribution to total cost [16]. Figure 3 provides the geographical context of the Rokan working area in Riau Province.

Figure 3. Rokan Working Area in Riau Province

Figure 3 shows the Rokan working area across several regions in Riau Province, including Siak, Bengkalis, Kampar, Rokan Hulu, Rokan Hilir, Dumai, and Pekanbaru [17]. The inset map indicates Riau's national position, highlighting the strategic importance of the Rokan Block in Indonesia's upstream oil and gas sector.

3.7. Analytical Framework and Research Output

The analytical framework integrates CPI, BV, and variance based analysis to provide a comprehensive evaluation of cost efficiency in SMO Earthwork service contracts. CPI and BV offer macro level insights into overall financial performance, while variance based analysis provides micro level understanding of cost behavior at the work item and quantity levels [18].

Table 3. Analytical Framework of the Study

Analysis Stage	Method	Output
Cost Efficiency Evaluation	CPI	Efficiency level
Budget Deviation Assessment	BV	Cost deviation
Cost Variance Identification	Item-level variance	Major cost drivers
Quantity Impact Assessment	Quantity variance	Effect of hypothetical volume
Interpretation	Integrated analysis	Cost efficiency insight

Figure 3 illustrates the geographical distribution of operational and production areas within Riau Province. The Rokan working area spans several administrative regions, including Siak Regency, Bengkalis Regency, Kampar Regency, Rokan Hulu Regency, Rokan Hilir Regency, Dumai City, and Pekanbaru City [17]. A supporting inset map of Indonesia is also provided to indicate the national level geographical position of Riau Province, contextualizing the scale and strategic importance of the Rokan Block within Indonesias upstream oil and gas sector.

4. RESULTS

4.1. Cost Performance Index (CPI) Results

The Cost Performance Index (CPI) was calculated to evaluate how efficiently project costs were converted into executed work value. The results show that Package X achieved CPI values close to or slightly above the efficiency threshold, indicating relatively controlled cost performance under the unit price contract scheme [19]. In contrast, Package X Mitigation demonstrated more volatile CPI values, indicating reduced cost efficiency primarily caused by reactive work execution driven by mitigation requirements. These results confirm that CPI is sensitive to execution dynamics and volume realization in hypothetical volume contracts.

Table 4. Cost Performance Index (CPI) Analysis

No.	Project Name	Project Performance Indicator Analysis (KPIs)						Deviation
		Planned			Actual			
		EV Initial Contract Value	AC Initial Cost	CPI Planned	EV Final Contract Value	AC Final Cost	CPI Actual	
a	b	c	d	e = c/d	f	g	h = f/g	i = h - e
1	SMO Construction Services Work Unit Rate Earthwork (Wur Ew) – Package X	118.851. 243.836,14	109.666. 526.534,16	1.08	118.851. 243.836,14	107.093. 364.520,57	1.11	0.03
2	SMO Construction Services Work Unit Rate Earthwork (Wur Ew) – Mitigation Package X	98.867. 922.812,03	94.543. 362.680,49	1.05	98.867. 922.812,03	88.032. 801.054,08	1.12	0.07

Table 4 shows that both projects achieved CPI values above one, indicating cost efficient performance and actual CPI values higher than planned targets. This reflects effective cost control and better than expected cost performance during execution. To provide clearer interpretation, the CPI values are categorized based on their performance implications for each contract package [20], as summarized in Table 5.

Table 5. CPI Results for SMO Earthwork Contract Packages

Contract Package	CPI Value	Performance Interpretation
Package X	> 1.00	Efficient / Cost Saving
Package X Mitigation	> 1.00	Efficient / Cost Saving

The Table 5 CPI results indicate that Package X achieved stable cost efficiency, with actual costs remaining proportional to executed work value. Although both packages achieved CPI values greater than one, Mitigation Package X recorded a slightly higher actual CPI, suggesting better resource utilization and cost control than initially planned [21]. This improvement was supported by a more balanced distribution of work orders between remote and non-remote areas, better execution stability, and closer alignment between planned and realized quantities [22]. These findings show that quantity realization, workload distribution, and operational planning are important factors affecting cost efficiency under unit price contracts with hypothetical quantities [23].

