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Risk Analysis on the Equipment and Material Procurement Process of Engineering, Procurement, and Construction (EPC) Projects

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Abstract

Equipment and material non-compliance with the project requirements is one of the issues causing delay in large EPC projects as rework actions are inevitable. Detecting and controlling the potential risks at the procurement process of equipment and material can be done to anticipate this issue. This study aims to identify the major risks and recommend the response strategies to the equipment and material non-compliance by adopting a quantitative method through expert validation using Delphi method, questionnaire surveys, and risk analysis, as well as qualitative method through benchmarking study and interview with experts. The result of this study shows that lacking in the inspection of requirement, complete Request for Quotation (RFQ) information, contract term verification, fixed design requirements, attention to Purchase Order (PO) review, supervision to engineering design and drawing, and proper fabrication procedure are major risks that can potentially cause non-compliance. Improvement in communication between stakeholders and supervision to ensure the conformity with specifications are considered as the key elements in mitigating the identified major risks.

Keywords: Procurement process, non-compliance, risk analysis, EPC projects

■1.0 INTRODUCTION

The success of a project is measured from the achievement of the project objectives within the agreed time and the budgetary limits, at the desired level of performance and technology, utilizing resources efficiently and effectively (Kerzner, 2009). A project is deemed successful when it meets customer satisfaction regarding quality, efficiency, and innovation (Berawi et al., 2012; Davis, 2014; Serrador & Turner, 2015). Nevertheless, there are still many cases of construction projects that fail to achieve their project objectives by undergoing time delay in work progress that usually leads to project cost overruns (Shahhosseini et al., 2018).

Project delay is one of the major challenges in EPC projects in some countries caused by various factors such as poor project management (Hung & Wang, 2016), uncertain on-time delivery of equipment and material purchased from international suppliers (Alhajri & Alshibani, 2018; Yeo & Ning, 2002), late start in purchasing the long-load materials (Salama et al., 2008), lack of construction technology with high productivity (Nawi & Lee, 2016), shortage of qualified engineers and productive workers (Assaf & Al-Hejji, 2006), etc.

These issues are faced by the practice of EPC projects in Indonesia as well. The procurement process of EPC project mainly plays a vital role in EPC project owing to its significant ratio of equipment and material cost compared to the total project cost (Salama et al., 2008) and if it is performed effectively, the cost and performance can be improved as well (Willoughby, 2005). Purchasing activity in the procurement of the EPC project accounts for up to 80% of the total project value (Cagno et al., 2004) and for up to 45% for the crucial supplies (Kim & Lee, 2019; Micheli et al., 2009). However, the delay in the procurement of equipment and material has been one of the major issues faced by EPC projects, particularly in the oil and gas industry in Indonesia that has been in a constant decline for these past few years (SKK Migas, 2014).

The phenomenon that usually happened in the procurement process of an EPC project is that the required equipment and materials are custom made and fabricated by suppliers for the project, and in some cases, the delivered equipment and material do not get the proper inspection and testing at supplier site to ensure the conformance with the requirements (Salama et al., 2008), thus creating procurement non-compliance that could lead to unsatisfactory performance of project productivity (Yeo & Ning, 2002), particularly time delay and cost overrun (Karjalainen et al., 2008). Non-compliance is a deviation of the product, process, or service to the required performance of cost, time, and quality that requires corrective action for a product to be accepted (Rithick & Kumar, 2019), the consequences of which can be severe in EPC projects (Ahmad et al., 2014).

On-time delivery has always been substantial importance to the success of a project since it impacts the performance of project cost and quality, and the stakeholders' success as well (Kabirifar & Mojtahedi, 2019). Therefore, studies regarding schedule delays in the construction of EPC projects and strategic recommendations regarding the procurement process have been widely done. A study by Pham and

Hadikusumo (2014) attempted to solve the project delay problem by defining the current business models used in the petrochemical industry and exploring the root cause of delays adopting a case study on selected EPC projects in Vietnam. Another study by Micheli and Cagno (2016) argued that procurement could contribute to deal with project deviation in terms of time, cost, and quality by presenting the strategy and process modifications used by high-performed EPC companies. Moreover, a study done by Cagno and Micheli (2011) provided a risk-based procurement management model called Procurement Risk Cube (PRC) to improve the understanding of the risks in EPC supply chain, and research conducted by (Panova & Hilletofth, 2018) showed the benefits of models and methods to manage the risks and delays of the supply chain in construction projects by depicting the dynamic behavior of material delivery delay.

