Six Decades Later: Modernizing the Happel Factor for Cost Estimation in Oil and Gas Projects[1]

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ABSTRACT

Equipment-factored estimation methods for storage terminal projects were developed decades ago for chemical process plants and have not been updated to reflect current Indonesian construction conditions — leaving a critical gap in Class 4 estimation at the FEL-2 Assess gate. This paper identifies, selects, and updates the most suitable equipment-factored estimation method to fill this gap. A structured Multi-Attribute Decision Making (MADM) analysis — comprising Non-Compensatory and Compensatory models — was applied to four candidate methods, selecting the Happel Factor with an Additive Weighting score of 0.967. The updated factor was derived from level 2 estimate records encompassing more than 15,000 WBS cost elements from completed storage terminal projects (2019–2025), with outlier analysis conducted using IQR and MAD methods simultaneously. A Monte Carlo simulation using a lognormal distribution generated probabilistic contingency provisions at P70, P80, and P90 confidence levels. Back-test results confirm estimates within the AACE Class 4 accuracy range of -30% to +50% at P70 to P90 (+6% to +47%). This paper provides the first published, data-validated equipment-factored estimation framework for Indonesian storage terminal projects.

Keywords: Happel Factor, Cost Estimation, Front-End Loading, Oil and Gas Projects, Capital Cost

INTRODUCTION

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1. The Importance of Cost Estimating

"Cost estimating is the process to produce an 'educated guess' of what a program, project, work package, or activity will cost at some point in the future, while cost budgeting is taking that approved estimate and allocating it over time by cost loading the phased, work packages or activities. Explained another way, cost estimating is the process of generating a monetary value or range of values for management to review and accept." "Upon acceptance, this value or range of values becomes the time-phased budget for

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the program, project, work package, or activity against which progress against the plan is assessed, analyzed, evaluated, the output of which is used by management to make decisions." [2]

"The cost estimation, including both fixed and variable costs, varies at each project design stage—such as concept screening, preliminary study, budget authorization, budget control, and construction—because the quality and quantity of available information differ across these stages of the project life cycle."[3]

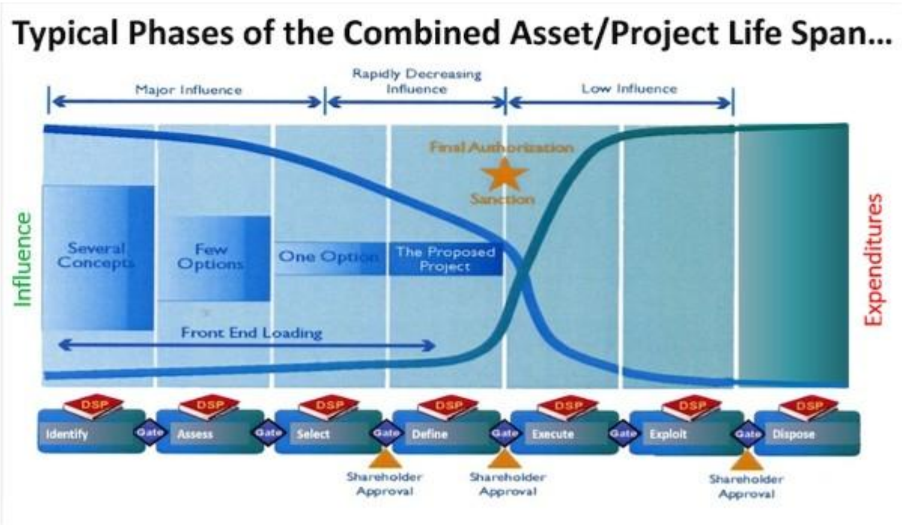

Figure 1 : Typical Phases of the Combined Asset/Project Life Span [4]

Figure 1 illustrates how this progression of project stages maps to the Combined Asset/Project Life Span. During the Front End Loading (FEL) phase — spanning from Identify through Define — the project team holds major influence over project outcomes while expenditures remain low. As the project progresses beyond Final Authorization/Sanction, influence rapidly decreases while expenditures escalate. This underscores the critical importance of producing reliable cost estimates at each FEL gate, before the window of influence closes.

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[2] PTMC, & Giammalvo, P. D. (2021). Unit 10- Managing Cost Estimating and Budgeting. In Project Controls/PMO Handbook of "Best Tested and PROVEN Practices.
[3] Cheali, P., Gernaey, K. V., & Sin, G. (2015, February 6). Uncertainties in early-stage capital cost estimation of process design – A case study on Biorefinery design. Frontiers. https://www.frontiersin.org/journals/energy-research/articles/10.3389/fenrg.2015.00003/full
[4] Giammalvo, P. D. (2021). Project Controls/PMO Handbook of "Best Tested and PROVEN Practices".

