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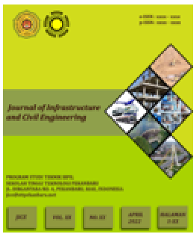

WBS-Pareto-ABC and CPI Model for Pre-Construction Cost Control of A-KRIS Hospital Building

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Abstract

Pre-construction cost control in hospital ward completion projects requires a systematic approach capable of identifying cost concentration before construction begins because healthcare rehabilitation works involve complex interations among MEP-HVAC, sanitation, air-conditioning systems and functional building components. This study aims to develop a novel pre-construction cost control framework by integrating the Work Breakdown Structure (WBS), Pareto-ABC analysis, Area Cost Index (ACI) and a newly proposed Control Priority Index (CPI) for the A-KRIS Hospital Building completion project at RSUD Hj. Anna Lasmanah Banjarnegara. A quantitative descriptive case study was conducted through Bill of Quantity (BoQ) validation, WBS mapping, cost aggregation by work zone and sub-work, area cost index calculation, Pareto-ABC classification, and CPI formulation. The project cost was IDR 930,571,644 (including 11% VAT), with an area cost index of IDR 606,093/m². Cost distribution was highly concentrated in Teratai Ward (60.18%) and Soka Ward (39.10%) accounted for 78.78% of the total project cost. The proposed CPI further differentiates priority among high-cost work items by integrating cost contribution, zone dominance, ABC classification, and optional technical risk, enabling more targeted prioritization of AHU isolation, air-conditioning, sanitation, piping, aluminium works and nurse station components. Unlike conventional Pareto-ABC analysis, which prioritizes work items solely based on cumulative cost, the proposed WBS-Pareto-ABC-CPI framework provides a structured decision-support model that links cost concentration with managerial control priorities during the pre-construction stage. The framework contributes to construction management by transforming conventional BoQ data into a practical and replicable tool for preventive cost, procurement, quality, schedule and safety control that can be applied tohospital rehabilitazion and other public-building projects.

Keywords: *cost control, pre-construction, WBS, Pareto-ABC, control priority index, hospital ward*

1. Introduction

Cost control is a decisive aspect of construction project success because cost reflects planning quality, estimation accuracy, resource efficiency, and managerial capability to anticipate risk. Cost overrun remains a global problem caused by weak planning, inaccurate estimates, design changes, contractual issues, resource constraints, and supply-chain disruption [1], [2]. In

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healthcare facility rehabilitation, cost management becomes more complex because work packages include architecture, mechanical, electrical, plumbing, sanitation, HVAC, and functional room elements.

Previous studies indicate that cost overruns remain one of the most persistent challenges in construction projects, with nearly 90% of project experiencing budget overruns. Systematic reviews further identify design changes, procurement uncertainty, planning deficiencies and project management issues as the dominant causes of cost escalation, particularly in complex public projects. [3]

Hospital projects are characterized by extensive building-service requirements, including HVAC, plumbing, electrical, medical gas and infection-control systems, which substantially increase coordination complexity and cost uncertainty [3]. Because these systems involve specialized equipment, long procurement lead times, and extensive coordination with architectural and structural works, even relatively small deviations in quantity, spesification or installation sequence can generate significant cost impacts during project implementation [4].

Hospital building projects exhibit cost-risk characteristics that differ significantly from conventional buildings because healthcare facilities require highly intergrated architectural, structural, MEP, HVAC, medical-gas and sanitation systems [5]. The relatively high proportion of MEP-HVAC expenditure means that a limited number of work packages often dominate the overall project budget. Concequently, identifying these dominant cost components before construction begins is essential for minimizing cost overruns, reducing procurement risks and improving coordination among project stakeholders[6][7]. Therefore, pre-construction cost control should extend beyond estimating the total budget to systematically identifying cost concentration across work zones, sub-works and detailed BoQ items.

Previous studies have examined cost overrun through causal factor mapping [1] , [2] , change order management [8] , material waste [9] , project cost control systems [10] , 5D-BIM [11] , digital cost management [12] , FEED-stage risk [13] , hospital construction cost overrun [14] , prediction models [15], reality capture cost valuation[16] , and value management [17] . These approaches contribute substantially to construction management knowledge; however, many require historical datasets, digital models, respondent surveys, or predictive modeling that may not be available in medium-scale rehabilitation projects. In many public facility projects, the most accessible pre-construction documents are the BoQ, technical specifications, drawings, and construction schedule.