Regarding project risks, a paper by Valipour et al. (2014) aimed to allocate the risks generally occurred in EPC projects utilizing analytic network process (ANP) method showed that the allocations distributed 12 risks to the developer, nine risks shared between the developer and contractor, and 12 risks to the contractor. Another research by Roeshardianto et al. (2015) identified main implementation risks arising in all stages of the EPC projects and measured the extent of the risks to develop the risk mitigation plan. A study conducted by Wang et al. (2019) developed a risk assessment model and evaluated the risks in the hydropower EPC project from the contractor's perspective. Moreover, the potential risk sources to the power plant EPC projects have also been investigated by Sudirman and Simanjuntak (2018), while the risks of oil and gas sector EPC projects have been analyzed as well by Mubin and Mannan (2013). A recent study by Dixit (2020) proposed an integrated framework to develop an optimal project procurement portfolio, considering that ensuring the availability of the complied items to avoid unfavorable effects on the project success can be obtained by having proper procurement risk management (Muneeswaran et al., 2020).

However, study regarding the risks particularly in the procurement process in the oil and gas EPC projects, which can delay construction work progress is still very limited; therefore, this study attempts to analyze the potential risks in the procurement process of equipment and materials and to recommend risk response strategy that can help reduce the occurrence of the delay-causing risks caused by non-compliance of required equipment and materials.

2.0 LITERATURE REVIEW

2.1 EPC Projects

Engineering, Procurement, and Construction (EPC) is an approach of contracting where a party is responsible for the completion of all project phases and hand it over later to the client within the specific agreed quality, the arranged time and budgeted cost (Mubin & Mannan, 2013). If all the requirements are failed to be fulfilled, the responsible contractor will need to pay monetary penalties to the client.

EPC contract usually covers many aspects of the project to be completed by the EPC contractor which include project management, site supervision, engineering, equipment and materials, foundation and infrastructure works, transport and installation, project commissioning, and all the efforts done to guarantee the entire solution (Pícha et al., 2015). Using this contracting method, the client who is usually responsible for the permit issuance and other site preparation works will get higher certainty of the project success because the risks have been distributed to the main contractor. Despite several advantages obtained from using EPC contract for construction projects including sole responsibility point, the certainty of price and project duration, fitness for purpose, less claim opportunity, and easy administration, there are also some disadvantages such as employee has no control in the project, strong commitment needed, complex cost management, high-risk cost, complicated tender comparison and bidder resistance (Hansen, 2015).

EPC contracting method has been widely applied in the engineering fields, particularly in the development of mega-scale infrastructure projects with the expectation of reducing project cost and shortening the project schedule (Huse, 2002; Ishii et al., 2014). Some of the typical EPC projects include power plants, factories, industrial plants, oil and gas developments, and infrastructure projects (Hansen, 2015).

2.2 Procurement in EPC Projects

Procurement, also interchangeably called purchasing, is defined as the application of the transactional function of buying goods and services at the lowest possible cost (Russel & Thukral, 2003). It is a business process that covers several activities such as determining requirement, selecting a source, requesting for quotations, issuing a purchase order (PO), receipt, invoice, and vendor payment (Bodnar & Hopwood, 2004; Nawi et al., 2016), conducted in different stages of the process including pre-acquisition phase, tender process and contract award, as well as contract and supplier management (Baldi et al., 2016).

The procurement procedure is considered one of the key improvement areas believed to able to significantly contribute to the project success (Cheung et al., 2003), and it plays a significant role in the success of EPC projects as well. Thus, it is critical that all of the requirements of procurement are met. There are several reasons behind the importance of procurement in EPC projects including: (1) it is a function that connects engineering and construction; (2) material costs denote a major portion of total EPC project cost; (3) it is dependent on external parties such as vendors and subcontractors; (4) it needs more communication to negotiate with the said external parties; (5) the control in outsourcing and purchasing long lead-time equipment is usually not as strong as in the engineering and construction; (6) major equipment vendors and client don't keep buffer inventory for the project; (7) very costly capital equipment needs long lead time to manufacture; (8) vendors and contractors separately use time buffers in order to be protected from uncertainty; (9) the successful procurement management leads to successful performance in the project cost and delivery (Yeo & Ning, 2002). Therefore, in order to achieve a successful procurement procedure, its activities should be carefully managed by utilizing the proper decision-support model for selecting the appropriate source, considering that every source has a different level of capacities (Jang et al., 2017).

Procurement management generally comprises several activities in its process including (1) procurement plan that determines when and how the required goods will be purchased; (2) contract plan that records the documentation of the required goods and services; (3) request for quotations (RFQ) from sources; (4) source selection process that includes activities such as evaluate offerings from the sources, negotiate with the all the sources, and select the suitable source; (5) vendor liaison management; (6) contract completion that manages unfinished matters (Eriksson, 2017; Hong & Kwon, 2012; Shehu et al., 2019). However, the procurement process of the EPC project has a bit different operating process; it is particularly more complex systems than the traditional procurement process. In EPC projects, not all required equipment and materials are ready mass products; hence they need to be specifically fabricated for the project beforehand. The manufacture of fabricated products is carried out in accordance with the engineering specifications and requirements, technical documents, project quality plan, as well as the law and regulation requirements (Neuman et al., 2015). This process takes longer time, higher cost, and more complex management system than the traditional procurement system, therefore, enhanced management in the procurement of EPC projects is highly needed considering that appropriate coordination between contractor, subcontractors, and suppliers is necessary for EPC projects (Yeo & Ning, 2002; Zhang et al., 2017).