4.2. Budget Variance (BV) Analysis

This analysis compares planned and actual Budget Variance (BV) to assess cost efficiency in each work package. The BV calculation is based on the difference between Earned Value (EV) and Actual Cost (AC) [24]. A positive BV indicates that the project generated a higher value than the actual cost incurred, while a lower BV may indicate reduced cost efficiency or potential cost pressure. Table 6 presents the BV results for Package X and Package X Mitigation, showing the cost deviation and its effect on project financial performance. Therefore, the BV analysis provides an important basis for evaluating whether the final project cost structure remained within the expected financial performance target.

Table 6. Budget Variance (BV) Analysis

No.	Project Name	Project Performance Indicator Analysis (KPIs)						Deviation
		Planned			Actual			
		EV Initial Contract Value	AC Initial Cost	CPI Planned	EV Final Contract Value	AC Final Cost	BV Realization	
a	b	c	d	e = c/d	f	g	h = f/g	i = h - e
1	SMO Construction Services Work Unit Rate Earthwork (Work Ewv) – Package X	118.851. 243.836,14	109.666. 526.534,16	9.184. 717.301,98	118.851. 243.836,14	107.093. 364.520,57	11.757. 879.315,57	2.573. 162.013,59
2	SMO Construction Services Work Unit Rate Earthwork (Work Ewv) – Mitigation Package X	98.867. 922.812,03	94.543. 362.680,49	4.324. 560.131,54	98.867. 922.812,03	88.032. 801.054,08	10.835. 121.757,95	6.510. 561.626,42

Table 6 shows that both SMO Earthwork packages achieved positive Budget Variance (BV). Package X recorded a deviation of Rp2.573.162.013,59, while Package X Mitigation achieved a higher deviation of Rp6.510.561.626,42.

Table 7. Budget Variance Summary

Contract Package	Budget Variance	Interpretation
Package X	2.573.162.013,59	Moderate positive variance, indicating improved cost efficiency and higher realized profit than the initial plan.
Package X Mitigation	6.510.561.626,42	High positive variance, indicating a significant increase in realized profit due to lower final cost.

Table 7 shows that both packages achieved positive budget variance due to lower realized costs [25]. Package X recorded Rp2.573.162.013,59, while Package X Mitigation achieved a higher variance of Rp6.510.561.626,42, indicating stronger cost efficiency.

4.3. Work Item Cost Variance Analysis

Item level cost variance analysis reveals that cost deviations are not evenly distributed across all work items. Instead, a limited number of earthwork related activities contribute most significantly to total cost variance.

Table 8. Work Item Cost Variance Analysis

Work Item	Planned Index	Actual Index	Variance Level
Excavation	100	118	+18%
Filling	100	112	+12%
Hauling	100	109	+9%
Lining	100	102	+2%

These findings confirm that earthwork-related activities are the primary sources of cost inefficiency in SMO contracts, reinforcing the importance of variance based evaluation at the work item level [26].

4.4. Quantity Variance and Cost Efficiency Implications

Quantity variance affects cost efficiency and profitability in unit rate contracts because hypothetical quantities may differ from realized quantities [27]. The Cost Budget Plan (RAB) serves as a contract attachment containing estimated work item costs. During implementation, call-out orders and Work Orders are issued based on the approved RAB, as shown in Table 9.

Table 9. Package X Initial Budget Plan

No.	Work Item	Unit	Initial Budget Plan: Unit Rate NR	Unit Rate R	Hypothetical Quantity Non-Remote	Hypothetical Quantity Remote	Amount Non-Remote	Amount Remote	Total	Weight
a	b	c	d	e	f	g	h	i	j = h + i	k
A	Piling	-	-	-	-	-	4.106.344.787	5.078.891.298	9.185.236.085	7.73%
B	Earthwork and Civil	-	-	-	-	-	56.272.635.402	49.287.061.544	105.559.696.946	88.82%
C	Survey	-	-	-	-	-	436.108.446	242.814.398	678.922.844	0.57%
D	Soil and Civil Testing	-	-	-	-	-	1.938.319.301	1.115.463.146	3.053.782.447	2.57%
E	Support	-	-	-	-	-	198.827.002	175.048.851	373.875.853	0.31%
Total		-	-	-	-	-	62.952.234.938	55.899.279.236	118.851.514.174	100.00 %

Table 9 shows 268 work items in five categories based on hypothetical volumes [28]. Technical details will be finalized later through call-out orders and Work Orders (WO) [29], while Figure 4 presents the remote and non-remote WO distribution for SMO Earthwork Package X.