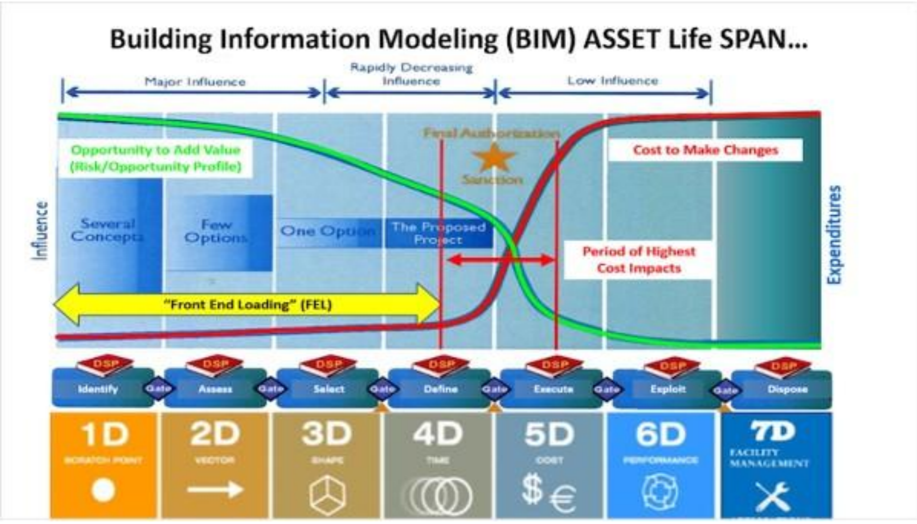


Figure 2 : BIM and Asset Life Span [5]

Figure 2 extends this concept by integrating Building Information Modeling (BIM) into the Asset Life Span framework. BIM maps each phase of the asset life span from 1D (Scratch Point) at Identify, through 5D (Cost) at Execute, to 7D (Facility Management) at Dispose. This means that cost estimates at each FEL gate are not isolated exercises — they are part of a continuously maturing information model, where the quality and completeness of project information at each stage directly determines the appropriate estimation methodology, as discussed in the following section.

2. AACE Class Estimation

AACE has classified cost estimates based on the amount of information, estimation methods, and their usefulness in the project stages as shown in Recommended Practice 18R-97 below:

[5] Ibid

	Primary Characteristic	*Secondary Characteristic*		
ESTIMATE CLASS	**MATURITY LEVEL OF PROJECT DEFINITION DELIVERABLES** Expressed as % of complete definition	**END USAGE** Typical purpose of estimate	**METHODOLOGY** Typical estimating method	**EXPECTED ACCURACY RANGE** Typical variation in low and high ranges [a]
Class 5	0% to 2%	Concept screening	Capacity factored, parametric models, judgment, or analogy	L: -20% to -50% H: +30% to +100%
Class 4	1% to 15%	Study or feasibility	Equipment factored or parametric models	L: -15% to -30% H: +20% to +50%
Class 3	10% to 40%	Budget authorization or control	Semi-detailed unit costs with assembly level line items	L: -10% to -20% H: +10% to +30%
Class 2	30% to 75%	Control or bid/tender	Detailed unit cost with forced detailed take-off	L: -5% to -15% H: +5% to +20%
Class 1	65% to 100%	Check estimate or bid/tender	Detailed unit cost with detailed take-off	L: -3% to -10% H: +3% to +15%

Notes: [a] The state of process technology, availability of applicable reference cost data, and many other risks affect the range markedly. The +/- value represents typical percentage variation of actual costs from the cost estimate after application of contingency (typically at a 50% level of confidence) for given scope.

Table 1 : Process Industries Cost Estimate Classification [6]

Table 1 shows typical accuracy ranges associated with the process industries. The actual accuracy for a given estimate depends on technical and project deliverables, other variables, and associated risks. While estimates generally fall within these ranges, extreme risks can cause the accuracy to be broader.[7]

Class 4 estimates are based on limited information, with wide accuracy ranges. They are used for project screening, feasibility, and preliminary budgets. Typically, engineering is 1%-15% complete and includes plant capacity, block schematics, layout, process flow diagrams, and preliminary equipment lists. They often use stochastic estimating methods like equipment factors, Lang factors, Hand factors, and other parametric techniques.[8]

[6] AACE. (2011). Cost estimate classification system - As applied in engineering, procurement, and construction for the process industries (p. 2).
[7] AACE. (2011). Cost estimate classification system - As applied in engineering, procurement, and construction for the process industries (p. 3).
[8] AACE. (2011). Cost estimate classification system - As applied in engineering, procurement, and construction for the process industries (p. 6).