The research gap lies in the limited availability of a simple pre-construction cost control model that directly reads cost concentration from the actual BoQ structure, especially for hospital ward completion projects. A BoQ is often treated only as a bidding and payment document, although it can be transformed into a cost-audit instrument for mapping cost risk and determining supervision priorities[18] [19][20]. Integrating WBS, Pareto-ABC, area cost index, and CPI can address this gap because it links each cost item to work zones, cumulative contribution, and managerial control actions.

This study aims to analyze the cost distribution of the A-KRIS Building completion project at RSUD Hj. Anna Lasmanah Banjarnegara, classify BoQ items using Pareto-ABC, calculate the area cost index, and formulate CPI as a pre-construction cost control instrument. The contribution of this study is a simple, measurable, and applicable audit model for projects that have not yet adopted 5D-BIM or digital cost management systems. The novelty is the transformation of BoQ data into a priority-control instrument for cost, quality, procurement, schedule, and construction safety based on the WBS-Pareto-ABC-CPI framework. Unlike previous studies that primarily classify cost items using Pareto analysis or predict cost overruns through statistical and digital approaches, this study introduces the Control Priority Index (CPI), which integrates cost concentration, work-zone dominance, and managerial priority into a single decision-support framework for pre-construction cost control.

2. Methodology

This research used a quantitative-descriptive case study approach. The object was the rehabilitation completion project of the A-KRIS Building at RSUD Hj. Anna Lasmanah Banjarnegara, Central Java, Indonesia. The unit of analysis was each BoQ work item with a description, volume, unit, unit price, and cost value. Because the study focused on pre-construction control, the analysis was directed at cost-audit planning rather than final cost realization.

The A-KRIS Hospital Building rehabilitation project was intentionally selected as a representative case because it exhibits characteristics commonly encountered in medium-scale public healthcare rehabilitation project in Indonesia. The project involves multidisiplinary work packages, including architectural, structural, mechanical, electrical, plumbing, HVAC, sanitation and functional healthcare facilities, all of which create a highly heterogeneous cost structure. Furthermore, the project documentation was complete, consisting of a validated Bill of Quantity (BoQ), technical specifications, reviewed drawings and construction schedule, allowing systematic development and testing of the proposed framework.

The purpose of employing a single-case was not to achieve statistical generalization but to support analytical generalization of the proposed WBS-Pareto-ABC-CPI framework. The case serves as a real-world demonstration of how the framework can be implemented using standard pre-construction project documents [21]. Therefore, while numerical result are project-specific, the analytical procedure is designed to be transferable to other hospital rehabilitation and public-building projects with similar document availability and cost characteristics.

The data sources were the bid BoQ/RAB, unit price analysis, technical specifications, reviewed drawings, and a construction schedule of nine weeks plus two days. The BoQ was the main source because it records work items, volume, unit price, subtotal, VAT, and total project cost. Technical specifications were used to interpret work quality and complexity, while drawings and the schedule were used to identify zones and weekly control implications.

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Table 1. Data sources and analytical functions

No	Data source	Analytical function
1	Bid BoQ/RAB	Source of work item, volume, unit price, subtotal, VAT, and total cost.
2	Unit price analysis	Basis for tracing unit-price reasonableness and cost components.
3	Technical specifications	Basis for interpreting material quality, work standards, and dominant items.
4	Reviewed drawings	Basis for identifying zones, rooms, and building elements.
5	Time schedule	Basis for interpreting weekly monitoring needs.

The analytical stages consisted of BoQ item validation, WBS development, cost normalization, cost recapitulation by zone and sub-work, area cost index calculation, Pareto analysis, ABC classification, CPI formulation, and control matrix development. The WBS was organized into four levels: project, work zone, sub-work, and detailed work item.

Table 2. Research variables and operational definitions

Variable	Symbol	Operational definition
Work item cost	Ci	Cost of item i calculated from work volume and unit price.
Project total cost	CT	Total cost of all valid BoQ items, including VAT when used in analysis.
Zone cost	Cr	Accumulated cost of items in a specific work zone.
Item contribution	Pi	Percentage contribution of an item to total project cost.
Cumulative cost	Ki	Cumulative percentage after items are sorted from highest to lowest cost.
Area cost index	IB	Project cost per square meter of work area.
ABC category	A/B/C	Priority group based on cumulative cost contribution.
Control Priority Index	CPIi	Index combining item cost, zone dominance, ABC weight, and optional technical risk.