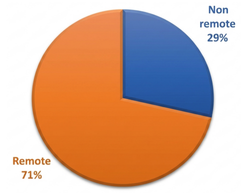

Figure 4. Package X Remote and Non-Remote WO Distribution

Figure 4 shows that 71% of WO were executed in remote areas and 29% in non-remote areas, reflecting higher logistics, mobilization, and operational risks [30]. This distribution helps explain quantity variance and cost efficiency. Figure 5 compares initial and final WO values for SMO Earthwork Package X [31].

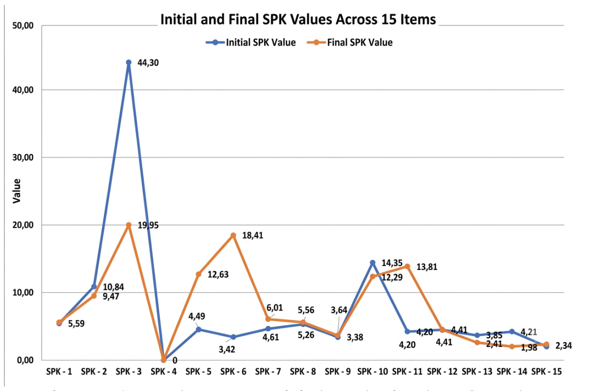

Figure 5. Package X Initial and Final WO Values

Figure 5 shows differences between initial and final WO values, with some decreasing and others increasing due to volume adjustments or scope changes [32]. These variations indicate that hypothetical quantities in unit rate contracts may differ from realized volumes, affecting quantity variance and cost efficiency.

Table 10. Mitigation Package X Initial Budget Plan

No.	Work Item	Unit	Initial Budget Plan						Total	Weight
			Unit Rate		Hypothetical Quantity		Amount			
			NR	R	Non-Remote	Remote	Non-Remote	Remote		
a	b	c	d	e	f	g	h	i	j = h + i	k
A	Piling	-	-	-	-	-	2.203. 396.016	3.661. 920.777	5.865. 316.793	5.93%
B	Earthwork and Civil	-	-	-	-	-	45.957. 112.049	45.170. 345.012	91.127. 457.062	92.17%
C	Survey	-	-	-	-	-	170. 261.103	140. 637.361	310. 898.464	0.31%
D	Soil and Civil Testing	-	-	-	-	-	895. 108.409	497. 903.590	1.393. 011.999	1.41%
E	Support	-	-	-	-	-	92. 373.428	78. 865.066	171. 238.494	0.17%
Total		-	-	-	-	-	49.318. 251.005	49.549. 671.807	98.867. 922.812	100.00%

Table 10 shows 268 work items in five subcategories based on hypothetical volumes [33]. Technical details such as locations, drawings, schedules, and requirements will be finalized later through call-out orders and Work Orders (WO). Figure 6 shows the WO distribution between remote and non-remote areas for SMO Earthwork – Mitigation Package X.

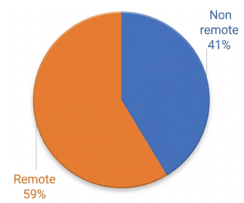

Figure 6. Mitigation Package X WO Distribution

Figure 6 shows that 59% of WO were executed in remote areas and 41% in non-remote areas, indicating a more balanced distribution than Package X and better cost control [34]. Figure 7 compares the initial and final WO values for SMO Earthwork Mitigation Package X.

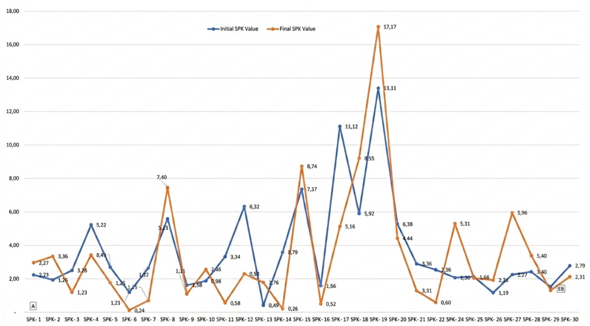

Figure 7. Comparison of Initial and Final WO Values for SMO Earthwork – Mitigation Package X

Figure 7 compares the initial and final WO values for SMO Earthwork Mitigation Package X, showing cost fluctuations across work orders, particularly SPK-2 and SPK-4 due to scope changes and field condition adjustments [35]. These quantity deviations affected cost performance and highlight the need for continuous monitoring in unit price contracts with hypothetical volumes. Beyond financial performance, the integration of CPI, BV, and variance-based analysis supports better resource utilization and cost control [36]. This contributes to SDG 9 by strengthening resilient infrastructure management and to SDG 12 by reducing resource waste, improving material use, and supporting more efficient project resource allocation.

