Current Challenges of Multidisciplinary Industrial Construction Projects: A Study of the EPC Design Model on Cost Performance in Indonesia

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Abstract—The Engineering-Procurement-Construction (EPC) system challenges contractors by running the Engineering, Procurement, and Construction of a one-stop multidisciplinary service project. After receiving the EPC lump sum contract, the contractor bears the risk of cost changes arising from the contractor's design, continuing the Front-End Engineering Design (FEED) as a reference in the bid price proposal. This study identifies EPC design risk in CPO Refinery plant-based agro-industrial projects in Indonesia (2013-2018) using cost-balancing options to obtain the lowest cost overruns or a maximum cost increase of 10% of the contract value after presenting an overview of the strategy and research tools. Subsequently, a suitable recommendation for the future directions of the EPC concept is proposed considering the tender, contractual, and engineering stages.

Keywords—design, Engineering–Procurement–Construction (EPC), Front-End Engineering Design (FEED), cost performance, agroindustry, multidisciplinary project

I. INTRODUCTION

The Engineering, Procurement, and Construction (EPC) businesses in Europe and Asia have been under pressure since 2018 because of the oil price decline in the world market. As a result, productivity for EPC Contractors decreases, and profit margins decrease/loss/poor cost performance causes a decrease in global competitiveness; thus, investors/ owners must save Capital Expenditure (CAPEX) of 40-50% [1]. In Indonesia, rising domestic prices for steel materials reached 19.43% when the global outbreak of the Covid-19 virus [2] added pressure to the domestic construction industry, and it became challenging to execute EPC projects for project budgets (CAPEX) released before 2018. To ensure that the project can continue to run well, the contractor must be able to offer innovative solutions with the latest integrated designs, appropriate construction quality, and methods by focusing on construction cost optimization to select the option through the construction technology system [3], which meets the needs of emerging technologies of the 21st

century. This option suits the EPC concept in which the contractor handles the design.

Research on EPC critical activities across large-scale residential construction projects in Iran, using the TOPSIS method as a multi-attribute decision-making technique to rank project risk variables, shows that project planning and designing is at the top ranking of The Engineering (E) phase and has a pivotal role in project performance [4]. As an initial process of an EPC project, the design is essential and risky for overall project performance [5]. The EPC contract runs with a lump sum system, meaning that the contractor's design using front-end engineering design (FEED) as the basic design reference for the EPC's further detailed design [6, 7] to prepare the construction document.

Research on the construction productivity of 31 industrial projects in the USA has shown that changes in the owner's design are risky because of the increased direct costs caused by construction rework [8]. Reference [9] studied design risk according to the perceptions of contractors, consultants, and owner organizations in Nigeria. The results share the same perception that design changes have a high-risk impact on project performance owing to changes in the Scope of work, which create cost and time risks. Regarding the EPC Oil and Gas project, Reference [10] showed that the risk of design changes is the main factor contributing to decreased project performance. Meanwhile, [11] identified the risk of design change at the owner's request, lack of Communication between the design team, delays in decision-making, and the experience of consultants and owners affecting the cost performance of EPC projects.

Research on the cost overrun risk impact for various EPC projects showed that design changes have indicated a cost increase in industrial projects by 5%–20% (USA, UK, Singapore); infrastructure projects, dams, civil, and hydroelectric projects by 20%–31% (Pakistan, Taiwan, Malaysia, USA); and the increase in maritime/dam project costs in Portugal reached 41% for various reasons [12]. The survey results of structured interviews, as in Reference [13], of three contractors in the field of agro-

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industrial Crude Palm Oil (CPO) refineries, referred to as "CPO Refinery Projects" in South Kalimantan, Indonesia, in 2015, found that due to design changes, the costs increased by 5–10%. The percentage of project cost overruns in Indonesia was still lower than that of overseas projects. However, the resulting survey through structured interviews [13] stated that these cost overruns disrupted the contractor's cash flow because an increase in costs of 5% was equivalent to suffering a maximum delay penalty, as stated in [14]. Moreover, if the price increases by up to 10%, the contractor's financing will be depressed because it is equivalent to losing its profit.

AACE International Recommended Practice (2019) et al. [15-17] described design issues that need to be addressed in this research problem: (1) input at the upstream EPC process of the tender stage regarding the quality of tender (FEED) documents, while in the downstream process, consider the post-tender process, that is, the EPC contract and Detailed Engineering Design during implementation; (2) the contractor needs to study the EPC project characteristics and their competence because it involves contractor strategies in handling the multidisciplinary design scope of the EPC project. Therefore, it is necessary to understand the internal processes to achieve the success of the EPC project and solve existing problems. It also relates to the availability of contractor resources, project risks, and company profit targets.

