Development of an Integrated Cost and Schedule Estimation Framework for ASME B31.3 Pipeline Projects [1,2]

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ABSTRACT

This paper develops a probabilistic–parametric rule of thumb model to support CAPEX Class 4 (feasibility) estimates for ASME B31.3 product pipelines (BBM, non-internal coating) in a national Indonesian oil and gas company. Historically, estimates were based on deterministic spreadsheets and single-point values, increasing the risk of cost overruns and schedule delays. The methodology standardizes WBS/CBS structures, builds a scalable historical database from 50 downstream pipeline projects (normalized to 100 m segments and expressed in ounces of gold at a P80 gold-price index), and derives empirical cost and time distributions. Four functional forms (linear, power, logarithmic, exponential) are calibrated using regression and evaluated using R^2, MSE, and ANOVA. The power model provides the best fit and is adopted to estimate cost and duration as functions of diameter, location, and year of construction. The resulting model accelerates feasibility studies while remaining consistent with AACE Class 4 accuracy expectations.

Keywords: Parametric Model, ASME B31.3, Pipeline, Cost Estimate, Forecasting Growth using Gold Price, National Oil Company, Capex Class 4.

INTRODUCTION

Oil and gas are the most used energy sources worldwide, accounting for 36.4% of primary energy consumption and 94.5% of global energy used for transportation. Maggio and Cacciola argue that world oil production can be modeled with ”a variant of the Hubbert curve” [3] to project long-term supply trends.

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[2] This paper was originally prepared during a 6-month-long Graduate-Level Competency Development/Capacity Building Program developed by PT Mitrata Citragraha and led by Dr. Paul D. Giammalvo to prepare candidates for AACE CCP or other Certifications. https://build-project-management-competency.com/our-faqs/

[3] Maggio, G., & Cacciola, G. (2009). A variant of the Hubbert curve for world oil production forecasts. Energy Policy, 37(11), 4761-4770. https://doi.org/10.1016/j.enpol.2009.06.053

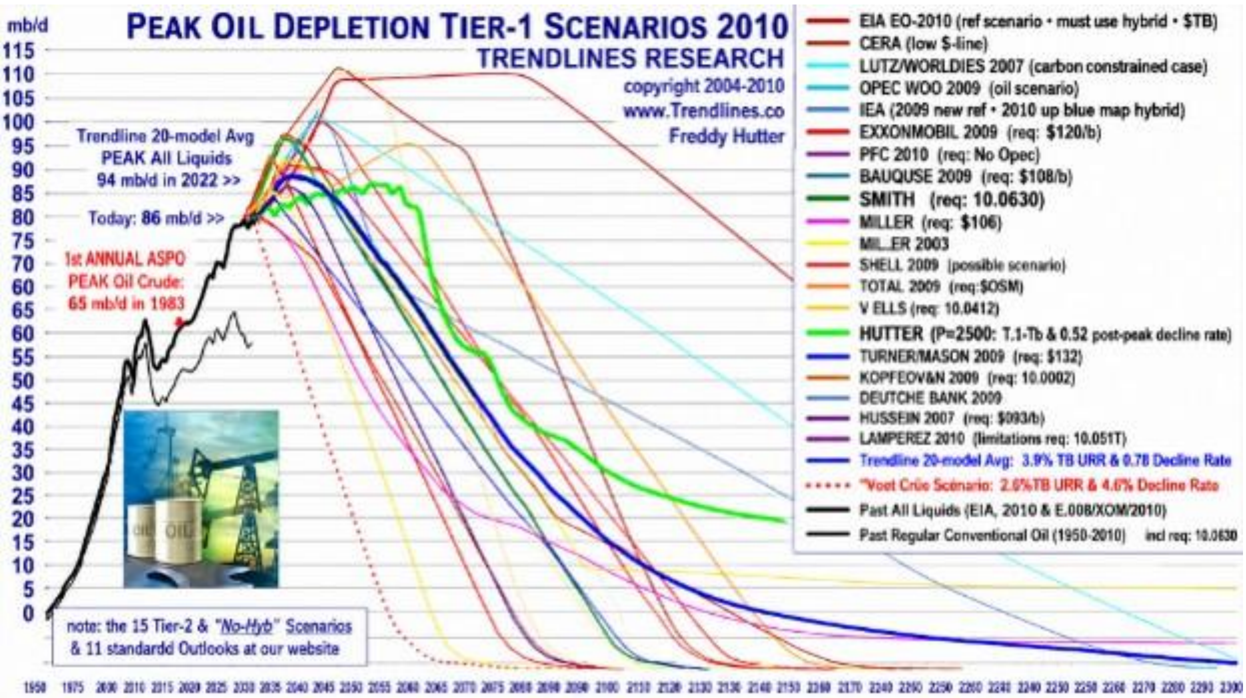

Figure 1: History of Oil Production[4]

For the oil and gas industry, sustainable production means cutting costs and streamlining operations to keep energy supply at these levels. “The company is the nation’s largest contributor to the state budget through taxes, dividends, non-tax state revenue (PNBP) and signature bonuses”,[5] Purwati says. It has contributed IDR 104.87 billion through the end of October 2023, underscoring the importance of accurate cost estimation and efficient operations as production scales up.

Atkinson explains that project success is inextricably linked to the “iron triangle of cost, schedule, and quality/scope”[6]. This implies that effective project management in oil and gas cannot be separated from cost and schedule performance. Table 1, which summarizes international project cost and time performance, shows that many projects still suffer from overruns and delays.

[4] Hutter, F. (2010). Peak Oil Depletion Tier-1 Scenarios 2010. http://www.trendlines.ca

[5] Purwanti, T. (2023, December 11). Berikut Kontribusi 66 Tahun Pertamina untuk Indonesia. CNBC Indonesia.

[6] Atkinson, R. (1999). Project management: Cost, time, and quality, two best guesses and a phenomenon, it’s time to accept other success criteria. International Journal of Project

ID project cost and time performance.

Country	Planned duration (months)	Actual duration (months)	Time variation* (%)	Planned cost (US$ million)	Actual cost (US$ million)	Cost variation** (%)
Bangladesh	59.91	80.53	34.41	126.55	115.86	8.44
China	59.40	67.50	13.63	486.67	460.33	5.41
India	51.03	79.45	55.69	418.29	308.92	26.14
Thailand	46.03	61.09	32.71	305.84	229.53	24.95
Average	54.09	72.14	33.37	334.34	278.66	14.55

* Variation is negative compared to planned duration.
** Variation is positive compared to planned cost.

Table 1 Project Cost and Time Performance[7]

Ahsan and Gunawan state that “the larger the size of the project, the more likely it is to experience cost overrun” and that remote locations are more prone to higher costs and delays[8]. Chandragiri et al. further highlight that variation in price according to the project schedule “also contributes to experiencing cost overrun” [9]. Thus, the project size, project location, and time-dependent price dynamics are key drivers of cost and schedule deviations.

Furthermore, the cost estimation process often results in cost overruns. “Traditionally, cost estimation has been conducted using single-point estimates” [10], Stamelos says. In the current method, the Indonesian Oil & Gas Company uses Monte Carlo simulation to produce probabilistic cost estimation by the Indonesian Oil & Gas Company. It produces the full distribution of possible outcomes (e.g. P50, P80) rather than a single deterministic value. This approach captures variability in the underlying data more effectively, reduces overconfidence, and improves the robustness of decisions in dynamic environments.

According to AACE International’s Estimate Classification System, Class 4 (Feasibility Study) estimates “are generally prepared with approximately 1–15% project definition and carry an expected accuracy range of about –15% to –30% and +20% to +50%” [11], depending on project complexity and risk conditions.

[7] Doloi, H. (2013). Cost Overruns and Failure in Project Management: Understanding the Roles of Key Stakeholders in Construction Projects. Journal of Construction Engineering and Management.
[8] Ahsan, K., & Gunawan, I. (2010). Analysis of cost and schedule performance of international development projects. International Journal of Project Management, 28(1), 68-78. https://doi.org/10.1016/j.ijproman.2009.03.005
[9] Chandragiri, A. B., Hamim Jeelani, S., Akthar, S., & Lingeshwaran, N. (2021). A study and identification of the time and cost overrun in the construction project. Materials Today: Proceedings, 47, 5426-5431. https://doi.org/10.1016/j.matpr.2021.06.268
[10] Stamelos, I., & Angelis, L. (2001). Managing uncertainty in project portfolio cost estimation. *Information and Software Technology*, *43*(13), 759-768. https://doi.org/10.1016/s0950-5849(01)00183-5
[11] AACE International Recommended Practice No. 18R-97"“Cost Estimate Classification System – As Applied in Engineering, Procurement, and Construction for The Process Industries” (August 7, 2020)

	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 at an 80% confidence interval
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%

Table 2 Class Estimate Classification Matrix for Process Industries[12]

Kwak and Watson note that "conceptual estimating tools based on parametric techniques can assist organizations in capturing both risks and opportunities more consistently during early project stages"[13]. In this context, parametric models become crucial not only for cost control but also for investment decisions and risk-informed feasibility studies. This paper focuses on ASME B31.3 pipelines in the downstream sector of the Indonesian Oil & Gas Company, where the main activities are receipt, storage, and distribution using product pipelines.

Mittas and Mitropoulos show that a data-driven probabilistic framework "can significantly improve cost management for natural gas pipeline projects by using historical data and statistical models"[14]. This supports the focus on building a probabilistic–parametric model specifically for downstream product pipelines.

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[12] AACE International Recommended Practice No. 18R-97""Cost Estimate Classification System – As Applied in Engineering, Procurement, and Construction for The Process Industries" (August 7, 2020)

[13] Kwak, Y. H., & Watson, R. J. (2005). Conceptual estimating tool for technology-driven projects: Exploring parametric estimating technique. *Technovation*, *25*(12), 1430-1436. https://doi.org/10.1016/j.technovation.2004.10.007

[14] Mittas, N., & Mitropoulos, A. (2022). A data-driven framework for probabilistic estimates in oil and gas project cost management: A benchmark experiment on natural gas pipeline projects. *Computation*, *10*(5), 75. https://doi.org/10.3390/computation10050075