2.3 Risk Management in EPC Projects

EPC projects are usually mega-scale projects with a certain degree of risk; therefore, a proactive approach needs to be carried out in order to deal with threats as well as to identify opportunities (Hillson, 2006). Risk management is a systematic application of management policies, procedures, and practices to assess and manage risks (Ennouri, 2018). It is a crucial part of project management practices done in order to reduce uncertainties in a project. The practice of risk management with risks in several steps including risk planning, risk assessment (identification and analysis), risk mitigation and response planning, and implementing risk monitoring and control (Kerzner, 2010). This approach shows the value of proactive project planning as a way to anticipate and mitigate issues that can affect the project (Mir & Pinnington, 2014).

The objective of risk management process is to produce a structured framework that will make management in handling project risks more efficient and effective (Bahamid & Doh, 2017). The risk management steps that requires the collaboration of all the involved parties in the project are outlined below (Project Management Institute, 2017):

1. Risk management planning determines the approach and activities to manage the risks.
2. Risk identification detects the uncertainty that can disrupt the progress of the project. Some techniques that can be utilized are document review, brainstorming, Delphi technique, interview, Root Cause analysis, expert judgment, and Strength, Weakness, Opportunities, and Threats (SWOT) analysis.
3. Qualitative risk analysis identifies and measures the importance of the risks. Several techniques that can be used include Risk Probability and Impact Assessment, Probability and Impact Matrix, Risk Data Quality Assessment, Risk Categorization, Risk Urgency Assessment, and Expert Judgement.
4. Quantitative risk analysis aims to quantify the impact of the risks and can be performed using Sensitivity Analysis, Expected Monetary Value (EMV) Analysis, modeling and simulation such as Monte Carlo, and expert judgment.
5. Risk mitigation & response planning refer to the optimal strategy selected and implemented to deal with the identified risks. Risks with a negative impact on the project will be responded with several strategies such as Avoid, Transfer, Mitigate, and Accept. Meanwhile, strategies for positive risks are Exploit, Enhance, Share, and Accept.
6. Risk monitoring & control measure the efficiency of the corrective actions and detects the potential risks unidentified previously

Procurement risks in EPC projects categorized as the aspect of project execution risks are considered as the most critical component, particularly in the cost composition (An & Shuai, 2011). As the quality of the purchased equipment and materials and the time duration of the delivery have a huge effect on the quality and schedule of the project, therefore the procurement risks can occur to the entire procurement process starting from the initial stage of determining the purchasing plan, selecting and managing the suitable vendors, getting the purchased equipment and materials in accordance with the time, cost, and quality requirements (Yang et al., 2015).

■3.0 METHODOLOGY

In order to achieve the objective of this study in identifying the potential non-compliance risks in the procurement process in EPC projects, this paper adopted both quantitative and qualitative research methods. The quantitative method included three systematic steps; expert validation, questionnaire survey, and risk analysis for the result of the questionnaire survey. These steps were then followed by a qualitative method utilized to further elaborate the mitigation strategies for the identified major risks through benchmarking study and interviews with experts. The steps in the research workflow can be seen in the following Figure 1.

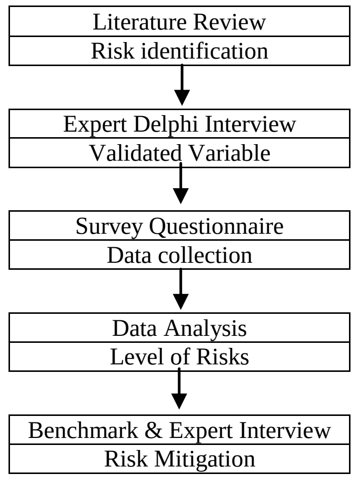

Figure 1 Research workflow

First of all, comprehensive investigation to literature including journals, books, and conference papers (Berawi et al., 2018; Berawi & Woodhead, 2008), as well as government's regulations and procedural information from EPC company in Indonesia were conducted to identify the risks regarding nonconformity in the procurement process of EPC projects as the research variables. The results of the literature review were then written into a list of initial variables to be validated and further elaborated by the experts through interviews. The experts interviewed have the requisite work experience in the field of oil and gas EPC projects of at least 15 years for Bachelor's degree holders and of at least ten (10) years for Master's degree holders. A summarized profile of the experts can be seen in Table 1 below.