This study identified the EPC design risk that correlates with the cost performance of CPO Refinery plant-based agro-industrial projects in Indonesia from 2013 to 2018. Cost performance is observed through project cost overruns owing to design changes. This study aims to create an EPC design model for the contractor's Cost Performance to obtain the lowest risk of cost overruns or a 10% maximum of the initial contract value [14] as a project's Cost Performance Benchmarking. Cost balancing is implemented as an option to anticipate the design risk. Finally, this study proposes a suitable recommendation for future directions of the EPC concept considering the tender, contractual, and engineering stages after presenting the strategy and an overview of the methodologies and research tools.

II. CHALLENGES IN THE EPC SYSTEM

A. Challenges of EPC Project Scopes and Characteristics

The EPC system is widely used to construct industrial refinery facilities, especially the processes of chemicals, petrochemicals, hydrocarbons, oil and gas, and other highly complex refinery plants [15], because of its multidisciplinary project scope. EPC systems are faster than conventional design-bid-construction systems, which require more time in the design stage. The contractor was entirely responsible for any part of the preliminary design. In addition, the certainty of the final project cost for the owner, where the contractor is responsible for determining the quantity and level of quality control, as well as the implementation of appropriate performance and reliability

requirements so that the final quality assurance in the operation phase will be fulfilled in the EPC project [5].

This study references the typical EPC project lifecycle in the oil and gas sectors. The first principal phase of EPC front-end loading before focuses on project implementation [18], comprising project feasibility, conceptual design, and basic design (FEED). Fig. 1 describes two main objectives for each decision gate: to check whether the previous stage was completed successfully and to decide whether the Project Owner wanted to continue the project to the next step [19]. Therefore, the gate 3 decision (DG 3) at the end of the FEED phase is the basis for the Approval for Expenditure (AFE) or the Final Investment Decision (FID). This means that the budget support for the implementation of the project has been released, and the EPC project idea can be executed.



Fig. 1. Typical life cycle of EPC projects [19].

The Scope of the main work packages of the CPO Refinery plant is to build a Refinery and Fractionation Plant and its supporting facilities and utility works. EPC services for CPO Refinery projects include multidisciplinary design, procurement, construction, commissioning, start-up, training, and acceptance handover activities. As in [13], a survey of structured interviews stated that contractors involved in this project must understand the design and technology of the main process plant. All obligations, including design, are EPC project characteristics that distinguish them from traditional systems until they are ready to operate and handed to the owner. Thus, this EPC system has become a new challenge in the construction industry owing to the merging of the goals of several stakeholders in a one-stop multidisciplinary service project [5].

EPC projects cannot be separated from lump-sumturnkey projects, collectively called lump-sum-turnkey EPC projects, owing to the following challenges [5]:

- In lump sum (EPC), the employer provides a basic engineering design to be deepened in the tender proposal process. Meanwhile, lump sum EPC usually uses third-party services, specialist vendors, or owners to complete commissioning and start-up responsibilities.
- In the Turnkey Project, the Employer only provides technical specifications, design criteria, standards, and codes. Furthermore, the contractor prepares the basic design and project design details.

B. Challenges of EPC Tender Stage

1) Tender document risks

The specific characteristics of the EPC system, as previously described, are: (1) the contract is a lump sum, (2) the tender offer uses the basic design (FEED) document, the price offer with no detailed design, and (3) in the construction stage, the detailed design continues with the design proposal as a reference. There is potential for design changes to occur, leading to cost overruns due to inaccurate designs when submitting price offerings [5, 6, 15].

The tender of an industrial project with a unique plant process in developing countries has typical challenges for an EPC contractor that deals with documents issued by the Employer under the following conditions [5]:

- Incomplete conceptual design; an outline of functional specifications require finalization during the bid negotiation phase
- The initial Plot Plan with no fixed layouts also needs to be defined during the bid negotiation phase
- Uncoordinated technical and administrative requirements
- A series of ambiguous contract provisions tend to benefit employees.

Subsequently, contractors face challenges for design risk in the tender process because they are responsible for any costs arising from design changes following the

Federation Internationale des Ingenieurs-Conseils (FIDIC) terms as EPC contract conditions [6, 7].

