Abstract. The pipe installation of offshore EPC project has high risk of cost overruns due to the uncertainty of weather, human errors, pipe fabrication process, etc. All of those risks will cause the project delay. The optimization of risk-based project scheduling can reduce the risks. Risk management can be optimized with combining some methods, such as Failure Mode and Effect Analysis (FMEA), Fault Tree Analysis (FTA), Critical Path Method (CPM) and Crashing Project method. The combination of these methods are used to do the data analysis in order to reduce the project total duration. Based on analysis using FMEA, FTA, CPM and crashing project method, the total project duration can be reduced from 499 days to 489 days with Rp. 6,822,472,- as the additional cost of workers.
Procurement, dan Construction (EPC) pipes instalation project. This kind of project has high risk of cost overruns due to the uncertainty of weather and the condition of sea stream, the pipe fabrication process and human error [8]. Risk management can be optimized with combining Failure Mode and Effect Analysis (FMEA), Fault Tree Analysis (FTA), Critical Path Method (CPM) and Crashing Project method. FMEA method focusses in identifying risks, risk factors, risk impacts and risk level in order to get the right decision [9].

2. Research Methodology

Primary data was collected by interviewing the project risk experts. The experts selected the critical path activities’ duration that will be reduced in order to accelerate the total duration of the project. Secondary data was collected from the expert judgement of volume details and the cost of the activity. Data processing was analyzed with FMEA, FTA, CPM and crashing project methods. CPM method was conducted with Primavera P6 program.

Failure Mode and Effect Analysis (FMEA) is a systematic method used to identify a failure of a system with the aim of reducing the risk of failure. These failures are classified based on the impact given on the success of a mission of a system. FMEA calculations use qualitative data that has been collected from a scale of event rates, severity of events and detection scores for each of the existing risks. Risk Priority Number (RPN) is used to rate the risk priority [9].

FTA method identifies the causes of failure. CPM and Crashing project are used to control all the project work items can be finished on time and to optimize the project duration with the lowest price[10]. Primavera P6 software is used to easily simplify the management and controlling process of construction project from the project design, network construction and data management in order to get the more effective design process and project progress monitoring [11].

3. Result and Analysis

3.1. Failure Mode and Effect Analysis (FMEA)

The Risk Priority Number (RPN) and RPN cumulative value with FMEA method can be seen in Table 1.

| Code                  | O | S | D | RPN | RPN Percentage (%) | RPN cumulative percentage (%) |
|-----------------------|---|---|---|-----|--------------------|-------------------------------|
| R13 (Long Lead Item/LLI) | 9 | 10 | 8 | 720 | 10.43%             | 10.43%                        |
| R6 (Process Flow Diagram / PFD) | 9 | 9 | 8 | 648 | 9.38%              | 19.81%                        |
| R16 (Fabrication)      | 8 | 9 | 8 | 576 | 8.34%              | 28.16%                        |
| R20 (Force Majeure)    | 7 | 9 | 7 | 441 | 6.39%              | 34.54%                        |
| R8 (PLEM (Pipe Line End Manifold) Data) | 9 | 9 | 5 | 405 | 5.87%              | 40.41%                        |
| R14 (Shipping)         | 6 | 9 | 7 | 378 | 5.47%              | 45.88%                        |
| R3 (Social Issue)      | 8 | 9 | 5 | 360 | 5.21%              | 51.10%                        |
| R18 (Soil Data)        | 8 | 9 | 5 | 360 | 5.21%              | 56.31%                        |
| R21 (Pressure Test)    | 8 | 8 | 5 | 320 | 4.63%              | 60.94%                        |
| R4 (Change in Currency) | 6 | 7 | 7 | 294 | 4.26%              | 65.20%                        |
| R19 (Offshore Pipeline) | 7 | 8 | 5 | 280 | 4.06%              | 69.26%                        |
| R9 (Engineering Document Approval Process) | 8 | 8 | 4 | 256 | 3.71%              | 72.96%                        |
| R2 (Licensing)         | 9 | 9 | 3 | 243 | 3.52%              | 76.48%                        |
| R11 (Master list)      | 5 | 8 | 6 | 240 | 3.48%              | 79.96%                        |
The formula of RPN is given in Equation 1:

$$RPN = O \times S \times D$$

(1)