Table 1 Profile of experts

No	Expert	Degree	Company	Position	Work Experience
1	E1	Master	State-Owned Enterprise	Expert staff	33 years
2	E2	Master	Private Company	Manager	16 years
3	E3	Master	Private Company	Manager	18 years
4	E4	Master	Private Company	Manager	21 years
5	E5	Bachelor	State-Owned Enterprise	Expert staff	34 years

The variables obtained from interviews with experts were analyzed using Delphi method. Interview conducted in Delphi method consisted of a set of questions aiming to investigate the perceptions of the interviewees through the same sequence and the same questions with the same words (Gillham, 2005; Johnson & Christensen, 2000). Delphi analysis was a method described as an effective process to let a group of people to deal with complex issues (Hirschhorn, 2019), it is useful to get perceptions that may advise the process of planning, problem-solving and the overall decision making by providing helpful insights and collecting the ideas of the panelist on a specified topic (Brydon-Miller et al., 2011; Scott & Walter, 2003). The experts in Delphi interview of this study were asked to justify their answers to questions identifying necessary factors causing non-compliance in the procurement process of EPC projects.

The survey questionnaire was created based on the results of Delphi analysis, and it was then sent to the project stakeholders with experience in EPC projects in Indonesia. The target respondents were the middle and top management whose work experience in EPC projects for at least five (5) years and held a Bachelor's degree. Even though the number of upper managements from EPC contractors that completed the survey questionnaires was limited, a total of 37 survey questionnaires were collected. However, since the central limit theorem holds true for sample size that is larger than 30 (Ling et al., 2009; Ott & Longnecker, 2001), the results of this questionnaire could still be analyzed using statistical analysis such as homogeneity test, validity test, and reliability test, which was followed by risk analysis using probability-impact assessment in order to get the level of non-compliance risks.

The profile of respondents was summarized and presented in Table 2. 78.3% of the respondents hold a Bachelor's degree, 16.22% hold a Master's degree, and others (5.41%). Moreover, most of the respondents were from private companies (75.68%), while 21.62% from state-owned companies, and 2.7% from the educational institution. In regard to their current position, 27.03% were leaders, 21.62% were expert staff, 10.81% were general managers, and 16.22% were staffs. In addition, the work experience of respondents was mostly in sub-criteria of 10-15 years (45.95%), and 5-10 years (24.32%), only 2.7% and 5.41% of respondents have work experience of less than five years and more than 20 years, respectively.

The respondents were asked to identify the risks faced and give a rating to the frequency of occurrence likelihood and the magnitude of identified risk impacts. To determine the significance level of the identified risks, risk analysis matrix, a quantitative method using an evaluation table of the low, medium, and high indicators to show the score of risk level, was created by multiplying the frequency of risk occurrence and impact of risks, the matrix of which can be seen in Table 3. This value was used as data input for further risk analysis showing the level of potential risks with high impact on the occurrence of non-compliance risks in the procurement process of EPC projects.

Table 2 Profile of respondents

Criteria	Sub-criteria	Total
Educational background	Bachelor's	29
	Master's	6
	Doctoral	0
	Others	2
Place of work	State-owned enterprise	8
	Government agencies	0
	Private company	28
	Educational institution	1
Current position	General Manager	4
	Manager	8
	Expert Staff	8
	Lead	10
	Staff	6
	Scholar/Researcher	1
Work experience	≤ 5 years	1
	5 - 10 years	9
	10 - 15 years	17
	15 - 20 years	8
	> 20 years	2

Table 3 Probability/Impact matrix

Probability	***Treats***				
0.90	0.05	0.09	0.18	0.36	0.72
0.70	0.04	0.07	0.14	0.28	0.56
0.50	0.03	0.05	0.10	0.20	0.40
0.30	0.02	0.03	0.06	0.12	0.24
0.10	0.01	0.01	0.02	0.04	0.08
	0.05 ***Very Low***	**0.10** ***Low***	**0.20** ***Moderate***	**0.40** ***High***	**0.80** ***Very high***

Based on the matrix table above, values that determine the risk levels are as follows:
1. Low risk: 0.01 - 0.05
2. Moderate risk: 0.06 - 0.14
3. High risk: 0.18 - 0.72

■4.0 RESULTS AND DISCUSSION

4.1 Initial Risk Variable Identification

After the literature review has been conducted, 48 identified variables for the risk factors of non-compliance in the procurement process of EPC projects were validated by the experts through interviews and analyzed using Delphi method. The validated variables that have been analyzed can be seen in Table 4 below.

Table 4 Validated risk variables

Risk Variable		Reference
X1	Design changes in the utility and main equipment	(Halari, 2010; Kennedy et al., 2013)
X2	Lack of supervision to the engineering design and drawing	(Halari, 2010)
X4	Lack of complete information in the RFQ regarding the technical description, specifications, and number of equipment	(Neuman et al., 2014)
X5	Requirement inspection does not accommodate all specifications	(Kumar, 2012; Sahoo et al., 2014)
X9	Preference to the lowest price in the final selection	(Natarajarathinam et al., 2009; Rao & Goldsby, 2009; Tse et al., 2011)
X10	Lack of vendor's attention to the PO review	(Andi et al., 2005; Neuman et al., 2014)