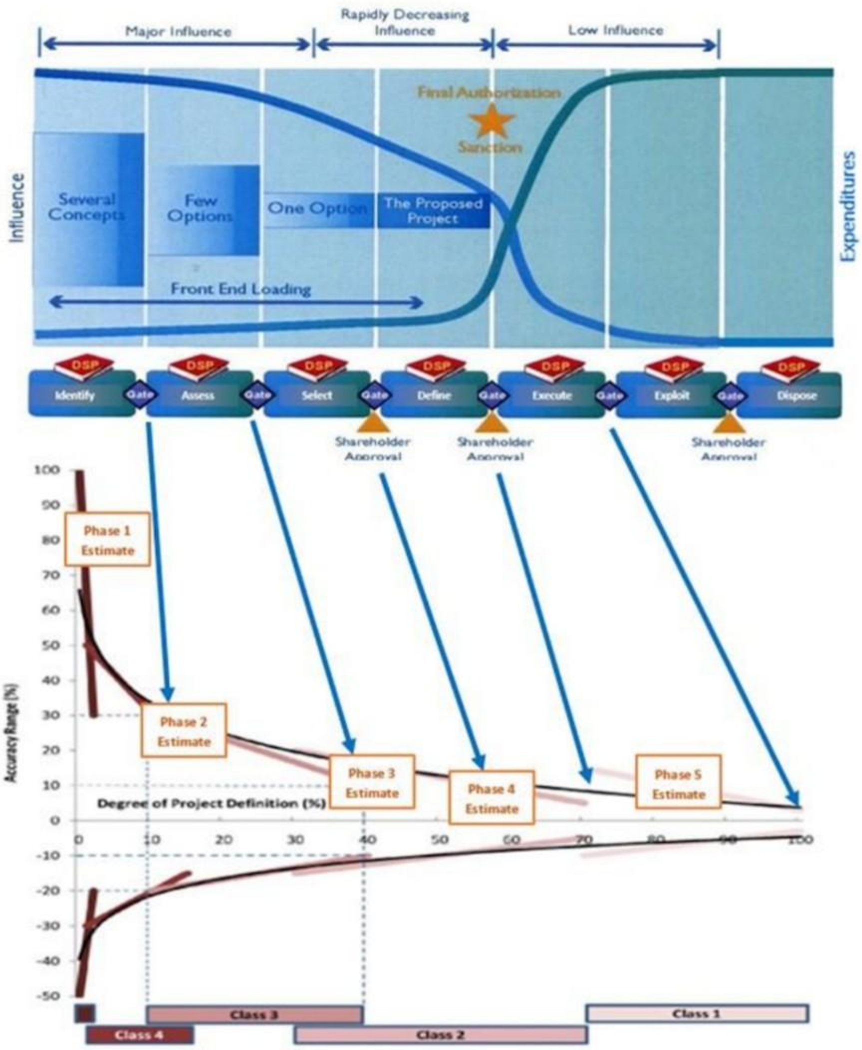


Figure 3 : Asset Life Span & Variability in Accuracy/Uncertainty Ranges [9]

[9] Zain, R. A. (2024). Developing Parametric Modelling for Class 4 Estimate of Pier and Jetty Construction by Analyzing Historical Databases using AI Tools & EVM Techniques. PM World Journal, 8(4).

In accordance with to Figure 3, "it can be observed that there is a relationship between the magnitude of Influence and Expenditures throughout the overall Asset Life Span. During Phase 1 to Phase 4 (Front End Loading), the level of influence tends to decrease until the Proposed Project is reached. Referring to AACE Class 4, the typical purpose of the obtained estimates is for a study or feasibility study."[10]

3. Project Cost Estimation Challenge

To satisfy customer needs, the company continues to expand by building new facilities. Therefore, to maximize asset benefits, it must first manage projects as effectively as possible, because studies from A.T. Kearney[11] "show that 60% of participants' capital projects experience over 10% cost overruns, and nearly a third have over 25% cost overruns."

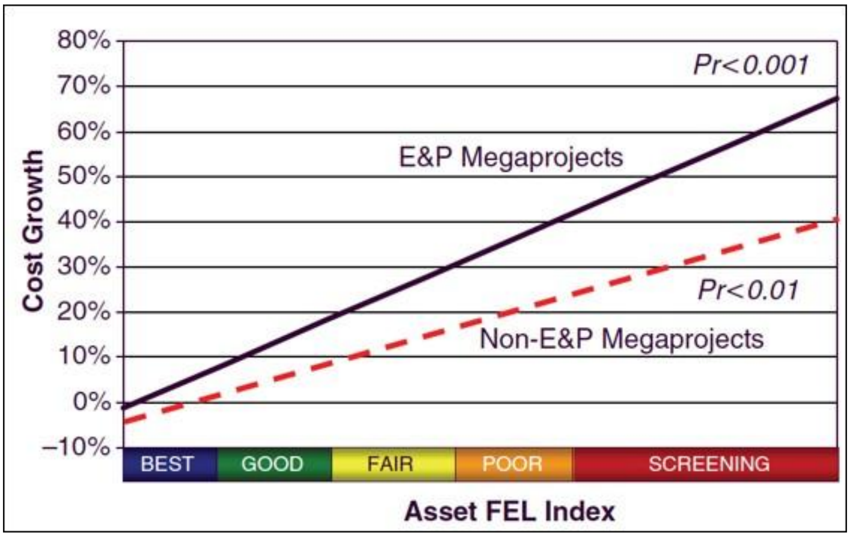


Figure 4 : The Effect of FEL on Cost Growth[12]

"Oil and gas project results highly depend on thorough front-end work. As Front End Loading levels decrease, megaproject cost overruns escalate rapidly".[13]

https://pmworldlibrary.net/wp-content/uploads/2024/04/pmwj140-Apr2024-Zain-Parametric-Modelling-for-Class-4-Estimate-of-Pier-and-Jetty-Construction.pdf
[10] Ibid.
[11] AT Kearney. (2017). Excellence in Capital Projects: A Goal Yet to be Achieved
[12] Merrow, E. W. (2012). Oil and gas industry Megaprojects: Our recent track record. Oil and Gas Facilities, 1(02), 38-42. https://doi.org/10.2118/153695-pa
[13] Ibid.