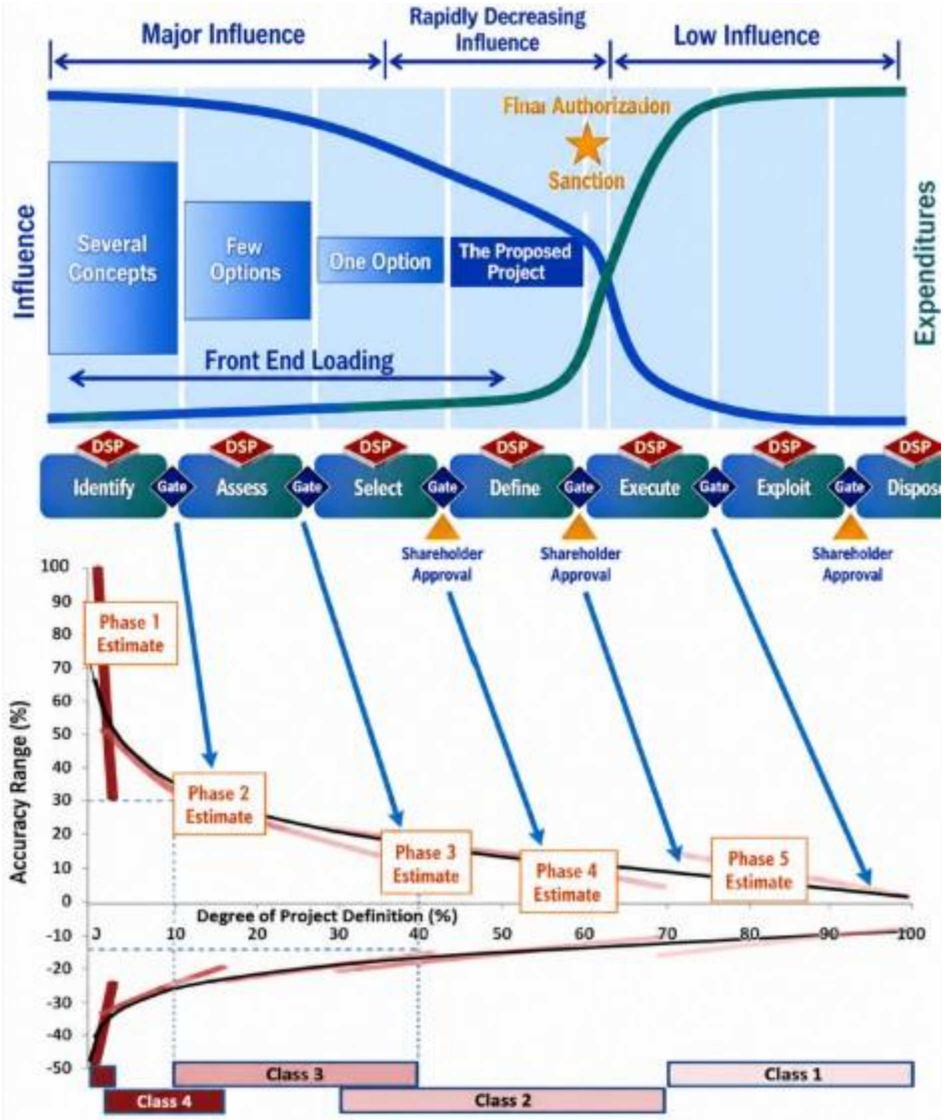

Figure 2: Level of Influence on Project Cost [15, 16]

Therefore, this paper analyzes and develops a probabilistic-parametric ”rule of thumb” model to assist the Indonesian Oil & Gas Company in project estimation and decision-making, particularly for feasibility studies. The Parametric Model the author will create will utilize historical data from the construction of pipeline at National Oil Company over the past five years and forecast the growth using ”gold price over the next 10 years”[17].

[15] Paulson, B. C. (1976). Designing to Reduce Construction Cost; Journal of The Construction Division, Vol. 102, Issue Number C04, retrieved from https://www.danieldavis.com/papers/boyd.pdf

[16] *U.S. Department of Energy. (2011). Cost Estimating Guide*

[17] *Gangopadhyay, K., Jangir, A., & Sensarma, R. (2016). Forecasting the price of gold: An error correction approach.* IIMB Management Review, 28*(1), 3.* https://doi.org/10.1016/j.iimb.2016.02.006

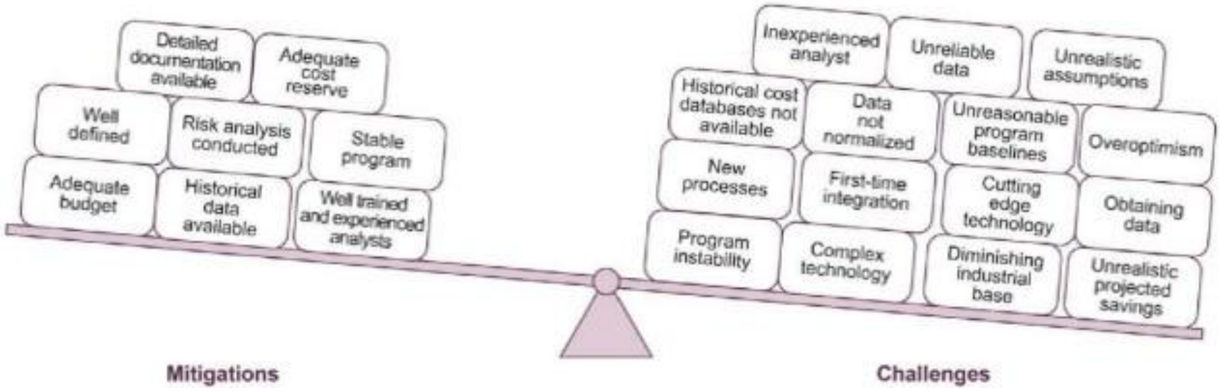

Figure 3 Cost Estimating Challenges and Mitigations[18]

The result of this paper will be a parametric model for pipeline construction, including accessories, mobilization, testing, and commissioning. This parametric model will ”facilitate estimators in compiling the construction costs of pipeline to prepare CAPEX Class 4 (feasibility study) with variables of Diameter Pipeline, Location of construction”[19] and planned year of construction. This approach will help address the challenges posed by high global oil production and contribute to more sustainable, efficient operations in the oil and gas industry.

[18] *Government Accountability Office. (2020). 2020 cost estimating and assessment guide: Best practices for developing and managing capital program costs (GAO-20-195G). U.S. Government Accountability Office.*

[19] Remer, D. S., Huynh, L., Agarwal, K., Auchard, B. J., & Heaps-Nelson, T. (1998). A compilation of inflation and location indexes. *International Journal of Production Economics*, *54*(1), 41-55. https://doi.org/10.1016/s0925-5273(97)00121-7

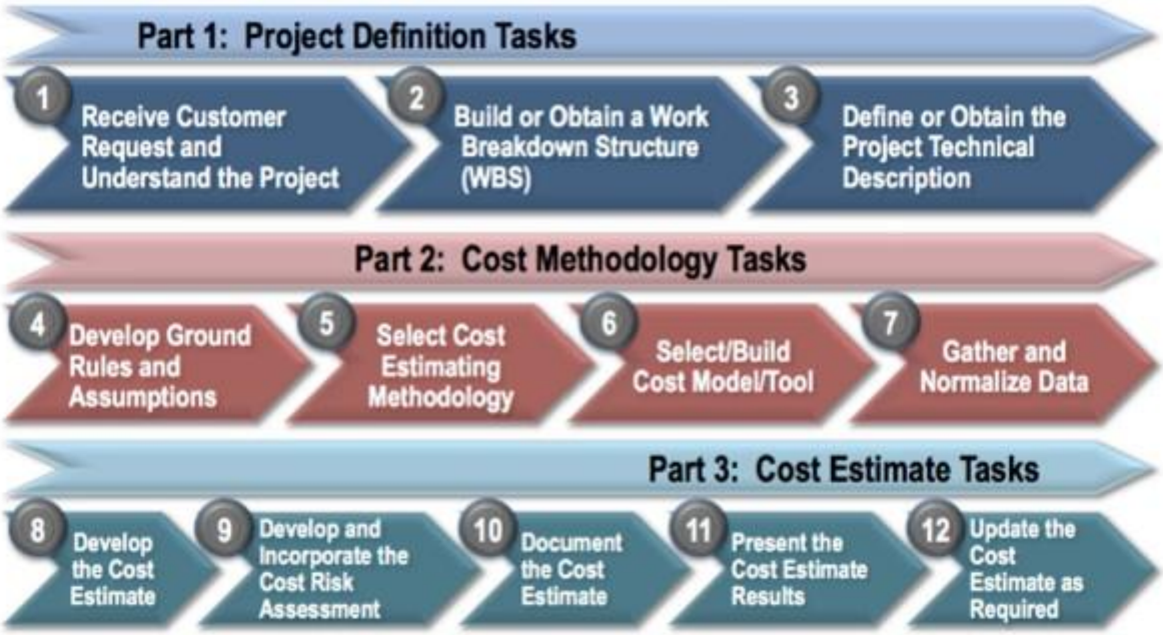

Figure 4 NASA Cost Estimating Process[20]

In conclusion, this paper aims to address the following research questions:

1. How can the traditional single-point estimation method be improved to better account for the inherent uncertainty and variability in cost estimation for oil and gas projects?
2. How to develop and implement a parametric model to support the National Oil Company in project estimation and decision making, especially for feasibility studies for the construction of Pipeline ASME B31.3?
3. How can the parametric model propose the preparation of CAPEX Class 4 (feasibility study) with variables of Diameter Pipeline, Location of Construction, and planned year of construction, and how can this contribute to more sustainable and efficient in oil and gas projects in the word?

This paper aims to add to the body of knowledge of cost estimation in the oil and gas industry and provide practical insights for the National Oil Company and other oil & gas industry companies addressing these questions.

[20] National Aeronautics and Space Administration. (2015). NASA cost estimating handbook (CEH) (Version 4.0). National Aeronautics and Space Administration.

METHODOLOGY

The study uses a seven-step engineering-economy-based approach to develop a probabilistic-parametrical rule-of-thumb model for ASME B31.3 product pipelines in the Indonesian Oil & Gas Company. Sullivan et al. define engineering economy as “a systematic approach to the problem of selecting the best method of allocating scarce resources to achieve a given objective” [21].

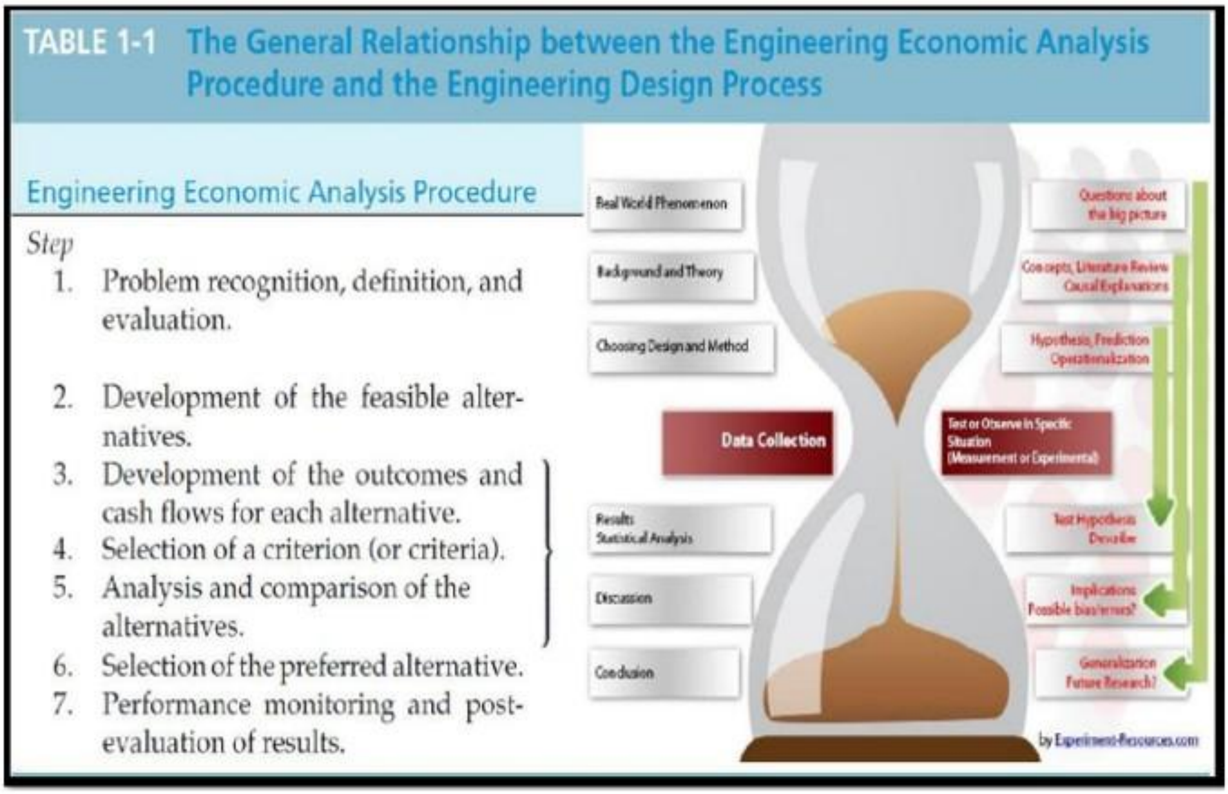

Figure 5 Engineering Economic Analysis Procedure [22]

I operationalize this through three core building blocks, as illustrated in Figure 6 below:

[21] Sullivan, W. G., Wicks, E. M., & Koelling, C. P. (2019). Engineering economy (17th ed.). Pearson.
[22] Sullivan, W. G., Wicks, E. M., & Koelling, C. P. (2019). Engineering economy (17th ed.). Pearson.