Risk Variable		Reference
X12	No verification for the contract terms by the owner, contractor, and vendors.	(Mai & Wang, 2017; Pícha et al., 2015)
X13	Preference to lowest price over performance and quality in choosing subcontractors	(Pfohl et al., 2011; Theodorakioglou et al., 2006)
X14	Lack of understanding of the importance of PO	(Zsidisin et al., 2000)
X16	No provision of access, documents, and procedures for review and supervision by the vendors to the owners and contractors	(Andi et al., 2005)
X18	Fabrication procedure is not conducted properly	(Andi et al., 2005; Halari, 2010)
X20	Poor inventory of raw materials	(Andi et al., 2005; Mai & Wang, 2017)
X23	Faulty inspection tool at the time of testing	(Andi et al., 2005; Mai & Wang, 2017)
X24	Expired certificate of the inspection tool's calibration	(Andi et al., 2005; Mai & Wang, 2017)
X25	Objects not ready to be inspected	(Rahman et al., 2017)
X26	Incompetent inspectors	(Abdul-Rahman et al., 2012)
X28	Inappropriate preservation and protection procedures	(Andi et al., 2005; Rao & Goldsby, 2009; Tse et al., 2011)
X30	Error in collecting the data of equipment/materials	(Ramadhani & Baihaqi, 2018)

4.2 Risk Analysis

The identified risks that have been validated through Delphi interviews with experts were then sent to respondents. The results of 37 returned questionnaires were analyzed using statistical tests to investigate the homogeneity, validity, and reliability of the data prior to risk analysis to determine the risk level.

4.2.1 Homogeneity, Validity, and Reliability Tests

The homogeneity test is carried out to determine the understanding of each respondent regarding risk variables measured based on educational background, place of work, position, and work experience. Kruskal-Wallis test was selected since the profile of respondents has more than two categories. In testing the homogeneity, hypotheses determined in this test were:

H_0 =There is no difference in the perception of respondents with various educational background, workplace, current position, and work experience

H_1 =There is a difference in the perception of respondents with various educational background, workplace, current position, and work experience

Where H_0 is accepted if the value of Asym. Sig > level of significance (α=0.05), while H_0 is rejected if Asym. Sig < level of significance (α=0.05). The result of homogeneity tests obtained was Asym. Sig> 0.05. Therefore, there is no difference in the perception of respondents with various educational backgrounds, workplace, current positions, and work experience.

The validity test of this study was computed using Pearson Product Moment correlation test with the requirement if $r_{count} > r_{table}$ and the sig. (2-tailed) < 0.05 in order for the instrument to be valid. With 37 total respondents, degree of freedom (df) = N-2 = 37-2= 35, and significance level of 5 %, thus the r_{table} is 0.325. Based on the validity testing done with statistical analysis software, the r_{count} of all research instruments tested are bigger than r_{table} 0.325, and the sig. (2-tailed) of all tested items are smaller than the significance level 0.05. Since all items fulfilled the decision-making basics of validity test, it can be concluded that all of the items in this study are valid and can be used to collect the research data.

Cronbach's alpha method was used to test the reliability of this study. The requirements for reliability test using Cronbach's alpha were:

a. Cronbach's Alpha value ≤ 0.6 indicates that the research questionnaire was not reliable.

b. Cronbach's Alpha value ≥ 0.6 indicates that the research questionnaire is reliable.

Table 5 Output of reliability test

Case Processing Summary			
		N	%
Cases	Valid	37	100.0
	Excluded[a]	0	.0
	Total	37	100.0
a. Listwise deletion based on all variables in the procedure.			

Table 6 Cronbach's alpha value

Reliability Statistics	
Cronbach's Alpha	N of Items
0.782	18

Table 5 above showed the number of samples (N) of 37 respondents and the 100% validity. The total numbers of the respondent (N) are 37. The percentage of valid is 100% because all of the questions are answered by the respondents. Based on the value of Cronbach's Alpha of 0.782 with 18 total research variables shown in Table 6, which was bigger than 0.6, it can be concluded that the research instruments are reliable.

4.2.2 Risk Level Analysis

Data filled by respondents in the questionnaires were then analyzed to determine the level of frequency and impact of each risk variable using the process of Qualitative Risk Analysis as the guideline. The results for the average frequency and impact of the entire questionnaire survey results can be seen in Table 7 and Table 8.

Table 7 Average frequency score of risk variables

Variable	Very low frequency 0.1	Low frequency 0.3	Moderate frequency 0.5	High frequency 0.7	Very high frequency 0.9	Frequency	Average frequency score
X1	0	7	26	4	0	17.9	0.484
X2	0	7	26	4	0	17.9	0.484
X4	0	4	30	3	0	18.3	0.495
X5	0	7	28	2	0	17.5	0.473
X9	0	16	18	3	0	15.9	0.430
X10	2	10	21	4	0	16.5	0.446
X12	1	9	24	3	0	16.9	0.457
X13	0	14	22	1	0	15.9	0.430
X14	8	23	6	0	0	10.7	0.289
X16	1	18	16	2	0	14.9	0.403
X18	0	16	21	0	0	15.3	0.414
X20	0	19	18	0	0	14.7	0.397
X23	1	29	6	1	0	12.5	0.338
X24	9	24	4	0	0	10.1	0.273
X25	1	20	16	0	0	14.1	0.381
X26	9	21	7	0	0	10.7	0.289
X28	0	22	14	1	0	14.3	0.386
X30	4	16	17	0	0	13.7	0.370