"Front-end loading (FEL) is the early planning work, or definition, of a capital project. It is the core work process by which a project team translates the business case into a scope of work, and then from a completed scope of work into a project that is ready to execute and deliver on the business objectives."[14]

FEL consists of three phases[15]:

FEL – 1: Opportunity Identification and Assessment

FEL – 2: Scope Development and Conceptual Engineering

FEL – 3: Execution Planning and Basic Engineering

Most companies require an accurate cost estimate to meet and pass the FEL gate system. The system illustrates that these requirements generally follow the AACE International classifications, with some variations to the specific practices and related accuracy classifications required by each company or business unit.[16]

Phase	FEL 1	FEL 2	FEL 3
Objective	Business Planning	Scoping Facility Planning	Project Planning
Key Activities	Identify & Assess the Business Opportunity	Review Project Concepts & Select Preferred Scope	Define Project Scope & Complete Basic Design Package & Execution Plans
AACE International Estimate Class	Class 5 L: -25% to -50% H: +30% to +100%	Class 4 L: -15% to -30% H: +20% to +50%	Class 3 L: -10% to -20% H: +10% to +30%

Table 2 : Typical FEL Phase and AACE International Estimate Class [17]

Given the significance of a Class 4 Estimation methodology in helping the Company evaluate the feasibility study in FEL 2, a precise, accurate, valid, and reliable Class 4 estimate method is required.

Additionally, to support the company's long-term standardization objectives, the selected method must be compatible with a structured Work Breakdown Structure (WBS) aligned

[14] Griffith, A. (2026, February 19). What is front-end loading (FEL) in project management? Independent Project Analysis (IPA). https://www.ipaglobal.com/news/article/what-is-front-end-loading-fel-in-project-management/
[15] The H+M Industrial Team. (2026, March 5). FEL deliverables for capital project success. EPC Industrial Services | H+M Industrial EPC. https://www.hm-ec.com/blog-posts/fel-deliverables-for-capital-project-success-hm
[16] Asmoro, T. H. (2014). Facing Project Cost Exposure during Front End Loading (FEL) Implementation. PM World Journal, 3(9). https://pmworldlibrary.net/wp-content/uploads/2014/09/pmwj26-sep2014-asmoro-facing-cost-exposure-during-FEL-implementation-FeaturedPaper.pdf
[17] Ogilvie, A., Brown Jr, Robert A., Biery, Frederick P., Barshop, Paul (2012). Quantifying Estimate Accuracy and precision for the process industries: a review of industry data. Cost Engineering Journal November/December 2012 (pp. 28-38). AACE International, WV, USA

with OmniClass coding, and integration with Building Information Modeling (BIM) applications throughout the asset life span.

Over the decades, significant changes in equipment production, fabrication technology, construction methods, and regulations have rendered many of the existing equipment-factored estimation factors non-representative of current construction conditions — particularly in the context of Indonesian storage terminal projects. An update grounded in actual project data is therefore needed to produce estimates that are both accurate and aligned with current industry practice.

The aim of this paper is to address the following questions:

1. What is the difference between the original equipment factored estimation method and its updated version for the Indonesian storage terminal project?
2. Does the updated factor tend to overestimate or underestimate project costs relative to higher-level estimates?
3. How can the updated factor be structured as a practical and systematic Class 4 estimation tool?

METHODOLOGY

Step 1 - Problem Definition

As established in the Introduction, no validated Class 4 equipment-factored estimation tool currently exists for Indonesian storage terminal projects. The following conditions specifically define the gap that this paper addresses:

- The factors available were identified as early as 1958, before major advances in fabrication technology, construction methods, and project delivery systems.
- "The fuel distribution in Indonesia, with its more than 17,000 islands, relies heavily on tanker transportation as its primary mode of transportation. Consequently, facilities such as jetties play a significant role in the supply and distribution chain, where the continual improvement and construction of jetties are undertaken to enhance the reliability of the supply across Indonesia."[18]
- The material and labor cost structure of Indonesian storage terminal construction differs from the general process industry baseline reflected in the original factors.

To address the conditions above, this study identifies and selects the most suitable equipment-factored estimation method for updating, calibrates it against actual Indonesian storage terminal project data, and evaluates its accuracy as a practical Class

[18] Zain, R. A. (2024). Developing Parametric Modelling for Class 4 Estimate of Pier and Jetty Construction by Analyzing Historical Databases using AI Tools & EVM Techniques. PM World Journal, 8(4). https://pmworldlibrary.net/wp-content/uploads/2024/04/pmwj140-Apr2024-Zain-Parametric-Modelling-for-Class-4-Estimate-of-Pier-and-Jetty-Construction.pdf

4 estimation tool — directly addressing the three research questions introduced in the Introduction.

Step 2 - Identify The Feasible Alternative

Four AACE-recognized Equipment-Factored Estimation methods were identified as candidates for updating and calibration, as summarized in Table 5 below.

Alternative	Method	Last Updated
A1	Updated Lang Factor[19]	Wain, 2014
A2	Hand Factor	AACE International, 1992
A3	Wroth Factor	Original, 1960
A4	Happel Factor	Original, 1958

Table 3 : Feasible Alternatives — Equipment Factored Estimation Methods

2.1 Updated Lang Factor

Since the Original Lang Factor originates from 1947 and costs have changed over time, the author seeks to include more recent factors that mirror current trends. This involves considering the Total Installed Cost (TIC) using Yosep Asro Wain's 2014 Lang Factor Method, as shown in Table 6.