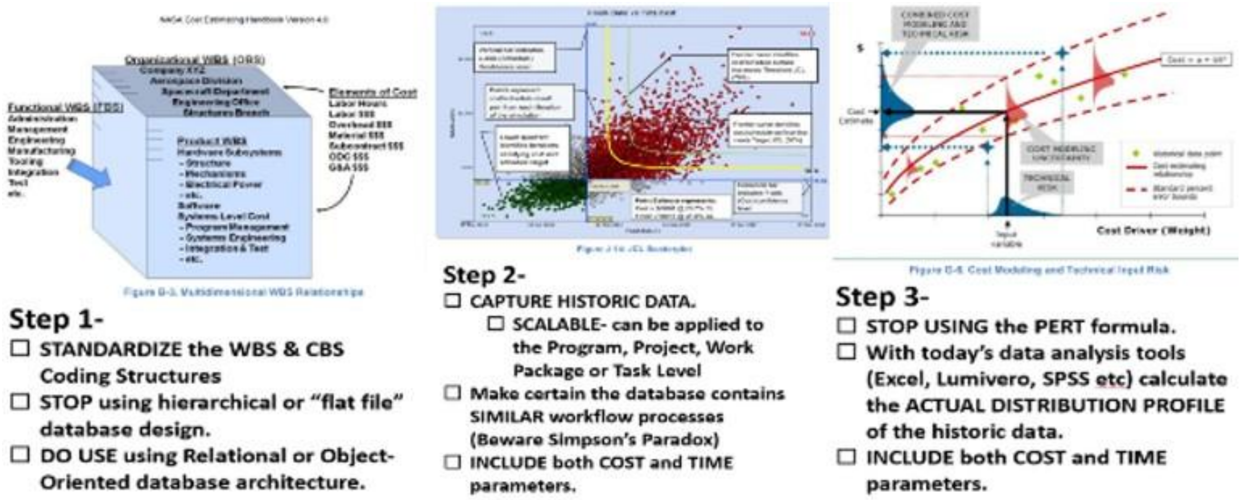

Figure 6 NASA Probabilistic Parametric Cost–Time Model [23]

Step 1 - Problem Definition

Historically, pipeline project data were stored in heterogeneous "flat file" spreadsheets with inconsistent coding, scopes, and naming conventions, making it difficult to compare projects or build credible parametric models. NASA explains that the WBS "ensures that all work to be performed on the project is organized and aligned in accordance with the total scope of a program, using a hierarchical structure"[24].

Step 2 - Identify The Feasible Alternative

Once standardization is mandated, the next step is data architecture: stay with flat files or move to a relational/object-oriented database keyed to the standardized WBS/CBS. GAO mentions that "reliable cost estimates are based on a historical database that is properly normalized and consistently structured to support analysis"[25]. Flat files can't do this because they are subject to coding errors, missing fields, and hidden scope changes.

Giammalvo argues that organizations should "develop and maintain project historical databases that support the creation of company-developed complex models and parametric estimating relationships"[26]. In line with Figure 6 Step 1, a relational database is selected, mapping each project to the standardized WBS/CBS and each 100-meter

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[23] National Aeronautics and Space Administration. (2015). NASA cost estimating handbook (CEH) (Version 4.0)
[24] National Aeronautics and Space Administration. (2015). NASA cost estimating handbook (CEH) (Version 4.0)
[25] Government Accountability Office. (2020). 2020 cost estimating and assessment guide: Best practices for developing and managing capital program costs (GAO-20-195G).
[26] Giammalvo, P. D. (2021). Project management caught in a 1960's time warp – The sequel? – Part 2: Exploring the underlying causes of our problems. PM World Journal, 10(1), 1–27

pipeline segment as a consistent data record. This provides the backbone for capturing scalable historical cost–time data (Figure 6, Step 2).

2.1 Parametric Estimating

Parametric estimating improves budgeting, scheduling and control by linking resources to a limited number of measurable cost drivers. Parametric models can be simple (single driver CERs) to complex (multiple CERs/algorithms). CERs are mathematical models based on historical data, usually derived through regression, that relate cost to key drivers such as quantity, weight, timing, labor, overhead or production rates. Akintoye said that CERs " offer a quick and fairly reliable means of estimating costs, particularly in the absence of detailed design data".[27]

2.2 Company Development Complex Models (CCDMs)

This CDCM focuses on three major variables for downstream pipelines under ASME B31.3, which are pipeline diameter, planned year of construction and location. According to NASA, parametric models should be based on "a small number of well-chosen technical parameters that explain most of the variation in cost"[28]. Diameter is important for material and the complexity of construction. Year reflects inflation and market conditions. Location is important for logistics and productivity. CDCMs provide customization, greater precision, and flexibility relative to single-driver CERs.

The CDCM is constructed as follows:

1. Data collection.
2. Specifying the model.
3. Calibration using metrics like R^2 and MCE.
4. validating against known project.

2.3 Evaluation Criteria

Evaluating CDCMs requires accuracy, reliability, and usability. NASA recommends that CERs and parametric models be "tested and documented using appropriate statistical measures to validate their predictive capability"[29]. Statistical methods such as R-square

[27] Akintoye, A. (2000). Analysis of factors influencing project cost estimating practice. Construction Management and Economics, 18(1), 77-89. https://doi.org/10.1080/014461900370979

[28] National Aeronautics and Space Administration. (2015). NASA cost estimating handbook (CEH) (Version 4.0). National Aeronautics and Space Administration

[29] Galvão, R., & Araújo, M. (2009). Variable selection. Comprehensive Chemometrics, 233–283. https://doi.org/10.1016/b978-044452701-1.00075-2

(R^2), Mean Squared Error (MSE), and related indicators can be used to assess both goodness-of-fit and predictive power.

2.4 R-Square (R^2)

In the context of CDCMs, R^2 indicates how well the model's predictions match the actual data. Galvão and Araújo describe R^2 as "a convenient summary index of how much of the variability in the response is explained by the regression model" [30]:

$$R2 = 1 - \frac{SS_{res}}{SS_{tot}}$$

Equation 1- R-Square

Where:

$SSres$ is the sum of the squared residuals.

$SStot$ is the total sum of squares.

Interpretation:

1. Value Range: R^2 ranges from 0 to 1.
2. Higher Value: A higher R^2 value (closer to 1) indicates a better fit of the model.
3. Lower Value: A lower R^2 value (closer to 0) suggests that the model does not explain much of the variability in the dependent variable.

Step 3 - Development of The Feasible Alternative

This step corresponds to Figure 6, Step 2. NASA notes that "data collection and data normalization are two cost estimating activities that are critical to the development of a credible and defendable cost estimate"[31]. Historical data from 50 ASME B31.3 product pipeline projects (2018–2023) are compiled, restricted to BBM pipelines without internal coating and similar downstream workflows (jetty–tank–gantry). The database is designed to be:

[30] Galvão, R., & Araújo, M. (2009). Variable selection. Comprehensive Chemometrics, 233–283. https://doi.org/10.1016/b978-044452701-1.00075-2

[31] National Aeronautics and Space Administration. (2015). NASA cost estimating handbook (CEH) (Version 4.0). National Aeronautics and Space Administration

- Scalable (query at program, project, WBS, work package, or 100-m segment).
- Workflow-consistent (only comparable process flows and scope definitions included).
- Cost–time integrated (for each 100-m segment, cost in ounces of gold at mid-2025 using a P80 gold price index, plus planned and actual durations, diameter, location, and year).

3.1 Data Collection

In this study, the author compiled cost data from 50 pipeline construction projects (ASME B31.3) for gasoline and gasoil from the 2018-2023 period. The dataset was collected under specific constraints to ensure consistency and reliability. All pipelines follow the ASME B31.3 standard, covering design, materials, fabrication, and testing requirements commonly used in process industries. [32]

Below are the building costs of the pipeline for gasoline & gasoil products, with each respective year and diameter:

[32] ASME. (2022). Process piping. The American Society of Mechanical Engineers - ASME. https://www.asme.org/codes-standards/find-codes-standards/b31-3-process-piping

	"As Planned"						"As Built"				
1	2	3	4	5	6	7	8	9	10	11	12
Project Numbe	Diameter of Pipe (Inch	Start Date (MM/YEA	Finish Date for 100 m pipe (MM/YEAI	Duration Planned (Month	Average Price of Gold (Midpoir	Original Ounces of Gold (Midpoin	Average Price of Gold (Midpoi	Actual Ounces of Gold Equivaler	Actual Duration (Month	As-Built CPI (BCWP/ ACW	As-Built SPI (BCWP/ BCW
Project 7	4	16-Aug-18	30-Aug-18	0.47	1286.00	14.61	1286.00	16.21	0.56	0.9009	0.8403
Project 11	4	10-Feb-19	26-Feb-19	0.53	1397.50	14.38	1397.50	16.82	0.69	0.8547	0.7752
Project 13	4	04-Sep-19	19-Sep-19	0.50	1397.50	14.78	1397.50	15.52	0.56	0.9524	0.8929
Project 17	4	21-Aug-20	05-Sep-20	0.50	1707.30	11.51	1707.30	13.81	0.59	0.8333	0.8475
Project 18	4	02-Sep-20	15-Sep-20	0.43	1707.30	11.42	1707.30	13.36	0.51	0.8547	0.8475
Project 28	4	04-Nov-21	18-Nov-21	0.47	1874.43	9.91	1874.43	11.40	0.52	0.8696	0.9009
Project 36	4	18-May-22	03-Jun-22	0.53	1812.58	10.99	1812.58	12.85	0.59	0.8547	0.9091
Project 2	6	21-Jan-18	10-Feb-18	0.67	1286.00	21.26	1286.00	22.75	0.73	0.9346	0.9091
Project 4	6	15-Jan-18	05-Feb-18	0.70	1286.00	21.13	1286.00	22.60	0.83	0.9346	0.8475
Project 8	6	27-Apr-18	16-May-18	0.63	1286.00	21.93	1286.00	24.12	0.80	0.9091	0.7937
Project 9	6	04-Jul-19	24-Jul-19	0.67	1397.50	20.88	1397.50	22.13	0.77	0.9434	0.8621
Project 14	6	18-Apr-19	07-May-19	0.63	1397.50	21.32	1397.50	24.31	0.79	0.8772	0.8065
Project 15	6	20-Oct-19	09-Nov-19	0.67	1397.50	20.31	1397.50	23.15	0.78	0.8772	0.8547
Project 19	6	17-Jul-20	08-Aug-20	0.73	1707.30	17.30	1707.30	19.89	0.95	0.8696	0.7692
Project 22	6	15-Jun-20	05-Jul-20	0.67	1707.30	17.50	1707.30	18.38	0.74	0.9524	0.9009
Project 27	6	19-Jul-21	07-Aug-21	0.63	1874.43	15.19	1874.43	16.86	0.75	0.9009	0.8403
Project 29	6	15-Aug-21	06-Sep-21	0.73	1874.43	15.25	1874.43	16.77	0.95	0.9091	0.7692
Project 33	6	11-Feb-22	03-Mar-22	0.67	1812.58	16.89	1812.58	19.09	0.75	0.8850	0.8929
Project 34	6	27-Aug-22	15-Sep-22	0.63	1812.58	16.84	1812.58	19.20	0.81	0.8772	0.7813
Project 35	6	02-May-22	22-May-22	0.67	1812.58	17.01	1812.58	20.41	0.79	0.8333	0.8403
Project 37	6	19-Jul-22	07-Aug-22	0.63	1812.58	16.89	1812.58	18.58	0.77	0.9091	0.8264
Project 41	6	13-Mar-22	02-Apr-22	0.67	1812.58	16.86	1812.58	18.20	0.79	0.9259	0.8403
Project 43	6	23-Jul-23	11-Aug-23	0.63	1960.83	15.60	1960.83	18.09	0.71	0.8621	0.8929
Project 44	6	05-Aug-23	27-Aug-23	0.73	1960.83	15.49	1960.83	18.59	0.92	0.8333	0.7937
Project 46	6	03-Apr-23	22-Apr-23	0.63	1960.83	15.44	1960.83	18.53	0.82	0.8333	0.7752