2) Bid Price Evaluation

This study discusses the performance evaluation of the EPC project's cost, consisting of the initial costs of the contract price and the final increase cost due to design changes, including contractors' profits, as illustrated by the EPC cost diagram in Fig. 2. [13, 20, 21] modified the diagram with a resulting survey through structured interviews to indicate cost overruns, as in [13]. The diagram guides the flow of cost overruns toward any direct or indirect cost budget item. Fig. 2 shows the budget line that predicts the flow of costs up to the lowest cost item of the work breakdown schedule for evaluating the project cost budget.



Fig. 2. EPC project cost composition diagram [13, 20, 21].

	Primary Characteristic		Secondary Characterist	ic
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 I. COST ESTIMATE CLASSIFICATION MATRIX FOR PROCESS INDUSTRIES [15]

The project cost performance indicates the achievement of quality and quantity progress to assess its suitability for project objectives [22]. The final cost is evaluated using a cost-balance approach to obtain the risk target limit of the lowest-cost overruns or a maximum of 10% of the initial contract value [14]. According to relevant literature, the resulting study said that the EPC tender considers two concerns sub-process steps of price analysis in preparing

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the tender price offer. The steps assume the design needs when submitting the bid price, that is, (1) owing to the risks of the schematic design that need to be detailed, and (2) owing to the accuracy of the tender cost estimation [15, 21, 23]. Mughees, Galloway, Zhang et al. recommend anticipating unexpected risk costs because the design requires further refinement. Additionally, there are potential gaps in interpreting the technical requirements of tender documents, which are multidisciplinary in Scope in the EPC tender proposal, resulting in inaccurate bids. By considering the level of cost accuracy at the tender stage (Table I) and illustrated by Fig. 3, this price challenges the contractors to find a tender strategy in which variants of cost risk are included in Class 2 based on the cost estimation classification system developed by the Association of Advancement Cost Engineering (AACE) International [15]; the range of low and high estimate accuracy at the tender stage is Low/most down: -5% to -15% and High/highest: +5% to +20% where the project has been defined and reached the Final Investment Decision (FID) stage.



Fig. 3. Illustration of variability of estimated accuracy range in the industrial process [15].

References [12, 16, 20] proposed the following subprocess steps in the preparation price analysis of the contractor during the tender process:

- A sub-process considers the risks of the schematic design and incomplete/unfixed FEED, reflecting unexpected costs of 5% to 7%, overrun costs of 10–12%, and profits of 5%–10% of the total base price offer.
- (2) A sub-process considers the Accuracy of Cost Estimation of AACE of the tender process, which reflects a 5% to 20 % increase in the total base price [15].

Thus, the contractor's tender bid price must be evaluated by improving the base price reflected by 10% to 25% to maintain cost overruns caused by design risk not exceeding a 10% target limit during construction, as described in the literature above.

C. Challenges in the Design Stage

The post-contract assignment of the EPC system begins with a Detailed Engineering Design (DED). DED continues the employer's FEED stage in the EPC tender proposal [5]. Design is the creation of innovative human hands and brains that transform FEED ideas into reality in an integrated manner during the engineering phase. This was done by certified professional engineers who performed this process following standards and design codes and iteratively analyzed and produced designs for construction execution documents.



Fig. 4. The execution strategies in EPC oil and gas projects with fast-track system [18].

The construction execution process is nearly sequential in an EPC system. This process is related to the industrial process system and the target for achieving the production capacity [24]. However, to speed up the project schedule and start early operations, most projects, usually in the EPC oil and gas project references, are conducted in a fasttrack mode with overlapping engineering, procurement, and construction phases. The fast-track system aims to accelerate construction completion using an EPC construction approach. Fig. 4 compares the regular and fast-track execution processes of an EPC oil and gas project [18]. Foundation, civil, and structural work can be initiated first during the Mechanical, Electrical, Electronic & Instrument (E&I) installation design work and the related factory design process. The process is still ongoing because it must involve main equipment plant approval and vendor/supplier determination and still requires time for the owner's authorization. Thus, multidisciplinary design challenges are bottlenecks that lead to the risk of project cost overruns owing to potential design changes during implementation. Therefore, optimizing the building costs is unavoidable, for example, if there is a change in the plant process layout.