Description	Solid	Solid - Fluid	Fluid
Original Lang Factor[11]	3.10	3.63	4.74
Peters & Timmerhaus[12]	3.90	4.10	4.80
AACE International RP 59R-10[13]	3.89	5.04	6.21
Perry's Chem. Eng. H.B.[14]	3.80	4.10	4.80
Dysert L.R.[15]	-	-	5.10
Wolf T.E.[16]	-	-	5.12
Wain, YA[17]	-	-	3.28 ± 1.123

Table 4 : Lang Factor developed by Wain [20]

2.2 Hand Factor

Rather than using single multipliers like the Lang factors, Hand proposed using a sum of individual factors multiplied by the delivered cost of different equipment types. The Hand factors were updated by the AACE International Cost Estimating Committee in 1992.

[19] Wain, Y. A. (2014). Updating the Lang Factor and Testing its Accuracy, Reliability and Precision as a Stochastic Cost Estimating Method. *PM World Journal*, *3*(10).
[20] Ibid.

Equipment	Factor
Fractionating Column Shells	4.0
Fractionating Column Trays	2.5
Pressure Vessels	3.5
Heat Exchangers	3.5
Fired Heaters	2.5
Pumps	4.0
Compressors	3.0
Instrument	3.5
Misc.	2.5

Table 5 : Updated Hand Factor [21]

2.3 Wroth Factor

The publication by Wroth in 1960 includes only a single page with Table 6. It features installation factors similar to those in Hand, using the same equation.

Equipment	Factor F	Equipment	Factor F
Blender	2	Electric motor	8.5
Blower or fan*	2.5	Centrifugal pump (motor)	7
Centrifuge	2	Centrifugal pump (turbine)*	6.5
Centrifugal compressor (motor)	2	Positive displacement pump	5
Centrifugal compressor (turbine)*	2	Reactor	x
Reciprocating compressor (steam/gas)	2.3	Refrigeration	2.5
Reciprocating compressor (motor)	2.3	Process tank	4.1
Ejector	2.5	Storage tank	3.5
Furnace	2	Field erected tank	2
Instrument	4.1	Tower columns	4

Table 6 : Wroth Factor [22]

2.4 Happel Factor

Happel first published the factor in 1958 as Equipment Cost Schedule – Process Unit, as shown in Table 8

[21] Humphreys, K. K. (2004). Project and cost engineers' handbook. CRC Press.
[22] Van Amsterdam, M. F. (2018). Factorial Techniques applied in Chemical Plant Cost Estimation: A Comparative Study based on Literature and Cases [Master's thesis]

Item	Material Cost	Labor Cost
Vessels	A	10% of A
Towers, field fabricated	B	30 to 35% of B
Towers, prefabricated	C	10 to 15% of C
Exchangers	D	10% of D
Pumps, compressors and other machinery	E	10% of E
Instruments	F	10 to 15% of F
Key Accounts G = Sum of (A to F)	**G = A + B + C + D + E + F**	—
Insulation	H = 5 to 10% of G	150% of H
Piping	I = 40 to 50% of G	100% of I
Foundations	J = 3 to 5% of G	150% of J
Buildings	K = 4% of G	70% of K
Structures	L = 4% of G	20% of L
Fireproofing	M = ½ to 1% of G	500 to 800% of M
Electrical	N = 3 to 6% of G	150% of N
Painting and cleanup	O = ½ to 1% of G	500 to 800% of O
COST SUMMARY		
Sum of Material and Labor	**P**	—
Overheads	30% of P	—
Total Erected Cost	**130% of P**	—
Engineering Fee (10% of erected cost)	13% of P	—
Contingency (10% of erected cost)	13% of P	—
TOTAL INVESTMENT	**156% of P**	—

Table 7 : Happel Factor [23]

"Material listing in the second column refers to delivered cost to the plant site, ready for erection. The labor items in the adjoining column are the direct labor involved in erecting each of the items noted. Naturally, the percentage indicated should be replaced by actual estimates when these are available."[24]

Step 3 - Development of The Feasible Alternative

A two-stage MADM (Non-Compensatory and Compensatory) analysis was conducted by first defining the criterion. Three evaluation criteria were defined based on structural characteristics relevant to the updating objective and the company's OmniClass-based WBS/CBS standardization initiative:

[23] Happel, J. (1958). Chemical process economics (1st ed.). John Wiley & Sons.
[24] Ibid

Criteria	Description	Direction
C2 (1st)	Equipment Coverage for Fuel Terminal	MAX
C3 (2nd)	Per-Item Cost Breakdown & WBS/CBS Compatibility	MAX
C1 (3rd)	Equipment-Type Differentiation (number of equipment categories)	MAX

Table 8 : Evaluation Criteria and ROC Weights (derived from Lexicographic priority: C2 → C3 → C1) [25]