Table 11. Pareto Analysis of SMO WUR EW Work Items – Package X

ERP Code	Item No	Work Item	Unit	Work Frequency in SPK / Final EAC Volume		Final RAB Weight/ Final EAC	Pareto
				n	%	%	
a	b	c	d	e	f	g	h = (f × g) / Max(f × g)
1	EW22003	Earthworks Fill from Company Designated Location, Haul and Compacted, Additional Cost per KM Above 15 KM Hauling Distance	Cu. Meter/KM	10	66.7%	48.0%	1.00
2	EW22002	Earthworks Fill from Company Designated Location, Haul and Compacted, with hauling distance from 0.5 KM to 15 KM	Cu. Meter	12	80.0%	3.29%	0.82
3	EW22008	Land Clearing and Grubbing	Sq. Meter	14	93.3%	5.0%	0.14
4	EW22015	Soil/Dirt Hauling, distance 0–10 KM without compaction	Cu. Meter	13	86.7%	5.2%	0.14
5	EW22012	Mud Pit Excavation/Construction	Cu. Meter	10	66.7%	1.2%	0.03
6	EW22001	Earthworks Fill from Company Designated Location, Haul and Compacted, Balanced Cut/Fill with hauling distance $<$ 0.5 KM	Cu. Meter	5	33.3%	2.3%	0.02
7	EW22007	Land Clearing	Sq. Meter	6	40.0%	0.5%	0.01
8	EW22014	Dress-up Road and Well Pad	Sq. Meter	7	46.7%	0.3%	0.00
9	EW22137	Fabricate and Install Structural Steel	Kilogram	2	13.3%	0.7%	0.00
10	EW21003	Install Steel Pipe Pile 8”	Meter	2	13.3%	0.6%	0.00
11	-	Other Work Items	-	-	-	3.3%	-

Table 11 presents a Pareto analysis of the Earthwork (EW) items under the SMO WUR Package X, combining work frequency and final budget weight. The Pareto index is calculated using the formula h = (f × g) / Max(f × g). The results indicate that EW22003 – Earthworks Fill with hauling distance above 15 km is the most dominant work item, with a Pareto value of 1.00 and a financial contribution of 48.0%. The second most influential item is EW22002 – Earthworks Fill with hauling distance 0.5–15 km, with a Pareto value of 0.82 and a budget contribution of 3.29%. Together, these two items account for the majority of the total project cost, confirming that hauling distance is a critical determinant in cost performance [37, 38]. Other items such as Land Clearing and Grubbing (EW22008) and Soil/Dirt Hauling 0–10 km (EW22015) show high execution frequency but lower budget contributions (around 5%), indicating moderate operational importance but limited financial impact [39, 40]. The remaining work items have relatively low Pareto values ($\leq$ 0.03), meaning their contribution to the overall cost structure is minor. Overall, the Pareto analysis demonstrates that a small number of work items particularly long-distance earthworks fill contribute disproportionately to the total project cost, highlighting the need for strategic cost control and optimization [41].