Value Engineering is an action plan for optimizing building costs against existing designs to obtain optimal added value for all stakeholders by reviewing aspects of quality, work methods, maintenance, and durability to minimize unnecessary costs [25]. According to the Silver FIDIC Book, as one of the Conditions of Contract (COC) reference for the EPC contract, the contractor can apply Value Engineering in the design stage, as required by clause 13.2 Value Engineering and 13.3 Variation Procedure [7]. Therefore, the implementation of value engineering is necessary from the beginning of the project, both at the tender and the entire EPC project life cycle, not only to cost optimize the project but also at the tender stage, which can improve the contractor's bid price by choosing the most appropriate technical method but also an opportunity to reduce the pressure of contractor finance [26] by cost-balancing options [13].

III. RESEARCH METHODOLOGY

A. Research Data Collecting

This study used qualitative and quantitative approaches to observe the research object. Research data sources were obtained from primary data by running surveys and secondary data from contractors' project reports and relevant literature reviews. The findings of previous studies and structured interview surveys have been used to strengthen the initial design risk variables that affect cost overruns. Subsequently, the initially obtained list variables and indicator measurements were validated in a forum group discussion to finalize it as the primary research instrument [27] for surveys to confirm the field facts faced by EPC contractor respondents in Indonesia.

B. Research Strategy

This paper presents an ideal research strategy, with research questions as a starting point. Research questions inspire seeking and stimulating systematic discussions on potential solutions guided by the background structure of problem. Therefore, the research research the methodology strategy needs to be developed to answer the "what" and "how" research questions [27-29] to achieve the main objectives and goals of the research. As illustrated in Table II, this study raises five main questions that must be answered to formulate the research problem: (1) What are the characteristics of EPC industrial construction projects in Indonesia? (2) What are the potential design risks of EPC industrial construction projects in Indonesia? (3) What are the measurement indicators of the cost performance of EPC industrial construction projects in Indonesia? (4) What are the results of the design risk model on the cost performance of EPC Industrial construction projects in Indonesia? (5) What were the recommendations of this study?

No.	Reasearch Questions	Step and Model Description	Methodology	Output	Literature/tools
1	What are the Characteristics of an EPC Project?	EPC'- PROPICT CIMAACTERISTIC	Literature studies, surveys and structured interviews		
2	What are the Potential EPC Design Risks?	EPC CONTRACTOR CONTRACTUAL EPC DISTALLED EPC DISTALLED DE SIGN DE SIGN OPTIMIZING IMPLEMENTATION	Literature studies, expert validation, pilot surveys, structured interviews and questionnaire surveys	 Statistical description (frequency analyses), The preliminary model from Factored Analysis of qualitative variables The quantitative model uses dominant variable data from step 2 analysis to obtain a regression correlation between the Final/Actual Project Cost affected by the initial contract value and the 	[4, 23, 39]
3	What are the Cost Performance Indicators of the EPC Project?	CONTRACT VAUE PERCEMANCE INDICATORS ACTUAL FINIA.COST	Literature studies, surveys and structured interviews	increase in direct and indirect costs due to design changes.	
	What are the Results of the Main Survey Data Analysis Model and Methods?	Description / frequency Analysis	Qualitative - Descriptive	Statistical description	S oftware
4					
		Multivariate Statistical and Factored Analysis - Qualitative Data	Qualitative - Descriptive	Initial Model	S oftware
		Analysis of Regression - Quantitative Data	Quantitative Analysis	Final Model	S oftware
5	What are the Results and Recommendations?	Analysis Result Model	Survey Results Model	Final Model Study Results	Survey Findings

TABLE II. RESEARCH STRATEGY

The research questions dealt closely with the framework of the initial model, methodology, outcoming results, and literature support (Table II) in determining the steps to compile the data survey following the research goals. The action plan for the research strategy is as follows:

- (1) Compilation of a list of variables and validated the measurement indicators in the statement checklist to become a research measurement tool (questionnaire).
- (2) A pilot survey of three prospective respondents' CPO refinery projects was conducted to ensure that grammar and writing were aligned with the same perceptions of the research goals.
- (3) Questionnaires were randomly distributed to prospective respondent projects with different projects running EPC-based CPO refinery projects in various regions of Indonesia. The questionnaire

was designed with one respondent reflecting on one project data, which differed from each other.

(4) **Analysis and discussion.** This study analyzed the data using both qualitative and quantitative approaches. A preliminary examination was validated, and reliability tests were conducted on the primary survey data. The ranking of the results of the qualitative analysis selected the most dominant variables. Meanwhile, a quantitative analysis generates a model between the final project cost, initial contract value, and cost overruns caused by design changes.