ID	Method	C1 Equipment-Type Differentiation (0/1 — MAX)	C2 Equipment Coverage for Fuel Terminal (0–2 — MAX)	C3 Per-Item Breakdown & WBS/CBS Compat. (0–2 — MAX)	Scoring Notes
A1	**Lang Factor (Wain, 2014 update)**	0	0	0	*C1=0: plant-type multipliers only (solid/mixed/fluid) C2=0: no equipment differentiation C3=0: global multiplier, cannot map to OmniClass WBS*
A2	**Hand Factor (AACE Int'l, 1992 upd.)**	1	1	1	*C1=1: 9 equipment types C2=1: moderate — general chemical plant basis C3=1: per equipment type*
A3	**Wroth Factor (original, 1960)**	1	2	1	*C1=1: 20 equipment types — highest granularity C2=2: comprehensive fuel terminal coverage C3=1: per equipment type, no subdivision*
A4	**Happel Factor (original, 1975)**	1	2	2	*C1=1: 14 equipment types, per-item basis C2=2: comprehensive incl. non-key items C3=2: per item + component; strongest WBS alignment*

Table 9 : Decision Matrix: Raw Performance Data [26]

[25] Kullit, R. A. (2026, March 30). W5.0_RAK_Selecting the most suitable equipment-factored estimating method for updating using multi attribute decision making (MADM) compensatory models. 14 Clovers. https://14cloversaace.wordpress.com/2026/03/30/w5-0_rak_selecting-the-most-suitable-equipment-factored-estimating-method-for-updating-using-multi-attribute-decision-making-madm-compensatory-models/
[26] By author

Step 4 - Selection of The Criteria

4.1 Non-Compensatory Model

MADM Model	A1 Lang	A2 Hand	A3 Wroth	A4 Happel	Key Finding
Dominance	ELIMINATED	ELIMINATED	ELIMINATED	No elim.	A1 & A2 & A3 eliminated — all dominated by A4 on all criteria.
Satisficing	ELIMINATED	Retained	Retained	Retained	A1 fails all three thresholds (C1=0, C2=0, C3=0). A2, A3, A4 pass all thresholds.
Disjunctive Resolution	ELIMINATED	Retained	Retained	Retained	A1 meets no threshold. A2, A3, A4 each qualify on all criteria. Models evaluated independently.
Lexicographic	Elim. Dominance	Elim. Step 1 (C2)	Elim. Step 2 (C3)	WINNER ★	Only A3 vs A4 compete. A4 wins on C3 (score 2 vs 1). Decisive — no further steps needed.

Table 10 : Consolidated MADM Non-Compensatory Results Summary [27]

A4 (Happel Factor) is the preferred method, with consistent results across four models, and dominates all three other alternatives in the Dominance analysis, which is explained by its structure: it uniquely scores maximum on all three criteria (C1=1, C2=2, C3=2).

4.2 Compensatory Model

Model	Blog	Type	A1 Lang	A2 Hand	A3 Wroth	A4 Happel
Dominance	W4	Non-Comp.	Elim.	Elim.	Elim.	**WINNER**
Satisficing	W4	Non-Comp.	Elim.	Retained	Retained	**Retained**
Disjunctive	W4	Non-Comp.	Elim.	Retained	Retained	**Retained**
Lexicographic	W4	Non-Comp.	4th	3rd	2nd	**WINNER**
Non-Dim. Scaling	**W5**	**Compensatory**	4th (0.150)	3rd (1.450)	2nd (2.500)	**1st (2.700)**
Additive Weighting	**W5**	**Compensatory**	4th (0.017)	3rd (0.495)	2nd (0.861)	**1st (0.967)**

Table 11 : Consolidated Results: Non-Compensatory and Compensatory Models [28]

[27] Kullit, R. A. (2026, March 22). W4.0_RAK_Selecting the most suitable equipment factored estimation using non-compensatory multi-attribute decision making (MADM). 14 Clovers. https://14cloversaace.wordpress.com/2026/03/22/w4-0_rak_selecting-the-most-suitable-equipment-factored-estimation-using-non-compensatory-multi-attribute-decision-making-madm/
[28] Kullit, R. A. (2026, March 30). W5.0_RAK_Selecting the most suitable equipment-factored estimating method for updating using multi attribute decision making (MADM) compensatory models. 14 Clovers. https://14cloversaace.wordpress.com/2026/03/30/w5-0_rak_selecting-the-most-suitable-equipment-

The consistency across different analytical frameworks — screening models that eliminate (Non-Compensatory) versus scoring models that trade off (Compensatory) — signals a robust selection not dependent on any one method. Therefore, the equipment factored method selected for updating is the Happel Factor.

The MADM criteria in this analysis were explicitly designed around the company's OmniClass WBS/CBS standardization and per-item recalibration objectives. A different objective set would produce a different MADM result.