Table 3 Pipeline ASME B31.3 Building Projects and Costs in National Oil Company (1/2) [33]

[33] National Oil Company. (2023). Internal Document Pipeline Projects in a National Oil Company

1 Project Number	2 Diameter of Pipe (Inch)	3 Start Date (MM/YEAR)	4 Finish Date for 100 m pipe (MM/YEAR)	5 Duration Planned (Months)	6 Average Price of Gold (Midpoint)	7 Original Ounces of Gold (Midpoint)	8 Average Price of Gold (Midpoint)	9 Actual Ounces of Gold Equivalency	10 Actual Duration (Months)	11 As-Built CPI (BCWP/ ACWP)	12 As-Built SPI (BCWP/ BCWS)
Project 49	6	29-Apr-23	19-May-23	0.67	1960.83	15.40	1960.83	17.86	0.87	0.8621	0.7692
Project 3	8	11-Apr-18	08-May-18	0.90	1286.00	27.86	1286.00	32.59	1.10	0.8547	0.8197
Project 5	8	22-Jul-18	20-Aug-18	0.97	1286.00	28.50	1286.00	33.34	1.23	0.8547	0.7874
Project 12	8	29-Mar-19	23-Apr-19	0.83	1397.50	27.06	1397.50	31.39	0.98	0.8621	0.8475
Project 20	8	05-Feb-20	06-Mar-20	1.00	1707.30	23.11	1707.30	26.80	1.27	0.8621	0.7874
Project 23	8	29-Sep-20	25-Oct-20	0.87	1707.30	23.00	1707.30	24.84	1.11	0.9259	0.7813
Project 24	8	18-Mar-20	11-Apr-20	0.80	1707.30	22.96	1707.30	27.33	0.95	0.8403	0.8403
Project 26	8	09-Aug-20	08-Sep-20	1.00	1707.30	23.14	1707.30	24.76	1.19	0.9346	0.8403
Project 30	8	06-Mar-21	30-Mar-21	0.80	1874.43	19.97	1874.43	23.17	0.94	0.8621	0.8475
Project 31	8	25-Jun-21	21-Jul-21	0.87	1874.43	20.02	1874.43	22.82	0.95	0.8772	0.9091
Project 32	8	08-Apr-21	03-May-21	0.83	1874.43	19.98	1874.43	22.58	1.02	0.8850	0.8197
Project 42	8	12-Mar-23	05-Apr-23	0.80	1960.83	20.82	1960.83	22.90	1.03	0.9091	0.7752
Project 45	8	28-Jun-23	26-Jul-23	0.93	1960.83	20.83	1960.83	24.17	1.15	0.8621	0.8130
Project 48	8	12-May-23	04-Jun-23	0.77	1960.83	20.79	1960.83	23.08	0.94	0.9009	0.8130
Project 6	10	03-Mar-18	06-Apr-18	1.13	1286.00	35.24	1286.00	38.06	1.31	0.9259	0.8621
Project 16	10	25-Jun-19	28-Jul-19	1.10	1397.50	33.56	1397.50	40.27	1.38	0.8333	0.8000
Project 21	10	11-Apr-20	16-May-20	1.17	1707.30	28.74	1707.30	33.05	1.51	0.8696	0.7752
Project 39	10	25-Jun-22	25-Jul-22	1.00	1812.58	26.41	1812.58	29.05	1.21	0.9091	0.8264
Project 40	10	09-Feb-22	12-Mar-22	1.03	1812.58	26.49	1812.58	28.07	1.18	0.9434	0.8772
Project 47	10	17-Sep-23	21-Oct-23	1.13	1960.83	24.54	1960.83	28.22	1.38	0.8696	0.8197
Project 50	10	03-Jul-23	03-Aug-23	1.03	1960.83	24.46	1960.83	25.93	1.34	0.9434	0.7692
Project 10	12	22-Sep-19	02-Nov-19	1.37	1397.50	38.08	1397.50	43.41	1.67	0.8772	0.8197
Project 25	12	27-May-20	10-Jul-20	1.47	1707.30	32.36	1707.30	38.83	1.61	0.8333	0.9091
Project 38	12	06-Sep-22	14-Oct-22	1.27	1812.58	33.28	1812.58	35.61	1.42	0.9346	0.8929
Project 1	16	07-Feb-18	04-Apr-18	1.87	1286.00	53.84	1286.00	62.45	2.30	0.8621	0.8130
Mean (Average) Database (P50) 13						21.62		24.44		0.89	0.83
MEDIAN Database (Most Frequent Value) 14						20.81		22.86		0.88	0.83
Standard Deviation 15						7.90		9.11		0.04	0.04

Table 4 Pipeline ASME B31.3 Building Projects and Costs in National Oil Company (2/2) [34]

- **(3.1) Project:** Number of historical projects. Population of 50 comparable projects from 2018 to 2023.
- **(3.2) Diameter of Pipe:** Size of pipe per inch.
- **(3.3) Start Date:** Project start date. (Issuance of the Notice to Proceed).
- **(3.4) Finish Date:** Project finish date. (Acceptance and put in service).
- **(3.5) Duration Planned:** Total duration planned. (BCWS).
- **(3.6) Average Price of Gold:** Gold Price at Midpoint (Mid-Year) of the Project START or FINISH (As Planned).
- **(3.7) Original Ounces of Gold**: Ounces of Gold Equivalent from AFE Approved Cost **(AFE Approved Cost / Average Price of Gold)**.
- **(3.8) Average Price of Gold:** Gold Price at Midpoint (Mid-Year) of the Project START or FINISH (As Built).

[34] National Oil Company. (2023). Internal Document Pipeline Projects in a National Oil Company

- **(3.9) Actual Ounces of Gold Equivalency:** Ounces of Gold Equivalent from Actual Acceptance Cost ACWP **(Actual Acceptance Cost ACWP / Average Price of Gold).**
- **(3.10) Actual Duration:** Total duration of the project, from the kickoff meeting until completion/commissioning.
- **(3.11) As-Built CPI:** Cost Performance Index of Project (BCWP/ACWP) or **(AFE Approved Cost/Actual Acceptance Cost).**
- **(3.12) As-Built SPI:** Schedule Performance Index of Project (BCWP/BCWS) or **(Duration Planned/Actual Duration).**
- **(3.13) P50 (Mean):** Average of Ounces of Gold from the historical project.
- **(3.14) Median:** Central tendency of the dataset and reflects the typical value of the observations.
- **(3.15) Standard Deviation:** Statistical measure that quantifies the dispersion or variability of data points relative to the mean.

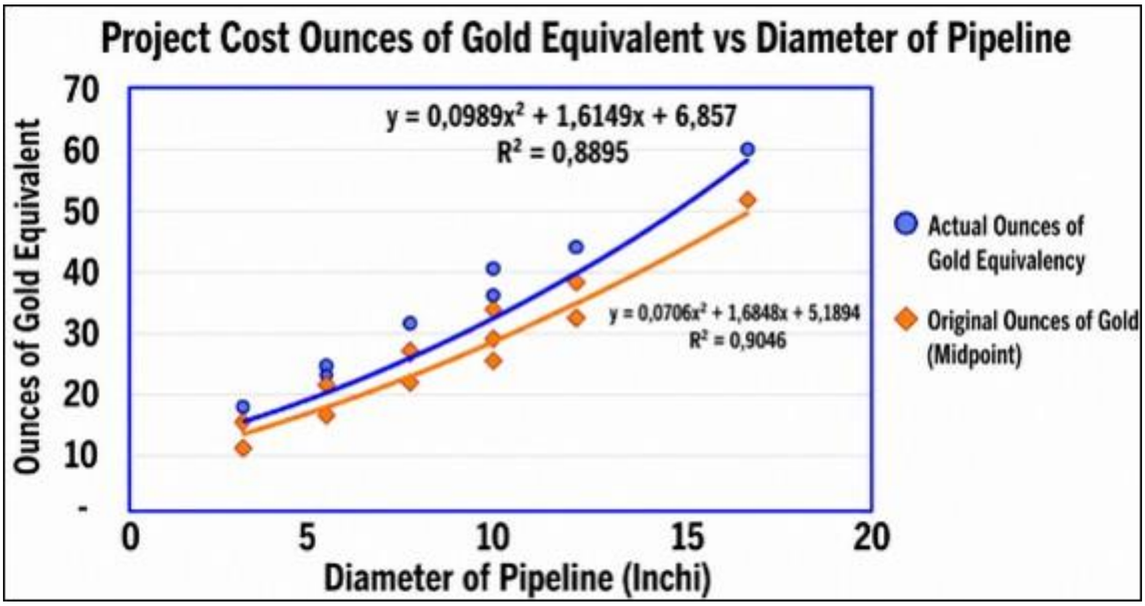

Figure 7 Historical Project Cost Vs Diameter of Pipeline [35]

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[35] By Author

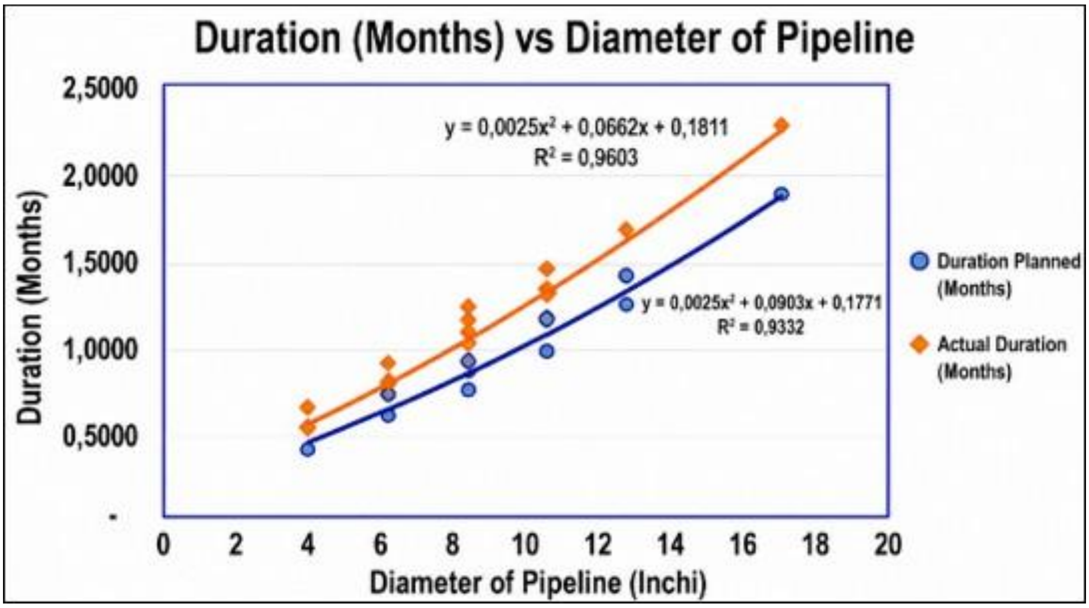

Figure 8 Historical Project Duration Vs Diameter of Pipeline [36]