C. Respondent Selection Criteria

This study observed refinery biodiesel plants as a subsample of respondents' projects. The project is part of the CPO Refinery plant-based agro-industrial sector under the Engineering-Procurement-Construction-Commissioning (EPCC) contract system. The criteria respondents' project domicile was determined by the number of cored agroindustry project companies engaged in the CPO refinery sector. Data were obtained from 17 sizable private companies whose businesses played a role in Indonesia from 2016 to 2020 [30]. During this period, the Indonesian government promoted CPO-based biodiesel through the B30 program as an alternative blend to biodiesel made from palm oil. Pertamina has collaborated with major Biofuel Business Entities-private parties appointed by the Ministry of Energy and Mineral Resources-to provide a 28-acceptance point of supply base for biodiesel production throughout Indonesia [31].

The project period of this study was five years, from 2013 to 2018. Prospective respondent projects were selected from four samples of CPO refinery projects built by each sizable private company to meet the acceptance point of the supply base as required. The initial population of the project sample was $17 \times 4 = 68$. Furthermore, the number of subsamples of respondents' projects was calculated using Slovin's formula, which is influenced by the sample size (n), known population size (N), and acceptable error value (e = 10%), as follows:

$$n = \frac{N}{1 + N(e)^2} \tag{1}$$

Therefore, the resulting value of n equals the sample size of 40 project respondents.

D. Variables and Measurement Indicators

This study was guided by a literature review and a primary research survey. The resulting analysis of relevant literature regarding design changes that cause cost overruns revealed six potential design risks as independent variables of X: (1) EPC project characteristics, (2) quality of the tender document, (3) EPC contractual, (4) Detailed Engineering Design, (5) contractor competence, and (6)

ability to carry out design optimization. The project cost performance as a dependent variable of Y indicates the cost at the end of the project, which measures the comparison between the actual project cost and the initial contract value, with a maximum cost target increase of 10% [14]. Table I summarizes the attributes and initial measurement indicators, consisting of six independent variables (X) for the 58 measurement indicators and one dependent variable (Y) for the four measurement indicators.

The indicators and analysis result scores were measured as follows:

- The contractor was provided with a statement as an indicator of variable X using a five-point Likert scale measurement to answer what respondents experienced in the project related to design risks that affect project cost overruns, with a score of (1) "Strongly Disagree"; (2) "Disagree"; (3) "Neutral"; (4): "Agree," and (5) "Strongly Agree".
- (2) The contractor was asked about the Cost Performance status, which indicated a comparison between the project's actual cost and initial contract value in the final account. Cost performance (variable Y), measured using a five-point scale, with scores as (1) "Very Poor" (>110%); (2) "Not Good" (> 106.5% to = 110%); (3) "Fairly Good" (> 103.5% to = 106.5%); (4) "Good" (= 100% to = 103.5%); and (5) "Very Good" (< 100%).
- (3) The ranking result is interpreted by comparing a total obtained survey score and the highest base score where (1) 0% to 19.99% show "Strongly disagree"; (2) 20.00% to 39.99% show "Disagree"; (3) 40.00% to 59.99% show "Neutral"; (4) 60.00% to 79.99% show "Agree"; and (5) 80.00% to 100% show "Strongly Agree".

TABLE III. RESUME ATTRIBUTES AND INITIAL MEASUREMENT INDICATORS				
Variable	Indicator	Attributes of EPC Design to Cost Performance	Literature Support	
EPC Project Characteristics (X1)	X1.1; X1.2; X1.3; X1.4; X1.5; X1.6; X1.7	It consists of 7 attributes:1. Benefits of the Project to the community; 2. Organizational hierarchy; 3. Project status; 4. Priority scale; 5. Factory process technology; 6. Difficulty degree; 7. Realistic schedule	[4]; [9]; [10]; [11]; [17]; [32]	
EPC Tender Document (X2)	X2.1; X2.2; X2.3; X2.4; X2.5; X2.6; X2.7; X2.8	It consists of 8 attributes:1. Scope of work; 2. Completeness of tender documents; 3. FEED document quality; 4. Technical specifications; 5. Planning standards; 6. FEED verification; 7. Correction of quotations; 8. Confirmation of the Plot Plan before running the contract	[4]; [9]; [10]; [16] [32]; [33]; [34]; [35]; [36];	
EPC Contractual (X3)	X3.1; X3.2; X3.3; X3.4; X3.5; X3.6; X3.7; X3.8; X3.9; 3.10; X3.11; X3.12; X3.13; X3.14; X3.15; X3.16; X3.17; X3.18; X3.19; X3.20	It consists of 20 attributes: 1. Risk allocation; 2. Price analysis; 3. specifications for material prices; 4. Design Tools; 5. Method Statement; 6. Design schedule; 7. Construction schedule; 8. Local material content; 9. Organizational Chart; 10. Sub-con support; 11. Supplier support:12. Communication and coordination; 13. Safety, Health, and Environment; 14. Site Instructions; 15. Due of payment; 16. Cost Escalation; 17. Penalty; 18. Contract Addendum; 19. Engineering fees; 20. Contract drawings attachment	[4]; [9]; [10]; [16]; [32]; [33]; [34]; [35]; [36]; [37]; [39]	