Table 8 Average impact score of risk variables

Variable	Insignificant	Minor	Moderate	Major	Severe	Impact	Average impact score
	0.05	**0.1**	**0.2**	**0.4**	**0.8**		
X1	0	0	3	28	6	16.6	0.449
X2	0	0	4	31	2	14.8	0.400
X4	0	0	1	27	9	18.2	0.492
X5	0	0	1	24	12	19.4	0.524
X9	0	1	25	11	0	9.5	0.257
X10	0	0	2	28	7	17.2	0.465
X12	0	0	6	16	15	19.6	0.530
X13	0	0	28	7	2	10	0.270
X14	0	6	24	7	0	8.2	0.222
X16	0	9	25	3	0	7.1	0.192
X18	0	0	2	28	7	17.2	0.465
X20	0	1	12	24	0	12.1	0.327
X23	0	0	8	24	5	15.2	0.411
X24	0	4	23	10	0	9	0.243
X25	0	13	24	0	0	6.1	0.165
X26	0	1	11	20	5	14.3	0.386
X28	0	1	21	12	3	11.5	0.311
X30	0	15	13	8	1	8.1	0.219

The risk score was determined by multiplying the average frequency score with the average impact score of each risk variable. By doing this calculation, the level of risks causing the non-compliance in the procurement process of EPC projects were obtained. Risk level for all risk variables affecting the non-compliance occurrence of equipment and materials with the project specifications was shown in Table 9.

Table 9 Risk score and level

Risk factors of non-compliance in the procurement process of EPC projects		Average frequency score	Average impact score	Risk Score	Risk level	
X1	Design changes of the utility and main equipment	0.468	0.449	0.217	4	**High**
X2	Lack of supervision to the engineering design and drawing	0.468	0.411	0.194	6	**High**
X4	Lack of complete information in the RFQ regarding the technical description, specifications, and number of equipment	0.468	0.508	0.243	2	**High**
X5	Requirement inspection does not accommodate all specifications	0.462	0.524	0.248	1	**High**
X9	Preference to the lowest price in the final selection	0.397	0.251	0.110	13	Moderate
X10	Lack of vendor’s attention to the PO review	0.462	0.481	0.207	5	**High**
X12	No verification for the contract terms by the owner, contractor, and vendors.	0.451	0.530	0.242	3	**High**
X13	Preference to lowest price over performance and quality in choosing subcontractors	0.435	0.270	0.116	11	Moderate
X14	Lack of understanding of the importance of PO	0.284	0.208	0.064	17	Moderate
X16	No provision of access, documents, and procedures for review and supervision by the vendors to the owners and contractors	0.397	0.192	0.077	15	Moderate
X18	Fabrication procedure is not conducted properly	0.408	0.465	0.192	7	**High**
X20	Poor inventory of raw materials	0.397	0.327	0.130	9	Moderate

Risk factors of non-compliance in the procurement process of EPC projects		Average frequency score	Average impact score	Risk Score	Risk level	
X23	Faulty inspection tool at the time of testing	0.332	0.411	0.139	8	Moderate
X24	Expired certificate of the inspection tool's calibration	0.289	0.243	0.066	16	Moderate
X25	Objects not ready to be inspected	0.386	0.165	0.063	18	Moderate
X26	Incompetent inspectors	0.305	0.386	0.112	12	Moderate
X28	Inappropriate preservation and protection procedures	0.397	0.311	0.120	10	Moderate
X30	Error in collecting the data of equipment/materials	0.392	0.219	0.081	14	Moderate

Identified major risk variables for non-compliance in the equipment and material procurement process were summarized in Table 10 below. Furthermore, the risk analysis results also indicated that the risks affecting the occurrence of equipment and material non-compliance should be further investigated through risk mitigation, which aimed to reduce the probability and impact of an event into a tolerable threshold level.

Table 10 Major risks and the response strategy

Risk factors of non-compliance in the procurement process of EPC projects		Risk Score	Risk level		Response strategy
X5	Requirement inspection does not accommodate all specifications	0.248	1	**High**	**Mitigate**
X4	Lack of complete information in the RFQ regarding the technical description, specifications, and number of equipment	0.243	2	**High**	**Mitigate**
X12	No verification for the contract terms by the owner, contractor, and vendors.	0.242	3	**High**	**Mitigate**
X1	Design changes of the utility and main equipment	0.217	4	**High**	**Mitigate**
X10	Lack of vendor's attention to the PO review	0.207	5	**High**	**Mitigate**
X2	Lack of supervision to the engineering design and drawing	0.194	6	**High**	**Mitigate**
X18	Fabrication procedure is not conducted properly	0.192	7	**High**	**Mitigate**