For more details, the CPI/SPI performance historical data is below:

[36] By Author

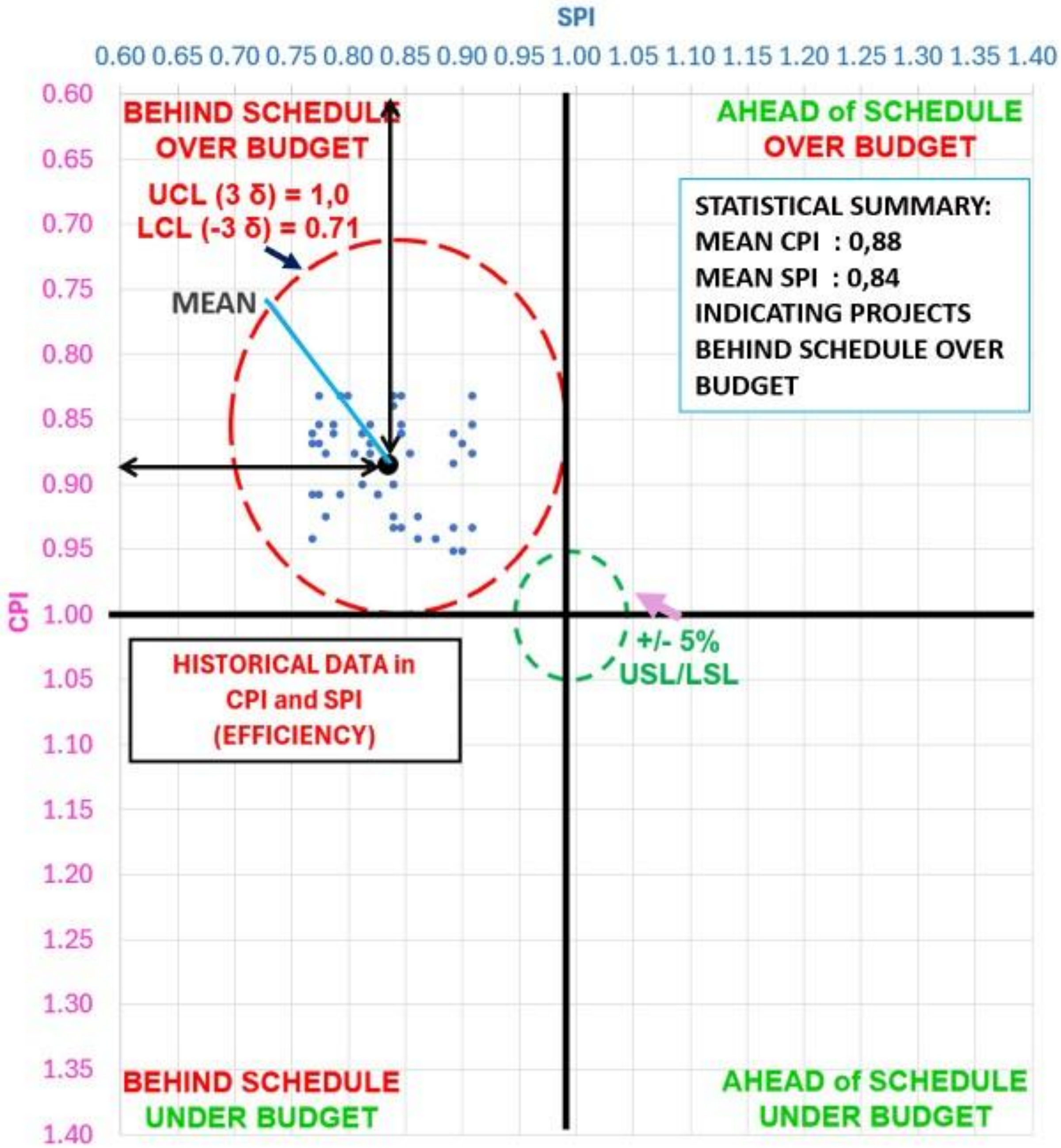

Figure 9 CPI/SPI performance Historical Data [37]

[37] By Author

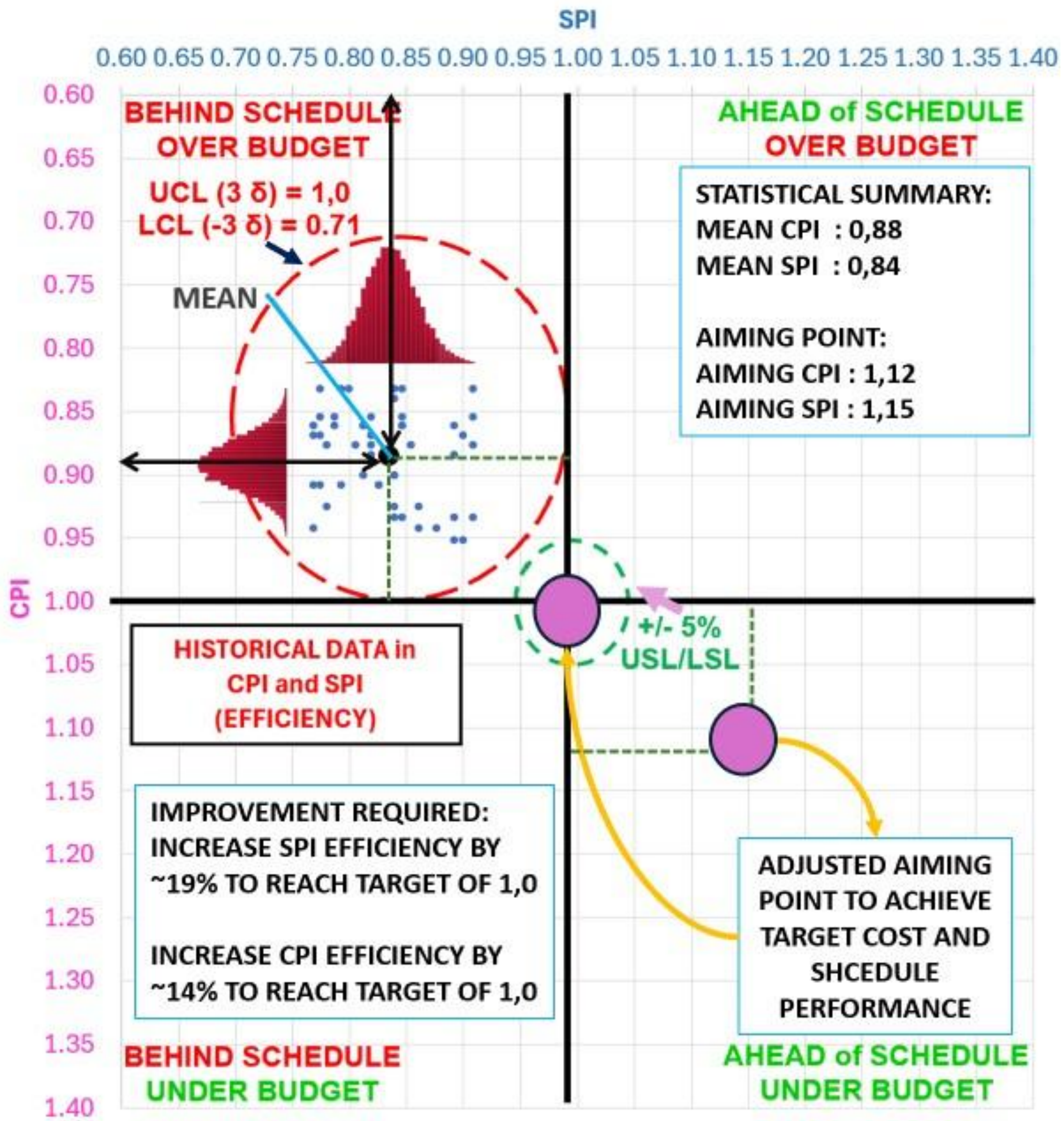

Figure 10 -Aiming Point of Scatter Plot [38]

By visually representing these indices on a plot, stakeholders can quickly assess the project's performance in terms of both time and cost, enabling more informed decision-making and targeted interventions as needed.

[38] By Author

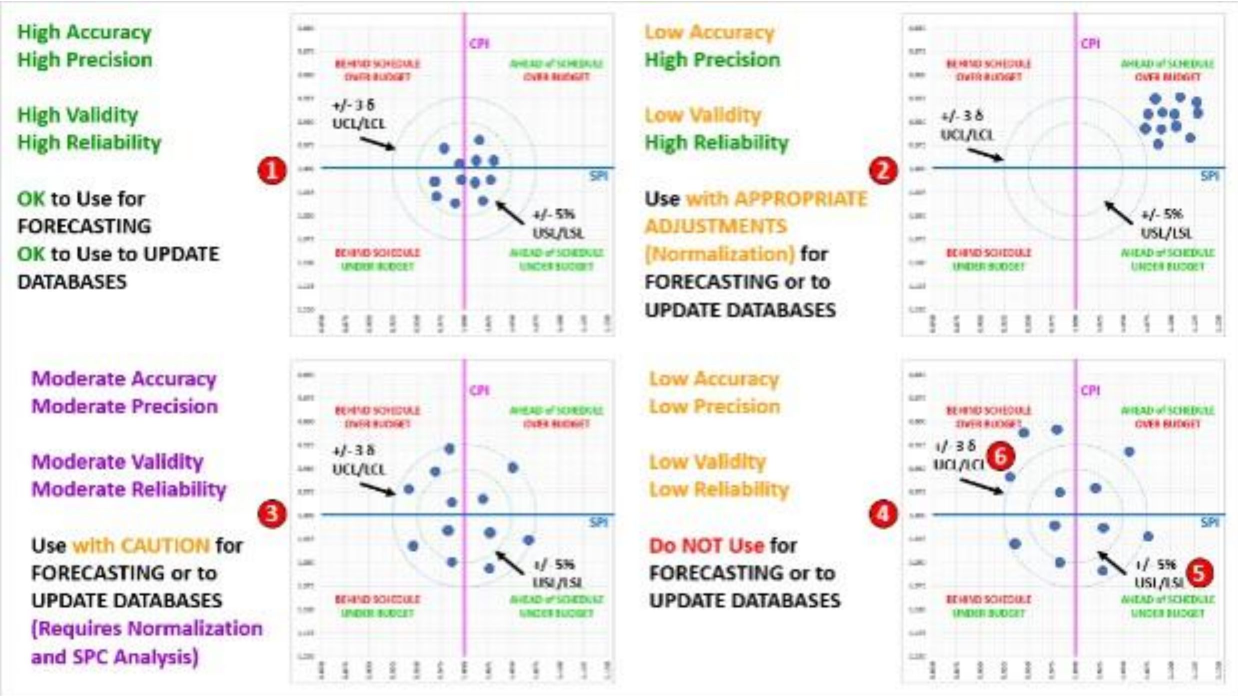

Figure 11 Illustrating Data Quality Metrics Validity, Precision, Reliability, and Accuracy[39]

Here are two proposed approaches to enhance project performance:

1. Improve your asset efficiency to boost both the Schedule Performance Index (SPI) and Cost Performance Index (CPI).
2. Alternatively, by adjusting the aiming point, you essentially change the graphical representation of your project's performance. However, this doesn't fix the root cause of inefficient asset utilization. The real solution lies in addressing and enhancing asset efficiency for sustained improvement.

The project dataset covers 2018–2023, matching the period of consistent ASME B31.3 downstream data and recent gold price history. Gangopadhyay et al. show that gold prices "can be reasonably forecast using time-series and error-correction approaches, making them a useful proxy for long-term cost escalation"[40]. In line with this, construction costs from different years are converted into equivalent 2025 values expressed in ounces of gold, providing an inflation-free baseline for deriving the parametric cost equations.