FINDING

Step 5 - Analysis of Alternative

Following the selection of the Happel Factor as the preferred method in Step 4, the updating process was applied to the analytical dataset comprising level 2 estimate records from storage terminal projects (2019–2025), containing more than 15,000 WBS cost elements. For each project, every WBS cost element was mapped to its corresponding Happel category per the framework established in Table 6, and the actual cost ratios were computed. After outlier removal using the IQR and MAD methods simultaneously, the updated factor ranges were derived and are presented in Table 12. The updated factor is structured in three tiers: Key Accounts (A–E), which represent the INPUT material costs to be obtained from the preliminary equipment list and are not factored; Bulk Items (G–K), which are factored as a percentage of F (Sum of Key Accounts); and Indirect Costs (M–P), which are factored as a percentage of L (Sum of Material and Labor).

factored-estimating-method-for-updating-using-multi-attribute-decision-making-madm-compensatory-models/

Item	Index	Material		Labor	
		Min	Max	Min	Max
Vessels	A			135% to	182% of A
Towers, Field Fabricated	B			0.05% to	2% of B
Pumps, Compressor, and other mac	C			0.4% to	0.7% of C
Instrument	D			1% to	14% of D
Jetty	E			19% to	40% of E
Sum of Key Accounts	F (sum of A to E)				
Piping	G	22% to	57% of K	5% to	13% of G
Foundation, Building, & Structure	H	24% to	58% of K	38% to	49% of H
Electrical	I	14% to	37% of K	6% to	7% of I
Painting and Cleanup	J	2% to	3% of K	125% to	136% of J
Fire protection	K	3% to	6% of K	2% to	5% of K
Sum of material & Labor	L				
Barge	M			0.7% to	1% of V
Testing	N			1% to	2% of V
Overheads	O			1% to	6% of V
Engineering Fee	P			1.8% to	2% of V
Installed Special Equipment	Q				
Total Erected Cost	R				
Management Reserve	S				10% of R
Total Investment Cost	T = R + S				

Table 12 : Modified Happel Factor [29]

Several findings from Table 12 merit specific discussion:

1. Jetty (E) is introduced as a new Key Account category absent from the original Happel framework, reflecting the geographical reality of Indonesian storage terminal construction, where marine structures are integral to the facility scope.

2. Variance between the original and modified Happel exhibits a wider range, reflecting variation in terminal configuration between projects.

3. The bulk material and indirect cost categories are similarly adapted:

   - Insulation and Fireproofing are excluded as non-applicable to the terminal typology studied, because of the ambient and fluid conditions being handled and the fire protection design using active fire protection.

   - Structure, Building, and Foundation are combined into a single element in Class 4 (FEL-2), with the available information level only reaching 1–15%

[29] By author

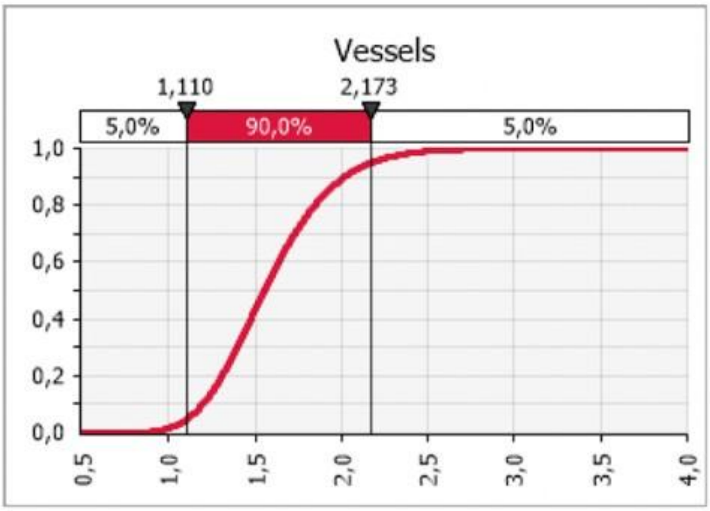
engineering completeness — at this stage, there is no detailed civil/structural design, no soil investigation results, and no architectural drawings.
- Fire Protection, Barge, and Testing & Commissioning are introduced as new categories reflecting regulatory requirements and island-based construction logistics.

4. Engineering Fee (1.8–2% of L) is substantially lower than Happel's original 10% of Total Erected Cost. This difference stems from a fundamental definitional distinction: in the original Happel framework, the engineering fee represents an allowance for profit or fee to the engineering contractor, whereas in Indonesian storage terminal projects within the company, Detailed Engineering Design (DED) is contracted as part of the construction scope and is therefore captured within the project cost structure rather than as a separate overhead allowance.

5. This paper departs from Happel's fixed 10% contingency by introducing two distinct provisions aligned with best practice. AACE distinguishes between Contingency — An amount included in an estimate to cover items, conditions, or events with uncertain occurrence, which history indicates will generally lead to additional costs. Management Reserve - An amount added to an estimate for discretionary management purposes outside the project's defined scope, as specified in the estimate.[30]

In this paper, a Monte Carlo simulation using a lognormal distribution was applied to each factor category to generate probabilistic estimates at the P70, P80, and P90 confidence levels for management to select, as presented in Table 13. “It is essential to avoid the impact of stopping using a bell or normal distribution. Start using log-normal or "skewed right" distribution as the "worst-case" scenario is almost always way worse than we think it possibly could be.”[31]

[30] AACE. (2026). RP No. 10S-90 Cost Engineering Terminology
[31] PTMC, & Giammalvo, P. D. (2021). 1.4.1.10 unit 10 – Managing Cost Estimating & Budgeting. Retrieved from https://build-project-management-competency.com/1-4-1-10-unit-10/ .