Work item cost was calculated by multiplying the volume and unit price. Total project cost was obtained by summing all valid cost items in the BoQ. Item and zone contributions were calculated to determine the financial influence of each item and work area on the project budget.

$$C_i = V_i \times H_i \quad (1)$$

$$C_T = \Sigma C_i, \text{ for } i = 1, 2, 3, ..., n \quad (2)$$

$$P_i = (C_i / C_T) \times 100\% \quad (3)$$

$$P_z = (C_z / C_T) \times 100\% \quad (4)$$

After the items were sorted from the highest to the lowest cost, the Pareto cumulative percentage was calculated to identify items forming about 80% of the project value. The area cost index was calculated as an initial indicator of cost intensity relative to work area.

$$K_i = \Sigma P_j, \text{ for } j = 1 \text{ to } i \quad (5)$$

$$I_B = C_T / A \quad (6)$$

ABC classification was determined from cumulative cost limits. Category A represents items forming approximately 80% of total cost and must receive intensive control. Category B covers cumulative contribution of more than 80% to 95%, while Category C covers more than 95% to 100%. To refine priorities within each category, this study proposes a mathematical CPI model.

$$CPI_i = \alpha(C_i/C_{max}) + \beta(Z_r/Z_{max}) + \gamma(W_{ABC\_i}/3) + \delta(R_i/5) \quad (7)$$

$$CPI_i = 0.50(C_i/C_{max}) + 0.20(Z_r/Z_{max}) + 0.30(W_{ABC\_i}/3) \quad (8)$$

Equation (7) is used when a technical-risk score is available from expert judgment. Equation (8) is used as an initial audit model when risk data are not yet available. The weighting coefficients presented in Equation (8) should be interpreted as an initial conceptual weighting scheme rather than statistically optimized parameters. Because this study aims to introduce a practical pre-construction audit framework, the weights were intentionally assigned according to logical managerial considerations reflecting the relative importance of each component in early cost control. To examine the robustness of the proposed weighting structure, a simple sensitivity analysis was performed by applying several alternative weighting scenarios and comparing the resulting control-priority ranking.

A higher weight (0.50) was assigned to normalized item cost because the primary objective of the proposed framework is to identify work items with greatest potential financial impact. Zone dominance was assigned a weight 0.20 to account for the spatial concentration of project cost, particularly in hospital rehabilitation project where specific wards may contain clusters of high-value work packages. The ABC classification received a weight of 0.30 because it complements the direct cost contribution by incorporating cumulative cost concentration into the prioritization process. Accordingly, the proposed weighting scheme emphasizes financial significance while maintaining consideration of spatial and managerial characteristics.

It should be emphasized that these weighting coefficients are not claimed tobe universally optimal. Instead, they constitute an initial conceptual framework intended to demonstrate the applicability of the proposed CPI model under typical pre-construction conditions where only standard project documents are available. Future, studies are expected to calibrate these coefficients using structured expert elicitation techniques such as the Delphi method, Analytic Hierarchy Process (AHP), Best-Worst Method (BMW), or the multi-criteria decision-making (MCDM) approaaches. Statistical calibration using multiple case studies may also be employed to improve the ribustness and generalizability of the weighting structure.

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Table 3. ABC and CPI decision criteria

Criterion	Limit	Control decision	Monitoring
Category A	0-80% cumulative	Audit volume, specification, procurement, quality, schedule, and cost.	Weekly
Category B	>80-95% cumulative	Periodic validation, field coordination, and stock control.	Periodic
Category C	>95-100% cumulative	Checklist, routine opname, and administrative control.	Routine
Very high CPI	CPI >= 0.70	Critical project priority and weekly meeting agenda.	Weekly
High CPI	0.50 <= CPI < 0.70	Main priority in the related zone.	Weekly/biweekly
Medium/low CPI	CPI < 0.50	Periodic or administrative control.	As needed

3. Results and Discussion

3.1. Cost profile and zone distribution

The validation showed that the project cost data were suitable for analysis because each work item had volume, unit, unit price, and cost value. The construction cost before VAT was IDR 838,352,832, VAT 11% was IDR 92,218,812, and the total cost including VAT was IDR 930,571,644. The total ward area was 1,535.36 m2, resulting in an area cost index of IDR 606,093/m2. This index indicates a completion or rehabilitation project rather than a full new-building construction project.