Table 12. Pareto Analysis of SMO WUR EW Work Items – Package X Mitigation

ERP Code	Item No	Work Item	Unit	Work Frequency in SPK / Final EAC Volume		Final RAB Weight/ Final EAC	Pareto
				n	%	%	
a	b	c	d	e	f	g	h = (f × g) / Max(f × g)
1	EW22002	Earthworks Fill from Company Designated Location, Haul and Compacted, with hauling distance from 0.5 KM to 15 KM	Cu. Meter	22	75.86%	45.86%	1.00
2	EW22003	Earthworks Fill from Company Designated Location, Haul and Compacted, Additional Cost per KM Above 15 KM Hauling Distance	Cu. Meter/KM	12	41.38%	26.81%	0.32
3	EW22015	Soil/Dirt Hauling, distance 0–10 KM without compaction	Cu. Meter	24	82.76%	5.91%	0.14
4	EW22001	Earthworks Fill from Company Designated Location, Haul and Compacted, Balanced Cut/Fill with hauling distance < 0.5 KM	Cu. Meter	21	72.41%	5.73%	0.12
5	EW22008	Land Clearing and Grubbing	Sq. Meter	19	65.52%	6.10%	0.11
6	EW22012	Mud Pit Excavation/Construction	Cu. Meter	27	93.10%	2.72%	0.07
7	EW22171	Install HDPE Geomembrane	Sq. Meter	27	93.10%	0.60%	0.02
8	EW22007	Land Clearing	Sq. Meter	13	44.83%	0.98%	0.01
9	EW22005	Earthworks Cut/Excavation	Cu. Meter	18	62.07%	0.60%	0.01
10	EW22014	Dress-up Road and Well Pad	Sq. Meter	16	55.17%	0.50%	0.01
11	EW–	Other Work Items	-	-	-	4.19%	-

Table 12 presents a Pareto analysis of Earthwork (EW) items using Work Frequency in WO and Final RAB Weight (%) with the formula h = (f × g) / Max(f × g). EW22002 shows the highest Pareto value (1.00) and largest budget contribution (45.86%), followed by EW22003 with 0.32 and 26.81%, while other items have lower values ($\leq$ 0.14). This confirms that a few earthwork fill activities dominate the budget and support SDG 9 and SDG 12 through improved cost evaluation, resource allocation, and waste reduction [42].

5. MANAGERIAL IMPLICATIONS

The findings provide practical implications for contractors, project managers, policymakers, and contract owners involved in unit price contracts with hypothetical quantities. For contractors, the integration of Cost Performance Index (CPI), Budget Variance (BV), and variance-based analysis can function as an early warning tool to identify cost inefficiencies and quantity deviations before they affect project profitability. For project managers, this framework supports data-driven decision making by helping evaluate contract performance, identify critical work items, improve planning accuracy, optimize work-order distribution, and reduce operational risks during project execution. Meanwhile, for policymakers and contract owners, the findings emphasize the importance of post-execution performance evaluation to improve transparency, support objective contractor assessment, and enhance infrastructure investment efficiency and resource utilization in large-scale projects.

6. CONCLUSION

This study evaluated cost efficiency in SMO Earthwork service contracts under a unit price contract scheme with hypothetical quantities by integrating Cost Performance Index (CPI), Budget Variance (BV), and variance-based analysis. The results show that both Package X and Mitigation Package X achieved cost-efficient performance, indicated by CPI values greater than one and positive budget variance outcomes. Package X Mitigation showed stronger efficiency through higher positive variance and more balanced work distribution.

The variance and Pareto analyses indicate that quantity realization and earthwork-related activities were the main contributors to cost deviations. Differences between hypothetical and realized quantities affected WO values, work item costs, and project profitability. Earthworks fill and hauling activities were identified as dominant cost drivers, showing the need for continuous monitoring of work orders, quantity realization, and field adjustments.

Future research may expand this framework by involving more contract packages, other construction service contracts, and different operational areas to improve generalizability. Further studies may also integrate predictive analytics, machine learning, or digital cost monitoring systems to forecast quantity variance and detect cost deviations earlier. This would support more accurate, transparent, and sustainable cost management in future infrastructure projects.

7. DECLARATIONS

7.1. About Authors

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7.2. Author Contributions

Conceptualization: DP and AA; Methodology: DP and AA; Software: AA; Validation: DP, SM, and BM; Formal Analysis: AA and DP; Investigation: SM; Resources: DP; Data Curation: BM; Writing – Original Draft Preparation: AA; Writing – Review and Editing: DP; Visualization: SM; Supervision: BM. All authors, DP, AA, SM, and BM, have read and agreed to the published version of the manuscript.

7.3. Data Availability Statement

The data presented in this study are available on request from the corresponding author.

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The authors received no financial support for the research, authorship, and/or publication of this article.

7.5. Declaration of Conflicting Interest

The authors declare that they have no conflicts of interest, known competing financial interests, or personal relationships that could have influenced the work reported in this paper.

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