Percentiles	
Percentile	Value
1%	0,9661
2,5%	1,0406
5%	1,1098
10%	1,1953
20%	1,3079
25%	1,3532
50%	1,5528
75%	1,7819
80%	1,8442
90%	2,0176
95%	2,1726
97,5%	2,3173
99%	2,4975

Figure 5 : Cumulative Density Function for Vessel Factor obtained from Monte Carlo Simulation [32]

[32] By author

Item	Index	Material			Labor		
		P70	P80	P90	P70	P80	P90
Vessels	A				173%	184%	202% of A
Towers, Field Fabricated	B				1.2%	1.6%	3% of B
Pumps, Compressor, and other mac	C				0.6%	0.7%	1% of C
Instrument	D				8%	10%	16% of D
Jetty	E				34%	40%	49% of E
Sum of Key Accounts	F (sum of A to E)						
Piping	G	45%	54%	70% of K	11%	13%	16% of G
Foundation, Building, & Structure	H	47%	56%	71% of K	47%	50%	54% of H
Electrical	I	29%	35%	45% of K	6.5%	6.7%	7% of I
Painting and Cleanup	J	2.7%	3%	3.3% of K	135%	137%	141% of J
Fire protection	K	5%	6%	7% of K	4%	5%	6% of K
Sum of material & Labor	L						
Barge	M				0.9%	1.0%	1.1% of V
Testing	N				1.3%	1.5%	2.0% of V
Overheads	O				4%	5%	7% of V
Engineering Fee	P				2.1%	2.3%	2.4% of V
Installed Special Equipment	Q						
Total Erected Cost	R						
Management Reserve	S						10% of R
Total Investment Cost	T = R + S						

Table 13 : Happel Factor after Monte Carlo Simulation [33]

Step 6 - Selection of the Preferred Alternative

The updated factor was validated through a back-test applied across three projects from the dataset, comparing the Class 4 estimate produced using the updated Happel Factor against the corresponding Class 2 estimate of the same project. Results are presented in Table 14.

% versus Class 2 Estimate		
P70	P80	P90
+6%	+21%	+47%

Table 14 : Results from Happel Factor vs Class 2 Estimate [34]

Across P70 – P90 confidence level, the updated factor produces estimates varies at +6% to 47% relative to the Class 2 estimate, well within the AACE Class 4 accuracy range of

[33] By author
[34] By author

-30% to +50%.[35] This is consistent with the nature of a high-confidence probabilistic provision: a P90 estimate carries a larger contingency, significantly reducing the probability of cost overrun during bid and construction phases. "While no specific confidence level is considered a best practice, experts agree that program cost estimates should be budgeted to at least the 50 percent confidence level, but budgeting to higher level (for example, 70% to 80%, or the mean) is now common practice."[36]

Step 7 - Performance Monitoring

The updated Happel Factor presented in this paper represents an initial calibration based on available project data from 2019–2025. To ensure its continued validity as the company's project portfolio grows, the following performance monitoring framework is recommended.

The accuracy of each Class 4 estimate produced using the updated factor should be tracked at three progressive stages: against the Class 3 estimate at FEL-2 gate approval, against the Class 2 estimate at the bidding stage, and against actual construction costs at project completion. Systematic over- or underestimation observed at any stage should be documented and used to inform the next recalibration cycle.

CONCLUSION

This research aims to find answers to the questions listed below:

1. **What is the difference between the original equipment factored estimation method and its updated version for Indonesian storage terminal project?**
   Tables 12 and 14 highlight the key differences between the original and revised estimation methods. Key changes include adding Jetty to Key Accounts as a marine category, and new cost categories for Fire Protection, Barge, and Testing & Commissioning. The fixed 10% contingency is replaced by a Monte Carlo probabilistic range at P70, P80, and P90 levels, with a separate Management Reserve per company governance.

2. **Does the updated factor tend to overestimate or underestimate project costs relative to higher-level estimates?**

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[35] AACE. (2011). Cost estimate classification system - As applied in engineering, procurement, and construction for the process industries (p. 2)
[36] The United States. Government Accountability Office. (2009). GAO Cost Estimating and Assessment Guide: Best Practices for Developing and Managing Capital Program Costs. Washington, DC.

Back-test results across projects confirm that for P70 to P90, the updated factor produces estimates within the AACE Class 4 accuracy range of -30% to +50% relative to the corresponding Class 2 estimate, ranging from +6% to +47%. Consistent with the nature of a high-confidence provision designed to minimize the probability of cost overrun rather than optimize estimate precision.

3. **How can the updated factor be structured as a practical and systematic Class 4 estimation tool?**
   The updated factor can be applied as a practical Class 4 estimation tool at the FEL-2 gate by: (1) extracting Key Account material costs from the preliminary equipment list; (2) applying the updated factor ranges to derive all bulk and indirect costs; and (3) selecting the appropriate Monte Carlo confidence level based on the organization's risk tolerance to determine the final Total Investment Cost.

This paper provides the first published, data-validated equipment-factored estimation framework specifically developed for Indonesian storage terminal projects — filling a critical gap in the FEL-2 estimation toolkit and enabling company to evaluate competing project concepts with greater confidence, consistency, and traceability across its capital investment portfolio.

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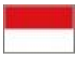

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