TABLE III. RESUME ATTRIBUTES AND INITIAL MEASUREMENT INDICATORS

Variable	Indicator	Attributes of EPC Design to Cost Performance	Literature Support
EPC Detailed Design Document (X4)	X4.1; X4.2; X4.1; X4.3; X4.4; X4.5; X4.6; X4.7; X4.8; X4.9	It consists of 9 attributes: 1. Quality Plan; 2. Number of appropriate drawings; 3. The ability of the design team; 4. Design reporting; 5. Owner supervision; 6. Design reviews; 7. Design errors; 8. Design changes; 9. Evaluation of design progress	[4]; [9]; [10]; [17]; [33]; [37] [40]
EPC contractor competence (X5)	X5.1; X5.2; X5.3; X5.4; X5.5; X5.6; X5.7; X5.8; X5.9	It consists of 9 attributes: 1. EPC project experience; 2. Financial background; 3. Software design support; 4. Human resources for engineering support; 5. HSE experiences; 6. Professional Indemnity Insurance; 7. Top ten risk rankings; 8. EPC risk database; 9. Internal approval of the proposed tender price	[4]; [9]; [10]; [11]; [16]; [17]; [26]; [32]; [33]; [41]
Implementation of Design Optimizing (X6)	X6.1; X6.2; X6.3; X6.4; X6.5	It consists of 5 attributes: 1. VE experiences; 2. VE implementation from the beginning; 3. VE Owner experience; 4. Resource constraints in VE implementation; 5. Consistency of VE Supporting from the Owner	[25]; [35]
EPC Cost Performance (Y1)	Y1.1; Y1.2; Y1.3; Y1.4	It consists of 4 attributes: 1. Final project cost performance; 2. Performance of the billing progress realization, 3. The version of payment due; 4. Implementation of the actual payment amount	[4]; [11]; [15]; [14]; [17]; [22]

IV. RESULTS AND DISCUSSION

A. Respondents Description

This research analyzes the results of the primary survey data by distributing 40 questionnaires across 14 provinces in Indonesia, covering project respondents in Sumatra, 20% in Java, 42.5% in Kalimantan, 27.5% in Sulawesi, 5% in Maluku, and 2.5% in West Papua at 2.5%. According to the legality classification of Indonesian contractors, the respondent's company as the research object is a Limited Liability Company (PT) at 70%, public companies (Tbk.) at 22.5%, and state-owned enterprises (BUMN) at 7.5%. Following the classification of annual sales performance, M2 grade contractors contribute 12.5%, with an annual sales value of IDR 10 billion to IDR 50 billion; B1 grade contractors contribute 52.5%, with an annual sales value of IDR 50 billion to IDR 250 billion; and B2 grade contractors contribute 35.0%, with an annual sales value above IDR 250 billion to infinity. The value of the respondents' projects was between IDR 50 billion and IDR 150 billion, with an eight-fifteen-month project duration for each project from 2013 to 2018. All respondents claimed to have been involved in the project from the beginning to completing the final account. Therefore, they understood the problems of handling EPC projects. Respondents also certified construction Work Competency as proof of a person's competence according to the classification of working in the field of construction services in Indonesia, as required by regulations.