The cost distribution by zone shows that project cost was highly concentrated in Teratai Ward and Soka Ward. Teratai Ward contributed IDR 560,039,469 or 60.18% of total cost, while Soka Ward contributed IDR 363,844,697 or 39.10%. Preparation work contributed only 0.72%. This indicates that project control should be zone-based rather than focused only on initial preparation work.

Table 4. Cost distribution by work zone

No	Work zone	Items	Cost including VAT	Contribution
1	Teratai Ward	105	IDR 560,039,469	60.18%
2	Soka Ward	99	IDR 363,844,697	39.10%
3	Preparation Work	11	IDR 6,687,478	0.72%
Total	-	215	IDR 930,571,644	100.00%

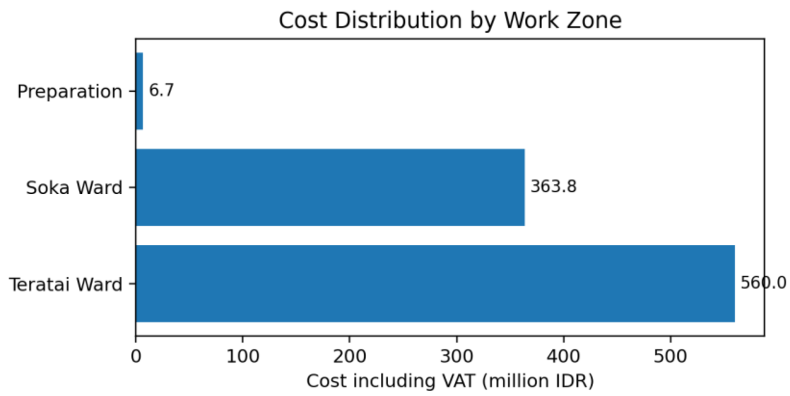

Figure 1. Cost distribution by work zone

Teratai Ward became the main cost center because it had a larger area and contained high-value items, especially AHU isolation, air conditioning, sanitation, piping, aluminium works, nurse station, and concrete works. From a managerial perspective, zone distribution provides early information about where supervision resources should be allocated. The owner, supervisor, and contractor can use this map to prioritize technical meetings, volume validation, material control, and quality inspection. This finding supports the view that cost risk should be identified at the early project phase because early decisions influence subsequent cost performance[13] .

3.2. Dominant sub-works and MEP-HVAC cost characteristics

Table 5. Ten sub-works with the highest cost contribution

No	Zone	Sub-work	Cost including VAT	Contribution
1	Teratai Ward	AHU Isolation	IDR 154,956,000	16.65%
2	Soka Ward	AHU Isolation	IDR 77,478,000	8.33%
3	Teratai Ward	Iron and Aluminium	IDR 72,836,646	7.83%
4	Teratai Ward	Air Conditioner	IDR 56,975,190	6.12%
5	Teratai Ward	Sanitation and Piping	IDR 52,523,979	5.64%
6	Soka Ward	Sanitation and Piping	IDR 50,637,090	5.44%
7	Soka Ward	Iron and Aluminium	IDR 46,288,976	4.97%
8	Teratai Ward	Nurse Station	IDR 42,566,510	4.57%
9	Teratai Ward	Concrete Work	IDR 40,018,202	4.30%
10	Soka Ward	Nurse Station	IDR 39,266,131	4.22%

The most dominant sub-work was AHU Isolation in Teratai Ward, contributing 16.65% of total cost. The second was AHU Isolation in Soka Ward, contributing 8.33%. Combined, AHU Isolation accounted for 24.98% of total project cost. This result shows that the hospital ward project was controlled by MEP-HVAC components. In this project, air-conditioning work is not merely a comfort element but is associated with service-room function and ward operational reliability.

The dominance of MEP-HVAC components is primarily associated with the functional requirements of hospital buildings, where enviromental control systems directly influence patient safety, infection prvention, and operational continuity. Unlike conventional residential or office buildings, hospital rehabilitation projects require compliance with stricter technical standards, resulting in higher equipment specifications, specialized installation methods, and longer procurement lead times. Consequently, relatively few MEP-HVAC work items account for a disproportionately large share of project cost.

This finding is consistent with previous studies reporting that building-service systems frequently become major cost drivers in healthcare facilities due to their technical complexity and extensive interdisciplinary coordination requirements. It also explain why changes in HVAC specifications often generate cascading impacts on architectural finishing, electrical systems and commissioning activities. Therefore, early identification of these dominant work packages provides a more effective basis for preventive cost control than relying solely on overall project budget monitoring.