[39] PTMC Team and Dr. Paul D. Giammalvo. (2021). Managing-Quality-Assurance-Quality-Control

[40] Gangopadhyay, K., Jangir, A., & Sensarma, R. (2016). Forecasting the price of gold: An error correction approach. IIMB Management Review, 28(1), 3–12

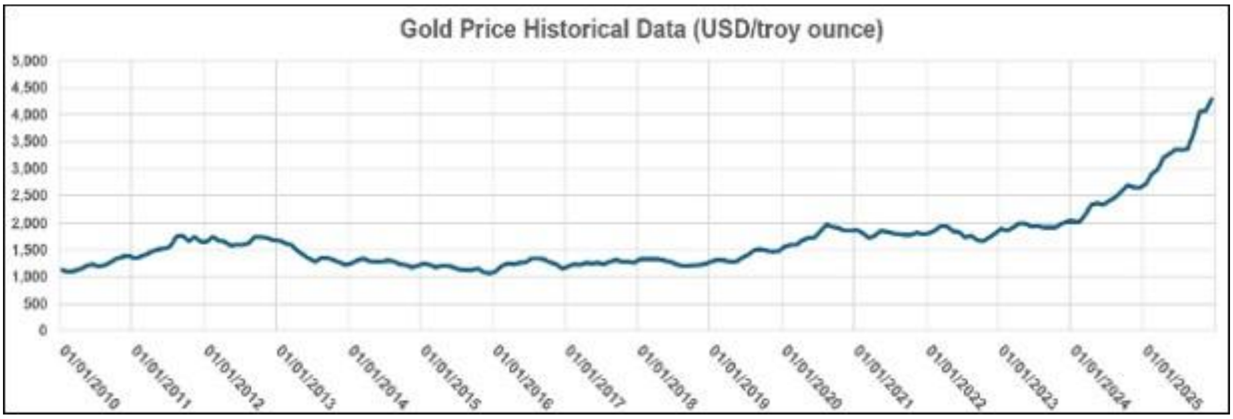

Figure 12 Gold Price Per Troy Ounce[41]

Year	Average Gold Price per Year (in USD)
2010	1224.7
2011	1568.6
2012	1668.8
2013	1411.0
2014	1266.2
2015	1160.1
2016	1248.3
2017	1257.1
2018	1269.1
2019	1392.2
2020	1769.6
2021	1799.6
2022	1800.8
2023	1942.7
2024	2387.0
2025	3434.8

Table 5 Average Gold Price Index for 2010 to 2025 [42]

Subsequently, utilizing the same chart, the author plotted the regression using linear equations and polynomials of the 2nd, 3rd, 4th, 5th, and 6th orders, as follows:

[41] Gold spot price and cost of gold. (2026). World Gold Council. https://www.gold.org/goldhub/data/gold-prices
[42] By Author

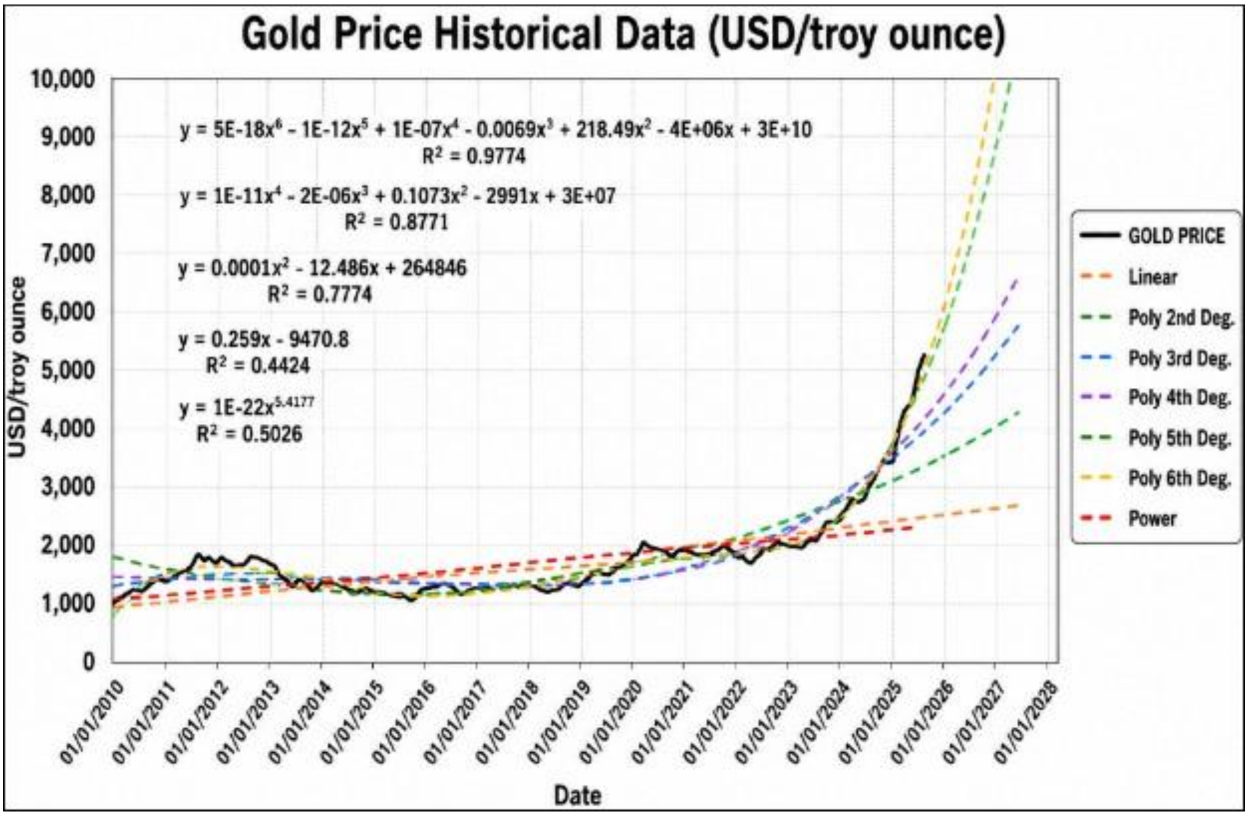

Figure 13 Gold Price Regression Chart (2010 – 2025) [43]

From the conducted regression analysis, we extract the value of R^2:

Regression Model	Y1 Gold Price in 27 March 26	Y2 Gold Price in 16 Jul 27	Trend	R-squared
Linear	2,471	2,594	Positive	0.442
Power	2,319	2,452	Positive	0.503
Poly 2nd Deg.	3,365	3,943	Positive	0.777
Poly 4th Deg.	4,143	5,787	Positive	0.877
Poly 6th Deg.	5,229	11,497	Positive	0.977

Figure 14 Gold Price R^2 Value [44]

Subsequently, based on the above prices, the author categorizes each output price into three classifications:

[43] By Author
[44] By Author

Categories	Price (USD)	Regression	Escalation Factor
Baseline	3,435	Average 2025	-
Low	3,943	Poly 2nd Deg.	1.15
Mid	5,787	Poly 4th Deg.	1.68
High	11,497	Poly 6th Deg.	3.35

Figure 15 Gold Price Regression, Value, and Escalation Factor [45]

A lognormal analysis with P80 confidence level is used, following GAO guidance for probabilistic cost estimates. These P80-normalized costs per 100 m become the dependent variable for the parametric model[46]. See Appendix.

Step 4 - Selection of The Criteria

Figure 6 Step 3 is implemented here as an explicit selection of decision criteria. NASA notes that probabilistic estimates "provide management with significant insight into the key cost and schedule drivers of the program, allowing them to actively manage and develop mitigation strategies to reduce cost" [47]. This requires using full distributions (P10, P50, P80), not only means.

The criteria are:

1. **Use distribution profiles**, not single points (P50, P80 of cost and duration per 100 m for each diameter–location–year). [48]
2. **Always include both cost and time**: any acceptable model must predict cost and duration per 100 m. [49]
3. **Statistical fit and residual behavior**: R^2, adjusted R^2, MSE, RMSE, and residual plots are used to check bias and spread. [50]
4. **Compatibility with AACE Class 4 ranges**: the model's error distribution must broadly fall within –15/–30% and +20/+50% ranges. [51]

[45] By Author
[46] Government Accountability Office. (2020). 2020 cost estimating and assessment guide: Accessible version GAO-20-195G
[47] National Aeronautics and Space Administration. (2015). NASA cost estimating handbook (CEH) (Version 4.0)
[48] Government Accountability Office. (2020). 2020 cost estimating and assessment guide: Best practices for developing and managing capital program costs (GAO-20-195G)
[49] Giammalvo, P. D. (2021). Project management caught in a 1960's time warp – The sequel? – Part 2: Exploring the underlying causes of our problems. PM World Journal, 10(1), 1–27.
[50] National Aeronautics and Space Administration. (2015). NASA cost estimating handbook (CEH) (Version 4.0)
[51] AACE International. (2020). AACE International recommended practice no. 18R-97: Cost estimate classification system – As applied in engineering, procurement, and construction for the process industries.

5. **Practical usability**: model must be implementable in Excel/Solver/@RISK and understandable to estimators.

After normalizing the data, the author formulated four distinct models to represent the relationship between Pipeline Diameter and Year-to-Built:

Model 1 – Linear Model
The linear model is expressed as:

$$\boldsymbol{Linear: \ Cost = C_1 + C_2\,x + C_3\,y}$$

Equation 1 - Linear Model

Where:
Cost = Pipeline Cost
x = Pipeline Diameter
y = Year-to-Construct (Midpoint)
C_1, C_2, C_3 = coefficients to be estimated

Model 2 – Power Model
The power model is expressed as:

$$\boldsymbol{Power: \ Cost = C_1 + C_2\,x^{C_4} + C_3\,y^{C_5}}$$

Equation 2 - Power Model

Where:
Cost = Pipeline Cost
x = Pipeline Diameter
y = Year-to-Construct (Midpoint)
C_1, C_2, C_3, C_4 & C_5 = coefficients to be estimated

Model 3 – Logarithmic Model

The logarithmic model is expressed as:

$$\boldsymbol{Logarithmic: \ Cost = C_1 + C_2\,\log x + C_3\,\log y}$$

Equation 3 - Logarithmic Model

Where:
Cost = Pipeline Cost
x = Pipeline Diameter
y = Year-to-Construct (Midpoint)
C_1, C_2, & C_3 = coefficients to be estimated

Model 4 – Exponential Model

The Exponential Model is expressed as follows:

$$\boldsymbol{Exponential:\ Cost = C_1 + C_2 exp^{C_4 x} + C_3 exp^{C_5 y}}$$

Equation 4 - Exponential Model

Where:
Cost = Pipeline Cost
x = Pipeline Diameter
y = Year-to-Construct (Midpoint)
C_1, C_2, C_3, C_4 & C_5 = coefficients to be estimated

Coefficient Formulation Using Solver® for Excel.

Solver for Excel stands as an optimization tool designed to identify the optimal solution for a problem by adjusting specific variable values to minimize or maximize an objective function. The process of employing Solver for Excel in estimating regression coefficients involves the following steps:

1. Define the objective function.
2. Specify the cells containing the coefficients to be estimated.
3. Set constraints.
4. Choose a solution method.
5. Execute Solver and interpret the results.