The ranked non-compliance risks are as follows:

1. *Requirement inspection does not accommodate all specifications (X5)*
   Inspection is a means used to control the suitability of the equipment and materials against specifications, datasheets, and drawings. Inspection is conducted to verify that the quality process functions properly, and the activities contained in the Inspection and Test Plan (ITP) have been carried out correctly. If the requirement inspection does not accommodate engineering specifications, the equipment, and material inspection process is incomplete. The incomplete Requirement Inspection will result in the vendor only performs the testing as requested at the Inquiry. If there are any additional inspections outside the purchase order, the vendor will ask for additional costs and additional time to complete the equipment testing. This can lead to project time and cost performance disruption because system facility failures caused by inadequate ITP will need to be reworked.
2. *Lack of complete information in the RFQ regarding the technical description, specifications, and number of equipment (X4)*
   RFQ is a quotation request from prospective suppliers for the procurement of required equipment and materials, and it is generally combined with non-technical requests and technical requests. If the RFQ with incomplete data of specifications, technical information, and the amount of equipment is sent to prospective suppliers, various risks of rework or repair and additional costs and time can occur. According to the interviewed experts, if the equipment and materials supplied don't meet the project specifications, characteristics, process parameters, procedures and records, then the unqualified product quality cannot be accepted.
3. *No verification for the contract terms by the owner, contractor, and vendors (X12)*
   Contract terms that are not verified by all stakeholders can lead to disagreements about the scope, definition, and work interface that should be performed by the contractor, owner, or vendor in the future. In the oil and gas industry, this is related to compliance with government regulations regarding the operation eligibility approval. If the procuration of this approval is delayed because the contractor and the owner do not remind each other, the gas processing facility project will be delayed. Contract management that is not properly implemented and controlled can have a negative impact on overall project performance, particularly on project completion schedules, project cost overruns, quality degradation, and security aspects.
4. *Design changes of the utility and main equipment (X1)*
   Undefined design scope has a high potential to cause many design changes. These design changes have the potential to add equipment, which can lead to increased project costs and delays in project completion. Furthermore, this change will require the design department to revise previous drawings and then create new drawings in order to meet the capacity of the added equipment.

5. *Lack of vendor's attention to the PO review (X10)*
   PO document is a commitment to purchasing the goods; hence all negotiations must be completed before the PO is issued. PO which generally contains information on the price, agreed amount, required specifications, quality (i.e., inspection and testing to be carried out), descriptions, and other special requirements should be thoughtfully managed because it includes important details for both seller and buyer. POs that are not in accordance with the offer can cause delivery delays because the vendor must eventually complete orders that meet the requirements.
6. *Lack of supervision to the engineering design and drawing (X2)*
   Minimal supervision of the technical designs and drawings has the potential to cause the incompatible drawings that are required by multiple disciplined involved in a project. This will then cause non-compliance of equipment and materials in the procurement stage of the project. This non-compliance can lead to rework that requires additional costs and causes delays in project schedules.
7. *Fabrication procedure is not conducted properly (X18)*
   Fabrication process is a complex set of work that must be done carefully and in accordance with the purchase order. This process generally includes several activities, such as the material measurement process done based on the shop drawings, material cutting process, and final material assembling process. Lack of supervision over fabrication activities can result in equipment and materials that are not in accordance with the purchase order. Correcting this non-compliance will require time and possibly additional costs.

4.3 Mitigating the Non-Compliance Risks in the Procurement Process of EPC Projects

A risk mitigation and response planning for the ranked non-compliance risks were then carried out in the form of benchmarking studies to the EPC projects in the oil and gas industry by collecting companies' archive data and lessons learned as well as conducting interviews to the companies' top management. The result of the benchmark study was a recommendation to manage non-compliance risks in the procurement process in EPC projects. The risk mitigation strategies were divided into two categories; preventive and corrective actions.