3.3. Pareto-ABC classification and critical work items

Table 6. ABC classification of work items

Category	Items	Item %	Cost including VAT	Cost %	Control meaning
A	68	31.63%	IDR 742,366,507	79.78%	Main priority: volume, specification, procurement, quality, and schedule.
B	51	23.72%	IDR 140,346,857	15.08%	Periodic control and field coordination.
C	96	44.65%	IDR 47,858,280	5.14%	Administrative control and checklist.
Total	215	100.00%	IDR 930,571,644	100.00%	-

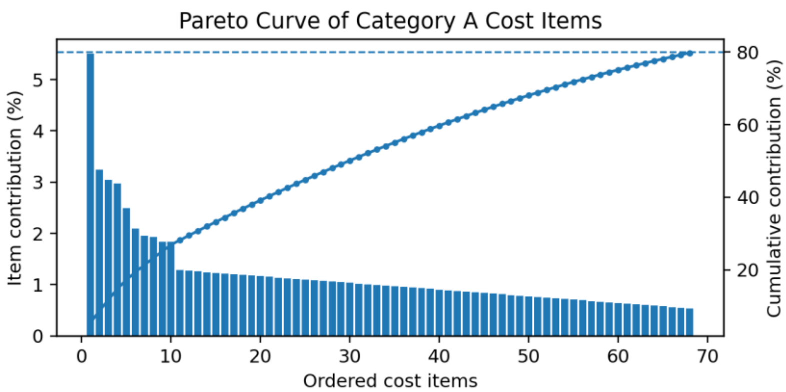

Figure 2. Pareto curve of dominant cost items

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Pareto-ABC results indicate that 68 items, or 31.63% of 215 work items, controlled 79.78% of total cost. Thus, the project cost structure follows a strong concentration pattern. Category A items must be the main control focus because small changes in volume, unit price, specification, work method, or procurement schedule can generate significant cost impact. Category C items still need to be recorded but can be controlled through administrative checks and field checklists.

This finding strengthens priority-based cost management. In the A-KRIS Building project, Category A items are the intersection of cost, quality, resources, and supply-chain control. This supports cost-overrun studies that identify project management, resources, and supply chain as important factors in cost growth [2] .

Table 7. Ten work items with the highest cost contribution

No	Zone/Sub-work	Work item	Volume / unit price	Contribution
1	Teratai / AC	Panasonic 2 PK AC unit (YN 18 WKJ/AKJ)	6 units / IDR 7,700,000	5.51%
2	Teratai / AHU	Ducting work	2 lots / IDR 13,600,000	3.24%
3	Teratai / AHU	Exhaust fan 1,250 CFM	2 units / IDR 12,800,000	3.05%
4	Teratai / Aluminium	Aluminium frame	208.15 m / IDR 120,000	2.98%
5	Teratai / Aluminium	Double 8 cm spandrel aluminium door	33.8 m2 / IDR 617,000	2.49%
6	Teratai / Sanitation	Washbasin + pedestal with accessories	11 units / IDR 1,600,000	2.10%
7	Soka / Aluminium	Aluminium frame	135.9 m / IDR 120,000	1.95%
8	Teratai / Sanitation	Sitting closet/monoblock P-trap	9 units / IDR 1,800,000	1.93%
9	Teratai / AHU	Panasonic 2 PK AC unit	2 units / IDR 7,700,000	1.84%
10	Soka / AC	Panasonic 2 PK AC unit	2 units / IDR 7,700,000	1.84%

The ten largest items show that cost risk is cross-disciplinary, covering air conditioning, ducting, exhaust fans, aluminium works, sanitation, closets, washbasins, and AC units. Delay in ducting can delay ceiling work; piping route changes can affect floor and wall finishing; aluminium dimension changes can cause rework; and late AC installation can disrupt room commissioning. Therefore, dominant items must be included in the weekly control list.

3.4. Proposed WBS-Pareto-CPI control model

The proposed model transforms the BoQ from a bidding document into a pre-construction cost-audit instrument. The model flow is BoQ -> WBS -> Ci -> Pi -> Ki -> ABC -> CPIi -> control

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matrix -> weekly monitoring. It consists of three layers: a work-structure layer based on WBS, a quantitative layer based on cost contribution and Pareto analysis, and a managerial layer consisting of ABC class, CPI score, and control actions.