Severity Score ($S$) is a rating that refers to the impact caused. Occurrence Score ($O$) is a rating that refers to the probability or frequency of potential failures occurred [11]. Severity and Occurrence Rating Scale can be seen in Table 2.

| Rating | Description                     | Severity Rating Scale                        | Occurrence Rating Scale                        |
|--------|--------------------------------|---------------------------------------------|------------------------------------------------|
| 10     | Certain probability             | Risk could cause loss of client              | Risk occurs at least once a day or risk occurs almost every time |
| 9      | Risk is almost inevitable       | Risk could cause major or permanent delay    | Risk occurs at least once a day or risk occurs almost every time |
| 8      | Very high probability           | Risk causes minor to moderate delay with a high degree of client dissatisfaction | Risk occurs frequently; or risk occurs about once per week |
| 7      | Moderately high probability     | Risk causes minor delay with some client dissatisfaction | Risk occurs about once per month |
| 6      | Moderately high probability     | Risk causes very minor or no delay but annoys client | Risk occurs about once every three months |
| 5      | Low probability                 | Risk causes no delay and client is unaware   | Risk occurs about once per year |
| 4      | Remote probability              | Risk causes no delay and has no impact on system | Risk almost never occur, even everyone cannot remember, when was the last time risk occur |

(Kabeer & Palaniappan, 2014)

Detection score refers to the possibility of a detected failure probability before the impact and its effects are realized [11]. The scale of rating can be seen in Table 3.
Tabel 3. Detection Rating Scale

| Rating | Description                | Definition                                                                 |
|--------|-----------------------------|-----------------------------------------------------------------------------|
| 10     | No chance of detection     | There is no known mechanism for detecting the risk                          |
| 9      | Very Remote/Unreliable     | The risk can be detected only with thorough inspection and this is not feasible or cannot be readily done |
| 8      | Remote                     | The risk can be detected with manual inspection but no process is in place so that detection is left to chance |
| 7      | Remote                     | There is a process for double-checks or inspection but it is not automated and/or is applied only to a sample and/or relies on vigilance |
| 6      | Moderate chance of detection | There is 100% inspection or review of the process but it is not automated |
| 5      | High                        | There is 100% inspection of the process and it is automated                 |
| 4      | Very High                   | There are automatic “shut-offs” or constraints that prevent risk            |

The highest risks based on RPN value are the delayed of Long Lead Item (LL1) procurement process, the delayed of Process Flow Diagram (PFD) design process, the delayed of subsea valve fabrication, tidal wave and Pipe Line End Manifold (PLEM) data was not matching with work item details. The RPN Pareto Diagram can be seen in Figure 1.

Figure 1. RPN Pareto Diagram

3.2. Fault Tree Analysis (FTA)  
There were 5 potential risk failures or 20% out of 100% risks based on RPN value. The potential risk failure factors were described with code R13, RR6, R20 and R8 as follow:
3.2.1. The delayed of Long Lead Item (LLI) procurement process

The fault tree of the delayed of Long Lead Item (LLI) procurement process can be seen in Figure 2 and the explanation can be seen in Table 4.

![Fault tree image](image)

**Figure 2.** The fault tree of the delayed of Long Lead Item (LLI) procurement process

| Event or Gate | Note |
|--------------|------|
| T            | The delayed of Long Lead Item (LLI) procurement process |
| G1           | Data sheet was not available |
| G2           | Needed materials were not available |
| G3           | Inquiry plan was not available |
| G4           | Change Order (CO) from owner |
| G5           | Owner's vendor couldn't provide materials needed |
| G6           | The shipping delay |
| G7           | Bill of Quantity was late provided by engineering team |
| G8           | Technical Bid Evaluation (TBE) was late provided by engineering team |
| G9           | Transportation was temporary stopped |
| P1           | Actual needs were different from needs in the contract |
| P2           | Owner hadn't approved the engineering data |
| P3           | Bad weather |
| S1           | Vendors were not capable enough to provide the special item |
| S2           | The delayed of giving offering data from vendor |
| S3           | The productions by vendor were not finished on time |

Table 4. The explanation of the fault tree of LLI procurement process

The top event of potential failure risk in this process was the delayed of LLI procurement process for subsea valve. These are the basic events or undeveloped events caused the potential failure risks:
actual needs were different from needs in the contract, owner hadn't approved the engineering data, bad weather, vendors were not capable enough to provide the special item, the delayed of giving offering data from vendor and the productions by vendor were not finished on time.