1. **Requirement inspection does not accommodate all specifications**
   Incomplete RFQ and supporting documents in the inquiry activity of the procurement process could lead to confusion as to what is the exact specifications of the required equipment or materials, so it is crucial to have Requirement Inspection accommodate all the required specifications.
   Preventive action: Review specification, conduct consignment between Engineering, Quality and Procurement divisions in the making of Requirement Inspection, and conduct regular inspections to the equipment and materials provided to ensure compliance with specifications, appropriate standards, and applicable laws.
   Corrective action: Verify RFQ judiciously and create an RFQ checklist.
2. **Lack of complete information in the RFQ regarding the technical description, specifications, and number of equipment**
   Non-compliance caused by this risk will directly affect the time schedule, and work progress as the process of moving forward to the next stage will not happen if the RFQ is not clear yet.
   Preventive action: Ensure all terms in contract have been followed up by the vendors, have all supporting documents for RFQ, such as checklist and datasheet developed together with the main stakeholders of the project (e.g., owner), and regularly check vendor's work progress.
   Corrective action: Postpone RFQ to be processed to PO Provide follow up comments in RFQ documents.
3. **No verification for the contract terms by the owner, contractor, and vendors**
   Failure to align and clarify the expectations of all parties involved is a potential risk that can occur at the beginning of the project.
   Preventive action: Improve coordination between owner, contractor, and vendor, develop effective mechanisms for getting feedback from the stakeholder regarding procurement, and make the requirements clear, using comprehensible sentences in all contract documents.
   Corrective action: Resolve biased clauses in the contract and contractor to provide project performance reports.
4. **Design changes of the utility and main equipment**
   Changes in the specification and engineering drawing of equipment and materials will lead to project delays and can also further affect the project cost and quality.
   Preventive action: Carry out freezing design engineering before PO issuance, improve basic design, conduct a thorough study to the design and the number of required main equipment, and verify the PO carefully.
   Corrective action: The contractor to review the initial design documents within a predetermined time period, and if any data discrepancies after the determined time, therefore the impact of those discrepancies is entire will be the responsibility of the contractor.
5. **Lack of vendor's attention to the PO review**
   Non-compliance occurred as the effect of the contractor's failure to accommodate engineering specifications in the PO activity, particularly when PO review is ignored, will lead to the delay.
   Preventive action: Develop a PO review checklist and verify the PO carefully.
   Corrective action: Improve communication and coordination between contractor and vendors, check the final draft of the contract and monitor the PO and its supporting documents.
6. **Lack of supervision to the engineering design and drawing**
   Engineering design and drawing are critical to procurement; therefore, the lack of supervision can cause incorrect deliverables that can affect the performance of the whole project.
   Preventive action: Hire competent engineering personnel, conduct both internal and external disciplinary checks, assess the work progress regularly, assign team personnel to oversee the equipment package, and participate in main activities with suppliers such as meetings and testing.
   Corrective action: Conduct an audit and review the record of supervision activities with vendors (e.g., inspection records, assessment notes, meeting notes, etc.)

7. **Fabrication procedure is not conducted properly**
The selection and purchase of materials not in accordance with engineering specifications will surely end up in nonconformity that needs to be reworked. Therefore, it should be conducted according to the specifications and requirements.
Preventive action: Carry out vendor selection more thoroughly based on quality and performance, assign an expeditor, perform readiness assessment, require a manufacturing and prequalification test, monitor fabrication's quality and progress, and assign team personnel to oversee the implementation of the fabrication process.
Corrective action: Conduct supervision and audit.

5.0 CONCLUSION

The procurement of equipment and material plays a significant role in the success of EPC projects. However, non-compliance with the procured equipment and materials to the project requirements will lead to unsatisfactory performance as project delay is inevitable. In order to reduce the occurrence of project delay caused by non-compliance in the procurement of equipment and materials in EPC project, this study attempted to conduct a risk analysis regarding the non-compliance and recommended the risk response strategies.

From the 18 variables identified as potential risks that can be causing non-compliance in the procurement process of equipment and materials in EPC projects, seven of them were categorized as high-level risks, the ranking of which was summarized as follows (1) Requirement inspection does not accommodate all specifications; (2) Lack of complete information in the RFQ regarding the technical description, specifications, and number of equipment; (3) No verification for all of the contract terms by the owner, contractor, and vendors; (4) Design changes of utility and main equipment; (5) Lack of vendor's attention to the PO review; (6) Lack of supervision to the engineering design and drawing; (7) Fabrication procedure is not conducted properly (see Table 10).

Risk mitigation as the response strategy recommended in this study was categorized into preventive and corrective actions. Improvement in communication between stakeholders and supervision to ensure conformity with specifications are considered as the key elements in mitigating major risks that could cause non-compliance with equipment and materials in EPC projects.

5.1 Implications, Limitations, and Recommendations

This study contributes theoretically to the literature, particularly in the field of risk management, by integrating knowledge regarding procurement risk of large-scale projects from literature and combination of both quantitative and qualitative methods with an outlook to identifying major non-compliance risks as well as recommending the risk response strategies. The findings of this study also offer insights about non-compliance risks that may occur in the procurement process to practitioners whose role as stakeholders of EPC projects, in which the risk ranking can be used as an input or reference for owners/contractors when conducting equipment and materials procurement. This paper has also delivered the preventive and corrective actions that can be done in order to address the identified risks, hence complied equipment and materials and on-time project schedule can be achieved.

Despite the contributions it may serve, this paper has some limitations, namely, the perspective used in this study was seen only from the owner's side, the focus of the study is on oil and gas EPC projects; hence the interviewed experts are from the oil and gas industry, and the focus of this study is also highlighted on specific stage of procurement, which is from PO accomplishment until the required equipment and materials are ready to be sent to the project site.

This study encourages researchers to develop a planning model for the procurement activities of EPC projects as a more effective and efficient alternative action for the risk factors that have been identified. Moreover, future studies also need to investigate the effect of the recommended risk response strategies on the performance of project costs.

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