CPI sharpens the analysis because not all Category A items receive the same control intensity. Items with high cost, located in dominant zones, and assigned high ABC weight obtain higher CPI scores. In the A-KRIS Building project, Category A items in AHU isolation, air conditioning, sanitation, piping, aluminium, and nurse station works became the main priorities for cost, quality, procurement, schedule, and safety control.

The principal contribution of the proposed Control Priority Index (CPI) is its ability to overcome one of the main limitations of conventional Pareto-ABC analysis. Traditional Pareto-ABC methods classify work items within Category A receive identical management priority. In practice, however, project managers also consider spatial concentration, work-package interdependency and implementation risk when allocating supervision resources.

The CPI addresses this limitation by integrating three complementary dimensions: relative cost contricbution, work-zone significance and ABC priority weighting. Concequently, work items with similar cost values may receive different priority rankings when whey belong to different project zones or managerial categories. This enables more selective allocation of engineering review, procurement monitoring, quality inspection and supervisory effort during the pre-construction phase.

For example, two work items may both belong to Category A because each contributes substantially to total project cost. Under conventional Pareto-ABC analysis, both items would receive equal management attention. Under the proposed CPI framework, however, the item located within the dominant Teratai Ward and associated with critical HVAC installation receives a higher CPI score than an equally expensive item located in a less dominant zone. This distinction allows project managers to prioritize limited supervisory resources toward work packages that combine high financial impact with higher implementation significance.

Table 8. Main components of the WBS-Pareto-ABC-CPI model

Component	Input	Analytical process	Managerial output
WBS	BoQ, drawings, specifications	Mapping items into zones, sub-works, and detailed items.	Traceable cost structure.
Cost analysis	Volume, unit price, item cost	Calculation of item cost, zone cost, and area cost index.	Cost profile and dominant zone.
Pareto-ABC	List of cost items	Sorting, contribution, cumulative cost, and ABC class.	Priority items A, B, and C.
CPI	Item cost, zone, ABC, risk score	Priority index calculation.	Ranked control priority.
Control matrix	ABC and CPI output	Determining cost, quality, procurement, schedule, and K3 actions.	Weekly control checklist.

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Table 9. Control action matrix based on the WBS-Pareto-ABC-CPI model

Item group	Main risk	Cost control action	Quality, schedule, and safety action
AHU isolation and AC	High unit price, special specification, procurement lead time.	Specification validation, unit-price review, material approval, procurement control.	Shop drawing, ceiling/electrical coordination, function test, electrical and lifting safety.
Sanitation and piping	Point changes, leakage, finishing rework.	Volume check, installation-point validation, change control.	Flow test, leakage test, coordination with floor and wall finishing.
Aluminium, door, and frame	Field measurement error, material waste, fabrication delay.	Re-measurement, profile approval, fabrication volume control.	Shop drawing, mock-up, installation inspection, cutting safety.
Nurse station and finishing	Functional mismatch, design change, many small components.	Design clarification, volume control, change limitation.	Material approval, finishing control, final inspection.
Category B and C items	Accumulated small deviations.	Periodic monitoring and volume checklist.	Routine opname, photo documentation, payment administration.

3.5. Managerial discussion and implementation implications

The results show that cost concentration in specific zones and items must become the basis for decision-making. This supports cost-overrun studies that emphasize the need for control from the early project phase [1], [2], [13]. In hospital projects, cost characteristics are shaped by service-room function, technical standards, and interdisciplinary coordination [14]. Therefore, BOQ audit using WBS-Pareto-ABC and CPI can guide procurement priority, shop drawing review, volume validation, material approval, and quality inspection.

Although this study has not yet included empirical validation using project implementation data, the proposed CPI framework possesses strong conceptual validity because it integrates three variables that are routinely available during the pre-construction stage, namely cost distribution, work breakdown structure and Pareto-ABC classification. Unlike many risk-based prioritization models requiring extensive historical database, the CPI can be calculated directly fromstandard BoQ and design document, making it suitable for practical implementation in rhabilitation projects with limited historical information.

Furthermore, the framework may serve as an initial decision-support tool for owners, colsultants and contractors when determining supervision priorities before construction activities begin. future studies may strengthen the model through expert validation using the Delphi technique, Analytic Hierarchy Process (AHP), Best-Worst Method (BWM), or other multi-criteria decision-making approaches.