FINDINGS

Step 5 - Analysis of Alternative

Based on Step-4 criteria, four parametric cost models are defined to relate construction cost per 100 m (in ounces of gold) to pipeline diameter and year-to-construct (midpoint):

Model 1 – Linear Model

$$Cost = 1 + 5x$$

Equation 5 – Linear Model for Construction Cost

Model 2 – Power Model

$$Cost = 1 + \ 3\,x + (y - 2018)$$

Equation 6 - Power Model for Construction Cost

Model 3 – Logarithmic Model

$$Cost = -362 + \ 93\ log\,x + 389\ log(y - 2018)$$

Equation 9 – Logarithmic Model for Construction Cost

Model 4 – Exponential Model

$$Cost = 1 \pm 409\,exp^{(-6553\,x)} + \ exp^{(y-2018)}$$

Equation 10 – Exponential Model for Construction Cost

Cost = Construction Cost in ounce gold equivalent

X = Diameter of Pipeline

Y = Year-to-Construct (Midpoint)

C1, C2, C3, C4 & C5 = Coefficients to be estimated

	LINEAR	POWER	LOGARITHMIC	EXPONENTIAL
NUM OF SAMPLE	50	50	50	50
STANDARD ERROR	4,061648603	3,980230726	5,16538892	11,51705803
MEAN SQUARE ERROR	75	73	189	1.612
ROOT MSE	9	9	14	40
R2	0,8782	0,8830	0,8030	0,0000
ADJUSTED R2	0,8756	0,8806	0,7988	-0,0204
F VALUE	345,9802897	362,2633234	195,5976737	0
SIGNIFICANT F	1,39468E-23	5,26282E-24	1,49362E-18	

Table 6 Summary of Model Calculation and Analysis using ANOVA [52]

COEFFICIENT	LINEAR	POWER	LOGARITHMIC	EXPONENTIAL
C1	1	1	-362	1
C2	5	3	93	-409
C3	0	1	389	1
C4		1		-6553
C5		1		1

Table 7 Coefficient for Each Model [53]

1. Linear Model
   - The low Standard Error, MSE, and RMSE indicate that the linear model has a small spread of residuals, suggesting a good fit.
   - The high R-squared (0.8782) implies that approximately 87,8% of the variance in the dependent variable is explained by the linear model.
   - The high F Value (345,98) and significant F value (1.3946E-23) suggest that the linear model is statistically significant.
2. Power Model
   - The low Standard Error, MSE, and RMSE indicate that the linear model has a small spread of residuals, suggesting a better fit than linear model.
   - The high R-squared (0.8830) implies that approximately 88,3% of the variance in the dependent variable is explained by the power model.
   - The high F Value (362,26) and significant F value (5.2628E-24) suggest that the power model is statistically significant.
3. Logarithmic Model
   - The intermediate values for Standard Error, MSE, and RMSE suggest a moderate fit for the logarithmic model.

[52] By Author
[53] By Author

- The R-squared value (0.8030) is below that of the linear and power models, indicating that is not as good as the linear and power models.
- The higher F Value (195.59) and significant F value (1.4936 E-18) suggest statistical significance.

4. Exponential Model
   - The highest values for Standard Error, MSE, and RMSE indicate a larger spread of residuals and a less accurate fit for the exponential model.
   - The lowest R-squared (0.000) suggests that the exponential model explains the least amount of variance in the dependent variable.
   - The lowest F Value (0,000) indicates a statistically lower level compared to other models.

From a statistical standpoint, the **Power model** appears to be the most appropriate as it has the lowest errors, the highest R-squared, and a significant F value.

Step 6 - Selection of the Preferred Alternative

The power model becomes the equation model with the lowest errors, the highest R-squared, and a significant F value. This model is the choice for projecting Pipeline construction cost using the following equation:

$$Cost = 1 + 3x + (y - 2018)$$

Equation 1-Proposed Equation for Pipeline Construction Cost

By combining the project database and gold-based regression (P80), the model is expected to increase confidence in staying within budget, account for unknown risks, and reduce the likelihood of re-baselining as the program progresses.

Step 7 - Performance Monitoring

To ensure ongoing accuracy and relevance, performance monitoring is recommended:

- **Establish a Feedback Loop:**
  Create a feedback loop that integrates real-world insights into ongoing model refinement, ensuring adaptability and continuous improvement.
- **Data Benchmarking:**

One of the primary benefits of your project's historical database system is to provide benchmarking data, metrics and factors that will be an invaluable aid for reviewing and validating estimates.

- **Statistical Software Packages:**
  Utilize statistical software for a comprehensive analysis of model results. Calculate performance metrics such as Mean Squared Error (MSE), Root Mean Squared Error (RMSE), and correlation coefficients to assess accuracy.

CONCLUSION

Based on the previously presented explanation, we can now revisit each question and its corresponding answer, as follows:

1. How can the traditional single-point estimation method be improved to better account for the inherent uncertainty and variability in cost estimation for oil and gas projects?

   The traditional single-point estimation method can be improved by incorporating a probabilistic–parametric approach that explicitly accounts for uncertainty and variability. Instead of relying on deterministic values, this study utilizes historical data distributions and adopts a P80 confidence level, enabling a more realistic representation of cost outcomes.
   Furthermore, by normalizing project costs using gold price equivalency, the model effectively eliminates the influence of inflation and currency fluctuations over time. This approach enhances comparability across projects and improves the reliability of cost estimates in a dynamic oil and gas environment characterized by high production levels and price volatility.

2. How can a parametric model be developed and implemented to assist the National Oil Company in project estimation and decision-making, particularly for feasibility studies related to constructing Pipeline ASME B31.3?

   A standardized historical database (50 ASME B31.3 projects, 2018–2023) and a consistent WBS/CBS provide the foundation. Four model families are tested; the power model is selected based on superior R^2 and error metrics. The resulting equation provides a practical tool for estimating cost per 100 m as a function of diameter and year, supporting faster and more consistent feasibility estimates. The resulting model:

$$Cost = 1 + 3x + (y - 2018)$$

Equation 2-Proposed Equation for Pipeline Construction Cost

3. How can the proposed parametric model facilitate the preparation of CAPEX Class 4 (feasibility study) with variables of Diameter Pipeline, Location of Construction, and planned year of construction, and how can this contribute to more sustainable and efficient operations in oil and gas projects?

   The model supports CAPEX Class 4 by delivering rapid, reasonably accurate estimates consistent with AACE accuracy bands at low project definition. By focusing on key drivers (diameter, time, location via database) and using gold-normalized cost, it simplifies escalation treatment while maintaining robustness. This improves budget accuracy, supports risk-informed decision-making, and enhances planning in a high-production, high-uncertainty oil and gas environment.

   This approach contributes to more sustainable and efficient operations by:
   - Improving budget accuracy and reducing cost overruns
   - Supporting risk-informed decision-making
   - Enhancing project planning under conditions of high global oil production and market uncertainty

Overall, the integration of probabilistic methods, parametric modeling, and gold based normalization provides a robust framework for improving cost estimation practices in the oil and gas industry.

FUTURE RESEARCH

Following the conclusion above, historical project data plays a significant role in modeling parametric cost estimates. According to Project Performance, both CPI and SPI need to be maintained between the Upper/Lower Specification Limit and Upper/Lower Control Limit. The Parametric Model of Cost Estimate can be used in developing CAPEX Class 4 during feasibility studies. To maintain both Cost and Schedule performance of the project, further research is needed to determine the Equation Model based on scheduling. It is hoped that with the approach of the equation model for Cost and Scheduling, the Front-End Loading phase in the project stages can achieve maturity level according to Estimate Class 4.

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APPENDIX A. LINEAR MODEL & ANOVA OUTPUT

C1	C2	C3				
1	5	0				
X	Y	Z	Actual Cost	Predicted Cost	Residual	Residual^2
4	2025	1	77.90	21.49	56.40	3181.19
4	2025	1	28.37	21.49	6.88	47.34
4	2025	1	40.66	21.49	19.16	367.21
4	2025	1	28.20	21.49	6.70	44.92
4	2025	1	41.59	21.49	20.09	403.73
4	2025	1	47.48	21.49	25.98	675.07
4	2025	1	20.22	21.49	-1.27	1.61
6	2025	1	30.09	31.49	-1.41	1.98
6	2025	1	29.18	31.49	-2.31	5.34
6	2025	1	57.23	31.49	25.74	662.57
6	2025	1	22.18	31.49	-9.31	86.75
6	2025	1	41.39	31.49	9.89	97.88
6	2025	1	20.46	31.49	-11.03	121.76
6	2025	1	32.05	31.49	0.56	0.31
6	2025	1	30.53	31.49	-0.97	0.94
6	2025	1	53.10	31.49	21.60	466.67
6	2025	1	18.16	31.49	-13.34	177.86
6	2025	1	17.56	31.49	-13.93	194.02
6	2025	1	26.14	31.49	-5.35	28.61
6	2025	1	35.23	31.49	3.74	13.97
6	2025	1	43.45	31.49	11.96	142.92
6	2025	1	24.15	31.49	-7.34	53.87
6	2025	1	32.65	31.49	1.16	1.34
6	2025	1	35.92	31.49	4.43	19.61
6	2025	1	51.04	31.49	19.55	382.17
6	2025	1	32.55	31.49	1.05	1.11
8	2025	1	24.15	41.49	-17.34	300.72
8	2025	1	16.33	41.49	-25.16	633.16
8	2025	1	24.02	41.49	-17.47	305.21
8	2025	1	33.19	41.49	-8.31	68.99
8	2025	1	32.69	41.49	-8.81	77.55
8	2025	1	32.34	41.49	-9.15	83.78
8	2025	1	24.31	41.49	-17.19	295.40
8	2025	1	24.44	41.49	-17.05	290.66
8	2025	1	25.99	41.49	-15.51	240.43
8	2025	1	16.37	41.49	-25.13	631.27
8	2025	1	23.66	41.49	-17.83	317.96
8	2025	1	45.35	41.49	3.86	14.86
8	2025	1	36.99	41.49	-4.50	20.24
10	2025	1	35.75	51.49	-15.74	247.90
10	2025	1	23.18	51.49	-28.31	801.67
10	2025	1	31.20	51.49	-20.30	411.96
10	2025	1	24.64	51.49	-26.85	720.90
10	2025	1	25.32	51.49	-26.17	685.05
10	2025	1	32.92	51.49	-18.57	344.95
10	2025	1	25.24	51.49	-26.25	689.00
12	2025	1	38.45	61.49	-23.05	531.14
12	2025	1	31.44	61.49	-30.05	903.06
12	2025	1	24.33	61.49	-37.16	1380.91
16	2025	1	35.32	81.49	-46.17	2131.77

R Square	MSE
0.0514	321

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.93710538
R Square	0.878166494
Adjusted R Square	0.875628296
Standard Error	4.061648603
Observations	50

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	5707.633162	5707.633162	345.9802897	1.39468E-23
Residual	48	791.8554899	16.49698937		
Total	49	6499.488652			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95,0%*	*Upper 95,0%*
Intercept	-0.917612295	1.865807985	-0.491804249	0.625099397	-4.669070681	2.83384609	-4.669070681	2.83384609
X Variable 1	0.836093898	0.044949967	18.60054541	1.39468E-23	0.745715932	0.926471863	0.745715932	0.926471863