B. Descriptive Analysis Results

The survey results in this study provided various answers to the questionnaire filled out by 40 respondents. The range of basic questionnaire in comparison scores (lowest to highest) is 40 to 200. The lowest survey result score is 123; the highest is 173; the lowest survey result Yscores are 138; the highest is 163. The lowest score reflects disagreement with the indicator's statement as a finding. The highest score represents the information agrees, so it is not stated as a finding unless a negative or aberration statement. The description of the top-ranking indicator results of the obtained total score against the maximum score is summarized:

1) Indicator X2.7 reflects the price offer improvement at the EPC tender stage

Indicator X2.7, with a total score of 165, then 165/200 \times 100%, resulting in 82.50% of respondents strongly agreeing that the contractor had increased the EPC tender price offer by 10% to 25% to anticipate that the design was not detailed when submitting a proposal. In [23], the Class 2 classification of the AACE Matrix [15], and based on the survey results of structured interviews in 2020, showed that when determining the cost markup, a subprocess is required by including risk factors related to the level of accuracy of EPC bidding costs (FEED stage) with an overrun factor cost of 5% to 20%. According to [12], the correction percentage is 10-20% of the base price at the tender offer stage. The results of their research also stated that the bidding price needed to be more accurate owing to gaps in interpreting the tender document's technical requirements, which involved a multidisciplinary scope during the preparation of the EPC tender proposal document [12]. The results of the structured interview with the Project Owner in South Kalimantan in 2020 revealed that the increase in project cost must not be more than 10% because during EPC tender clarification, balancing a cost approach can be adopted through the implementation of Value Engineering (VE) as an alternative solution when there is a cost overrun of more than 10%. However, according to the contractor, implementing VE requires good cooperation with the employer to be consistently enforced during the project lifecycle. In addition, the VE problem is constrained by the contractor's competence and experience, owing to the contractor's limited resources.

2) Indicator X4.8 identifies the request for design changes

Indicator X4.8, with a total score of 154, then $154/200 \times 100$ %, resulting in 77.00% of respondents agreeing with this statement; therefore, the factor causing a significant design change in the EPC project was the owner's request. This design-change impact was consistent with the results

of previous studies. The risk of design changes during project implementation causes direct cost overruns owing to the construction rework. Hence, design changes must be minimized [8–11]. The resulting survey through structured interviews, as in [13], according to owners' perceptions of agro-industrial projects in South Kalimantan, showed that contractor design changes due to overbudgets, high maintenance costs and work items supplied by owners had not yet dealt with plant process vendors when the EPC tender was decided so that design changes occurred.

3) Indicator X2.3 identifies the certainty of the FEED tender document

Indicator X2.3, with a total score of 123, then 123/200 $\times 100\%$, resulting in 61.50% of respondents agreeing that the drawings on the FEED tender document (Plot Plan, P&ID, and Flow Process) are uncertain before the submission offer of the EPC tender. Most respondents agreed that the tender EPC documents received were doubtful, so there was a risk of causing cost increases due to design changes during construction. Reference [15] states that unfixed FEED risks increasing costs. FEED is a basic design provided by the employer, consisting of a draft Plot Plan (building layout) related to land, a Piping & Instrumentation Diagram (P&ID), and process flow diagrams related to the factory process technology from the vendor. Reference [17] stated that this uncertain FEED caused the technical proposals submitted by the contractor to have the potential to undergo design changes, thus affecting the quantity and quality of the final work. Subsequent studies also support the same thing that a plot plan incomplete shows the rate of tender documents in the EPC tender process, and P&ID has not been fixed because of "land acquisition problems"; methodology, irrelevant design criteria, and it were not determined from the beginning at the time of tender, and non-detailed technical specifications can increase the costs [10, 12, 32, 34, 38, 40]. Therefore, this study emphasizes the preparation and completeness of FEED tender documents as the topranking factor in reducing cost overruns because design changes during construction can be avoided.

4) Indicator X3.16 concerning price adjustment on the EPC contract

Indicator X3.16, with a total score of 161, then $161/200 \times 100\%$, resulting in 80.50% of the respondents strongly agreeing that the EPC lump sum contract does not apply a price adjustment for cost escalation. Thus, respondents realized and reaffirmed the provisions of the lump sum EPC project with no cost escalation. Reference [15] states that the EPC model is a lump sum contract with a fixed price. However, the quantity and quality must be clear from the beginning of the project when the design is the initial assignment of the EPC contractor. The lump sum EPC system must be maintained until all work is completed, and the contractor bears a cost change owing to the contractor's design and work method [26, 37].

5) Indicator X3.17 regarding the penalty clause on the EPC contract

Indicator X3.17, with a total score of 158, then 158/200 \times 100%, resulting in 79.00% of respondents agreeing that the project consistently applies delay penalties, but "There

is no reward for an acceleration of completion" in the last sentence is an affirmation for respondents as input so that "reward if there is an acceleration of completion" can be adopted in the EPC contract. Reference [37] and [39] in their research both noted that the contract must consist of an explanation of the provisions and procedures in the event of a redesign at the owner's request, which has an impact on the delay or acceleration of the implementation of the EPC lump sum contract to assure the contracting parties.