Compared with neural-network prediction models or reality-capture technologies [15], [16], this model is simpler and can be implemented using conventional pre-construction documents. This is important for public-building rehabilitation projects that do not have large historical datasets. Nevertheless, the model can be extended by adding technical risk, procurement risk, schedule risk, and weekly progress realization data.

For the owner, the model helps determine strategic budget-supervision areas. The owner does not need to wait for end-of-project cost deviation but can require consultants and contractors to prepare Category A and high-CPI item lists at the pre-construction meeting. For consultants, the model supports review of volume reasonableness, unit price, and technical specifications. For contractors, the model assists in prioritizing procurement, weekly work plans, labor allocation, and cash-flow strategies.

From the perspective of construction management science, this study extends the conventional application of Pareto-ABC beyond descriptive cost classification by integrating it with the Work Breakdown Strcture (WBS) and the newly proposed Control Priority Index (CPI). Unlike traditional Pareto analysis that ranks work items solely according to financial contribution, the proposed framework incorporates spatial cost concentration and managerial weighting into a single prioritization model. Consequently, the frame work transforms cost analysis into a practical decesion-support system capable of directing cost, procurement, quality, schedule and safety control before construction begins. This integration represents the primary methodological contribution of the present study.

The proposed weekly checklist is the operational bridge between analysis and site management. Each Category A or high-CPI item should have a status: not yet clarified, volume verified, specification approved, material approved, shop drawing accepted, material ordered, material delivered, installed, tested, and accepted. This approach prevents cost control from becoming a retrospective activity and turns it into a preventive control process.

Table 10. Weekly control checklist for Category A and high-CPI items

Control object	Verification item	Responsible party	Evidence	Decision output
AHU isolation	Capacity, ducting, exhaust fan, HEPA, panel control.	Contractor, supervisor, owner.	Shop drawing, material approval, supplier document.	Proceed, revise, or hold procurement.
Air conditioner	Capacity, location, electrical point, installation sequence.	Contractor and supervisor.	Approved specification, layout, progress photo.	Install or revise location.
Sanitation and piping	Pipe route, fixture point, slope, leakage test.	Contractor, plumbing supervisor.	Checklist, test report, as-built sketch.	Close finishing or repair.

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Aluminium work	Field measurement, profile, accessories, fabrication volume.	Contractor and supervisor.	Measurement sheet, sample approval, mock-up.	Fabricate or re-measure.
Nurse station	Functional layout, finishing material, MEP interface.	Owner, planner, supervisor.	Approved drawing, material sample, site instruction.	Approve installation or adjust design.

The model has several limitations. First, its accuracy depends on BoQ quality; inaccurate volumes, unit prices, or zone mapping will affect Pareto-ABC and CPI results. Second, this study uses pre-construction data and has not measured actual deviations during implementation. Third, the technical-risk component in the CPI equation is optional and requires expert judgment when applied fully. Fourth, the study uses a single case; therefore, generalization must be made carefully. Fifth, the CPI weighting adopted in this study is conceptual and has not yet been calibrated through structured expert elicitation or statistical optimization. Another limitation concerns the weighting coefficients used in the C

Despite these limitations, the model provides an initial audit tool that can be applied with commonly available project documents. Future research may integrate actual cost data, weekly progress, change orders, quality reports, and procurement-delay records. Integration with Earned Value Management can use Category A and high-CPI items as packages for CPI and SPI control. Integration with BIM 5D can connect dominant BoQ items with digital model elements.

The weighting scenarios presented in Table 11 should ne interpreted as an initial conceptual framework rather than fixed parameter values. The proposed weights are intended to demonstrate the flexibility of the CPI model under different project management objectives. They are not derived from statistical optimization but from logical managerial considerations based on concentration, work-zone importance, and Pareto priority. Therefore, the weighting structure should be calibrated in future studies through expert judgement, Delphi surveys, or multi-criteria decision-making techniques such as AHP, ANP, BWM or TOPSIS to improve its robustness and general applicability.

Table 11. Alternative weighting scenarios for CPI development

Scenario	Cost weight	Zone weight	ABC weight	Recommended use
Basic audit	0.50	0.20	0.30	Early cost control using BoQ only.
Cost-dominant	0.60	0.15	0.25	Projects with tight budget ceilings.
Zone-dominant	0.45	0.30	0.25	Projects with strong spatial cost concentration.
ABC-dominant	0.40	0.20	0.40	Projects prioritizing cumulative cost class.
Risk-added	0.40	0.15	0.25	Projects with expert risk scoring and technical uncertainty.