APPENDIX B. POWER MODEL & ANOVA OUTPUT

C1	C2	C3	C4	C5		
1	3	1	1	1		
X	Y	Z	Actual Cost	Predicted Cost	Residual	Residual^2
4	2025	1	77.90	22.18	55.72	3104.27
4	2025	1	28.37	22.18	6.19	38.37
4	2025	1	40.66	22.18	18.48	341.38
4	2025	1	28.20	22.18	6.02	36.19
4	2025	1	41.59	22.18	19.41	376.63
4	2025	1	47.48	22.18	25.30	639.89
4	2025	1	20.22	22.18	-1.96	3.82
6	2025	1	30.09	32.05	-1.96	3.84
6	2025	1	29.18	32.05	-2.87	8.21
6	2025	1	57.23	32.05	25.19	634.30
6	2025	1	22.18	32.05	-9.87	97.40
6	2025	1	41.39	32.05	9.34	87.20
6	2025	1	20.46	32.05	-11.59	134.32
6	2025	1	32.05	32.05	0.00	0.00
6	2025	1	30.53	32.05	-1.52	2.32
6	2025	1	53.10	32.05	21.05	442.99
6	2025	1	18.16	32.05	-13.89	192.98
6	2025	1	17.56	32.05	-14.48	209.80
6	2025	1	26.14	32.05	-5.90	34.86
6	2025	1	35.23	32.05	3.18	10.13
6	2025	1	43.45	32.05	11.40	129.96
6	2025	1	24.15	32.05	-7.89	62.32
6	2025	1	32.65	32.05	0.60	0.36
6	2025	1	35.92	32.05	3.87	15.00
6	2025	1	51.04	32.05	18.99	360.78
6	2025	1	32.55	32.05	0.50	0.25
8	2025	1	24.15	42.39	-18.24	332.60
8	2025	1	16.33	42.39	-26.06	679.06
8	2025	1	24.02	42.39	-18.37	337.31
8	2025	1	33.19	42.39	-9.20	84.68
8	2025	1	32.69	42.39	-9.70	94.13
8	2025	1	32.34	42.39	-10.05	100.99
8	2025	1	24.31	42.39	-18.08	327.00
8	2025	1	24.44	42.39	-17.94	322.02
8	2025	1	25.99	42.39	-16.40	269.02
8	2025	1	16.37	42.39	-26.02	677.09
8	2025	1	23.66	42.39	-18.73	350.72
8	2025	1	45.35	42.39	2.96	8.76
8	2025	1	36.99	42.39	-5.39	29.10
10	2025	1	35.75	53.10	-17.35	300.93
10	2025	1	23.18	53.10	-29.92	894.98
10	2025	1	31.20	53.10	-21.90	479.57
10	2025	1	24.64	53.10	-28.45	809.51
10	2025	1	25.32	53.10	-27.78	771.50
10	2025	1	32.92	53.10	-20.18	407.04
10	2025	1	25.24	53.10	-27.85	775.70
12	2025	1	38.45	64.10	-25.66	658.23
12	2025	1	31.44	64.10	-32.66	1066.70
12	2025	1	24.33	64.10	-39.77	1581.66
16	2025	1	35.32	86.85	-51.53	2655.55

R Square	MSE
0.0475	420

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.939681846
R Square	0.883001972
Adjusted R Square	0.880564513
Standard Error	3.980230726
Observations	50

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	5739.061294	5739.061294	362.2633234	5.26282E-24
Residual	48	760.4273585	15.84223663		
Total	49	6499.488652			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95,0%*	*Upper 95,0%*
Intercept	0.006415594	1.777754283	0.003608819	0.997135542	-3.567998959	3.580830147	-3.567998959	3.580830147
X Variable 1	0.816233542	0.042884688	19.03321632	5.26282E-24	0.730008098	0.902458986	0.730008098	0.902458986

APPENDIX C. LOGARITHMIC MODEL & ANOVA OUTPUT

C1	C2	C3				
-362	93	389				
X	**Y**	**Z**	**Actual Cost**	**Predicted Cost**	**Residual**	**Residual^2**
4	2025	1	77.90	22.18	55.72	3104.27
4	2025	1	28.37	22.18	6.19	38.37
4	2025	1	40.66	22.18	18.48	341.38
4	2025	1	28.20	22.18	6.02	36.19
4	2025	1	41.59	22.18	19.41	376.63
4	2025	1	47.48	22.18	25.30	639.89
4	2025	1	20.22	22.18	-1.96	3.82
6	2025	1	30.09	38.48	-8.39	70.35
6	2025	1	29.18	38.48	-9.29	86.34
6	2025	1	57.23	38.48	18.76	351.88
6	2025	1	22.18	38.48	-16.30	265.55
6	2025	1	41.39	38.48	2.91	8.48
6	2025	1	20.46	38.48	-18.02	324.60
6	2025	1	32.05	38.48	-6.43	41.30
6	2025	1	30.53	38.48	-7.95	63.19
6	2025	1	53.10	38.48	14.62	213.76
6	2025	1	18.16	38.48	-20.32	412.84
6	2025	1	17.56	38.48	-20.91	437.28
6	2025	1	26.14	38.48	-12.33	152.06
6	2025	1	35.23	38.48	-3.24	10.52
6	2025	1	43.45	38.48	4.97	24.73
6	2025	1	24.15	38.48	-14.32	205.10
6	2025	1	32.65	38.48	-5.83	33.95
6	2025	1	35.92	38.48	-2.55	6.52
6	2025	1	51.04	38.48	12.57	157.94
6	2025	1	32.55	38.48	-5.93	35.13
8	2025	1	24.15	50.04	-25.89	670.05
8	2025	1	16.33	50.04	-33.71	1136.15
8	2025	1	24.02	50.04	-26.01	676.74
8	2025	1	33.19	50.04	-16.85	283.93
8	2025	1	32.69	50.04	-17.35	301.03
8	2025	1	32.34	50.04	-17.70	313.20
8	2025	1	24.31	50.04	-25.73	662.10
8	2025	1	24.44	50.04	-25.59	655.00
8	2025	1	25.99	50.04	-24.05	578.40
8	2025	1	16.37	50.04	-33.67	1133.61
8	2025	1	23.66	50.04	-26.38	695.67
8	2025	1	45.35	50.04	-4.69	21.98
8	2025	1	36.99	50.04	-13.04	170.11
10	2025	1	35.75	59.01	-23.26	540.90
10	2025	1	23.18	59.01	-35.83	1283.51
10	2025	1	31.20	59.01	-27.81	773.34
10	2025	1	24.64	59.01	-34.36	1180.74
10	2025	1	25.32	59.01	-33.69	1134.74
10	2025	1	32.92	59.01	-26.09	680.43
10	2025	1	25.24	59.01	-33.76	1139.82
12	2025	1	38.45	66.33	-27.89	777.65
12	2025	1	31.44	66.33	-34.89	1217.37
12	2025	1	24.33	66.33	-42.00	1764.05
16	2025	1	35.32	77.90	-42.57	1812.47

R Square	MSE
0.0798	**541**

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.896076885
R Square	0.802953783
Adjusted R Square	0.798848654
Standard Error	5.16538892
Observations	50

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	5218.789003	5218.789003	195.5976737	1.49362E-18
Residual	48	1280.69965	26.6812427		
Total	49	6499.488652			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95,0%*	*Upper 95,0%*
Intercept	-2.602415925	2.586717123	-1.006069006	0.319427325	-7.803359281	2.59852743	-7.803359281	2.59852743
X Variable 1	0.779274002	0.055719646	13.98562382	1.49362E-18	0.667242146	0.891305858	0.667242146	0.891305858

APPENDIX D. LOGARITHMIC MODEL & ANOVA OUTPUT

C1	C2	C3	C4	C5		
1	-409	1	-6553	1		
X	**Y**	**Z**	**Actual Cost**	**Predicted Cost**	**Residual**	**Residual^2**
4	2025	1	$ 78	$ 71	$ 7	$ 53
4	2025	1	$ 28	$ 71	$ -42	$ 1,783
4	2025	1	$ 41	$ 71	$ -30	$ 896
4	2025	1	$ 28	$ 71	$ -42	$ 1,798
4	2025	1	$ 42	$ 71	$ -29	$ 842
4	2025	1	$ 47	$ 71	$ -23	$ 535
4	2025	1	$ 20	$ 71	$ -50	$ 2,537
6	2025	1	$ 30	$ 71	$ -41	$ 1,641
6	2025	1	$ 29	$ 71	$ -41	$ 1,715
6	2025	1	$ 57	$ 71	$ -13	$ 179
6	2025	1	$ 22	$ 71	$ -48	$ 2,344
6	2025	1	$ 41	$ 71	$ -29	$ 853
6	2025	1	$ 20	$ 71	$ -50	$ 2,514
6	2025	1	$ 32	$ 71	$ -39	$ 1,486
6	2025	1	$ 31	$ 71	$ -40	$ 1,606
6	2025	1	$ 53	$ 71	$ -18	$ 306
6	2025	1	$ 18	$ 71	$ -52	$ 2,750
6	2025	1	$ 18	$ 71	$ -53	$ 2,812
6	2025	1	$ 26	$ 71	$ -44	$ 1,976
6	2025	1	$ 35	$ 71	$ -35	$ 1,251
6	2025	1	$ 43	$ 71	$ -27	$ 737
6	2025	1	$ 24	$ 71	$ -46	$ 2,157
6	2025	1	$ 33	$ 71	$ -38	$ 1,440
6	2025	1	$ 36	$ 71	$ -35	$ 1,202
6	2025	1	$ 51	$ 71	$ -20	$ 382
6	2025	1	$ 33	$ 71	$ -38	$ 1,448
8	2025	1	$ 24	$ 71	$ -46	$ 2,157
8	2025	1	$ 16	$ 71	$ -54	$ 2,945
8	2025	1	$ 24	$ 71	$ -47	$ 2,169
8	2025	1	$ 33	$ 71	$ -37	$ 1,399
8	2025	1	$ 33	$ 71	$ -38	$ 1,437
8	2025	1	$ 32	$ 71	$ -38	$ 1,464
8	2025	1	$ 24	$ 71	$ -46	$ 2,143
8	2025	1	$ 24	$ 71	$ -46	$ 2,130
8	2025	1	$ 26	$ 71	$ -45	$ 1,990
8	2025	1	$ 16	$ 71	$ -54	$ 2,941
8	2025	1	$ 24	$ 71	$ -47	$ 2,203
8	2025	1	$ 45	$ 71	$ -25	$ 637
8	2025	1	$ 37	$ 71	$ -34	$ 1,129
10	2025	1	$ 36	$ 71	$ -35	$ 1,214
10	2025	1	$ 23	$ 71	$ -47	$ 2,248
10	2025	1	$ 31	$ 71	$ -39	$ 1,552
10	2025	1	$ 25	$ 71	$ -46	$ 2,112
10	2025	1	$ 25	$ 71	$ -45	$ 2,050
10	2025	1	$ 33	$ 71	$ -38	$ 1,419
10	2025	1	$ 25	$ 71	$ -45	$ 2,057
12	2025	1	$ 38	$ 71	$ -32	$ 1,034
12	2025	1	$ 31	$ 71	$ -39	$ 1,533
12	2025	1	$ 24	$ 71	$ -46	$ 2,140
16	2025	1	$ 35	$ 71	$ -35	$ 1,244

R Square	MSE
0.0000	1,612

SUMMARY OUTPUT

Regression Statistics	
Multiple R	65535
R Square	-1.39933E-16
Adjusted R Square	-0.020408163
Standard Error	11.51705803
Observations	50

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	-9.09495E-13	-9.09495E-13	0	#NUM!
Residual	49	6499.488652	132.6426256		
Total	50	6499.488652			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*
Intercept	32.10189051	1.628757966	19.70942963	6.11124E-25	28.82877883
X Variable 1	0	0	65535	#NUM!	0

About the Author

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Naufal Abdurrahman is an engineer with over six years of professional experience in the oil and gas sector. He currently serves as a Cost Analyst Engineer at the national oil company of Indonesia. Throughout his career, he has been involved in various downstream oil and gas projects, including fuel terminal, pipeline, storage tank and related infrastructure. He earned a bachelor's degree in Civil Engineering from University of Indonesia (UI). Currently, he is participating in a distance learning mentoring program under the supervision of Dr. Paul D. Giammalvo, CDT, CCE, MScPM, MRICS, GPM-m, Senior Technical Advisor at PT Mitratata Citragraha, as part of his preparation toward obtaining the Certified Cost Professional (CCP) certification from AACE.

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