6) Indicator X1.6 regarding the degree of difficulty of the EPC project

Indicator X1.6, with a total score of 136, then 136/200 $\times 100\%$, resulting in 68.00% of respondents agreeing that "the degree of difficulty" in project work was undetected from the beginning. The survey revealed that most respondents acknowledged that the complexity of project work still needed to be seen from the start for various reasons. Therefore, they were aware of the risk of design changes occurring during implementation, which caused an increase in costs. According to the results of structured interviews, as in [13], the anticipation of the degree of difficulty of the project from the beginning to the time and cost implications can be controlled by implementing strategies of fast-track mode as a mainstay because the easy sequence of work can be done first, and complex work is done later according to the work sequence. This action plan can minimize the risk of cost overruns owing to design changes during project implementation. As in [18], which impacts acceleration as much as possible with minor likely additional costs but still meets technical requirements.

7) Indicator Y.1.1 assesses the project's cost performance

When comparing the final price to the initial contract value, indicator Y1.1, with a total score of 138, then $138/200 \times 100\%$, resulting in 69.00% of respondents above, correlates with the admitting that their project's final cost was "Fairly Good" to in Good. This survey results in the maximum increased costs for the respondent being 3.5%, less than 6.5% of the original contract value. A project's final price includes the cost overrun indicator. Project Cost Performance is used as one of the benchmarks of project success/failure in terms of cost by counting a maximum allowable cost increase of 10% of the initial contract cost as a project appointment with a "good cost performance", so as a guideline/criteria used as in [14]; article 54; 2, regarding Government Procurement of Goods/Services. Indicator Y.1.1 assesses the project's cost performance.

V. CONCLUSIONS AND RECOMMENDATIONS

A. Conclusions

The conclusions of this study resulted in top-ranking indicators of EPC design risk correlating with cost performance to answer the following research questions:

(1) The contractor improved the price offered when submitting the EPC tender (X2.7) by increasing the base price by 10–25% to anticipate the risk of design changes. This study shows that the risk of EPC project characteristics related to design uncertainty is the most salient reason for balancing the bid prices.

a) Significant design changes occurred because of "the owner's request" (X4.8) for projects handled by respondents; the cost increased during project implementation owing to the design changes.

b) The drawings on the FEED tender document (Plot Plan; P&ID and Flow Process) were uncertain before the EPC tender offer was submitted (X2.3) —the cost increases during project implementation due to design changes.

c) "Difficulty degree" project work has not yet been detected since the beginning of the project (X1.6); the cost increases during project implementation owing to design changes.

d) Compensation and price adjustment (escalation) are not included in the EPC lump sum contract (X3.16).

e) The project consistently applies a delayed penalty according to the conditions of the EPC contract (X3.17); there is no reward, if any, for the acceleration of completion owing to the design changes.

(2) The research survey results above correlate with the respondent's project cost performance (Y1.1), which shows that costs increased by 3.5%-6.5% compared to the original contract value. This study shows that the respondent's project can maintain the limit of cost overruns by less than 10% owing to design changes.

B. Recommendations

This research raises recommendations to address the challenges in the future direction of the EPC concept:

- The design optimization method with a costbalancing approach can adopt Value Engineering (VE) over the life of the project cycle, which is applied from start-to-finish planning to reduce contractor cost overruns.
- This research creates a new gap to expand on opportunities for further research to answer research questions that arise regarding the actual contract price after the contractor increases the bid price at the EPC tender stage by 10% to 25% of the base price owing to design risk; thus, the proposed solution can be implemented effectively to improve cost performance.
- "The reward if there is an acceleration of completion" can be adopted in the clause of the EPC contract.
- The FEED tender document must be well-prepared by the owner to reduce cost overruns owing to design changes during construction, emphasizing the completeness and certainty of the EPC tender document.
- Finally, the findings and solutions above recommend that starting good planning from the tender stage, contract preparation, and detailed

design stage will benefit parties in any industrial sector, especially contractors who carry out EPC industrial construction projects to achieve good project performance results.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

T. U. N. conceived and planned the research study and conducted simulations and sample preparation for data collection; D.E.H. and B. A. reviewed the methods analysis and models, and interpretation of the results; T. U. N. took the lead in writing this manuscript; all authors had approved the final version.

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