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The alternative weighting scenarios demonstrate the adaptability of the CPI framework to different project enviroments. Rather than prescribing universal weight values, the scenarios illustrate how management priorities may shift according to project characteristics, such as budget sensitivity, spatial concentration or technical uncertainty. Accordingly, the current weighting structure should be regarded as an initial framework for future refiment. Subsequent research is expected to calibrate these weights using structured expert judgement or multi-criteria decision-making methods, thereby enchancing the reliability and transferability of the proposed model across different types of construction projects.

3.6. Sensitivity Analysis of The CPI Weighting Scheme

Because the weighting doefficients in Equation (8) represent an initial conceptual framework, a simple sensitivity analysis was conducted to evaluate whether reasonable changes in weighting would substantially affect the ranking of control priorities. Five weighting scenarios were examined based on the alternative configurations presented in Table 11, namely the Basic Audit scenario (0.50-0.20-0.30), Cost-Dominant (0.60-0.15-0.25), Zone-Dominant (0.45-0.30-0.25), ABC-Dominant (0.40-0.20-0.40) and Risk-Added (0.40-0.15-0.25 plus optional technical risk). The purpose was not to determine the optimal coefficients but to assess the robustness of the proposed framework under different managerial priorities.

Table 12. Sensitivity Analysis of CPI Weighting Scenarios

Scenario	Weight (Cost-Zone-ABC)	Effect on Priority Ranking	Interpretation
Basic audit	0.50-0.20-0.30	Baseline	Reference model
Cost-dominant	0.60-0.15-0.25	Top-priority items unchanged	Projects emphasizing strict budget control
Zone-dominant	0.45-0.30-0.25	Zone-based ranking slightly strengthened	Suitable for projects with strong spatial cost concentration
ABC-dominant	0.40-0.20-0.40	Category A items become more dominant	Appropriate when cumulative cost is the main concern
Risk-added	0.40-0.15-0.25 (+Risk)	High-risk items move upward	Applicable when expert risk assessment is available

The sensitivity analysis indicates that the proposed CPI framework is relatively stable under moderate changes in weighting coefficients. Across all scenarios, the dominant work packages-include AHU isolation, air-conditioning, sanitation and piping, aluminium works, and nurse station components-remained within the highest control-priority group. Variations in weighting primarily influenced the relateve ordering among items with similar cost contrinutions rather than altering the overall set of critical work packages. This suggests that the proposed framework is sufficienlt robust for practical pre-construction decision-making despite the use of an initial conceptual weighting scheme.

The analysis also demonstrates that each weighting scenario reflects a different managerial perpective. Increasing the cost weight emphasizes financially significant work items, whereas increasing the zone weight strengthens the priority of items located within dominant work areas. Similarly, increasing tha ABC weight reinforces cumulative cost concentration as the principal decision criterion. Consequently, the weighting coefficients should be interpreted as adjustable managerial parameters rather than universally fixed values.

Although the sensitivity analysis supports the robustness of the proposed framework, it does not constitute formal optimization of the weighting coefficients. Future studies should calibrate the coefficients using structured expert judgement (Delphi), Analytic Hierarchy Process (AHP), Best-Worst Method (BWM) or other multi-criteria decision-making techniques and validate the frame work using multiple hospital rehabilitation projects.

4. Conclusion

This study demonstrates that the BoQ/RAB can be transformed from a bidding document into a pre-construction cost-audit instrument. In the A-KRIS Building completion project at RSUD Hj. Anna Lasmanah Banjarnegara, the total cost including 11% VAT was IDR 930,571,644 with an area cost index of IDR 606,093/m2. The cost structure was highly concentrated in Teratai Ward (60.18%) and Soka Ward (39.10%), while preparation work contributed only 0.72%. AHU Isolation was the dominant sub-work, contributing 16.65% in Teratai Ward and 8.33% in Soka Ward. Pareto-ABC analysis found that 68 items, or 31.63% of all items, controlled 79.78% of total project cost. The proposed WBS-Pareto-ABC-CPI model provides control priorities based on item cost, zone dominance, ABC category, and optional technical risk. The model helps owners, consultants, and contractors identify critical items that require volume validation, specification review, procurement control, quality assurance, schedule monitoring, and safety supervision. Further research should integrate this model with field realization data, Earned Value Management, BIM 5D, and change-order records to test its accuracy in actual project performance control.

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