3.2.2. The delayed of Process Flow Diagram (PFD) design process

The fault tree of the delayed of Process Flow Diagram (PFD) design process can be seen in Figure 3 and the explanation can be seen in Table 5.

![Fault Tree](image)

Figure 3. The fault tree of the delayed of Process Flow Diagram (PFD) design process

| Event or Gate | Note |
|---------------|------|
| T             | The delayed of Process Flow Diagram (PFD) design process |
| G1            | Owner's approval process needs a quite long time |
| G2            | Low level of work productivity |
| G3            | Late review from owner |
| G4            | A lot of revisions from owner |
| G5            | Workers were doing some projects at some time |
| G6            | Different perceptions between owner and contractor |
| P1            | Design changing |
| P2            | Limited number of workers |
| P3            | Lack of coordination between contractor and owner |
| S1            | Low level of workers performance |
| S2            | Busy owner |

Table 5. The explanation of the fault tree of Process Flow Diagram (PFD) design process

The top event of potential failure risk in this process was the delayed of Process Flow Diagram (PFD) design process. Based on the minimal cut set determination, the basic event or undeveloped events
caused the potential risks were design changing, limited number of workers, lack of coordination between contractor and owner, low level of workers performance and busy owner.

3.2.3. The delayed process of subsea valve fabrication

The fault tree of the delayed process of subsea valve fabrication can be seen in Figure 4 and the explanation can be seen in Table 6.

![Fault Tree](image)

**Figure 4.** The fault tree of the delayed process of subsea valve fabrication

**Table 6.** The explanation of the fault tree of the delayed process of subsea valve fabrication

| Event or Gate | Note |
|---------------|------|
| T             | The delayed of subsea valve fabrication process |
| G1            | Approval drawing process required a quite long time |
| G2            | Lack of workers productivity in fabrication process |
| G3            | Raw materials needed were not available |
| G4            | A lot of revisions by owner to engineering team |
| G5            | Different perceptions between owner and contractor |
| P1            | Lack of meeting intensity between owner and engineering team |
| P2            | Materials delivery process needed a quite long time |
| P3            | Design changing |
| P4            | Lack of coordination between contractor and owner |
| S1            | The low level of workers' performance |
| S2            | Vendor Purchase Order (PO) was delayed |
| S3            | The low level of vendors' performance |

The top event of potential failure risk in this process was process of subsea valve fabrication.
Based on the minimal cut set determination, the basic event or undeveloped events caused the potential risks were: lack of meeting intensity between owner and engineering team, materials delivery process needed a quite long time, design changing, lack of coordination between contractor and owner, the low level of workers' performance, vendor Purchase Order (PO) was delayed and the low level of vendors' performance.

3.2.4. Tidal wave
The fault tree of the delayed process because of tidal wave can be seen in Figure 5 and the explanation can be seen in Table 7.

![Fault Tree of Tidal Wave]

**Figure 5.** The fault tree of the delayed process because of tidal wave

| Event or Gate | Note                                      |
|---------------|-------------------------------------------|
| T             | Tidal wave                                |
| G1            | Monsoon period                            |
| G2            | The high level of rainfall intensity      |
| P1            | The extreme changes in air pressure       |
| P2            | The changes in wind direction in a certain period |

The top event of potential failure risk in this process was tidal wave. Based on the minimal cut set determination, the basic event or undeveloped events caused the potential risks were the extreme changes in air pressure and the changes in wind direction in a certain period.

3.2.5. The delayed process because of PipeLine End Manifold (PLEM)
The fault tree of the delayed process because of PipeLine End Manifold (PLEM) can be seen in Figure 6 and the explanation can be seen in Table 8.

![Fault Tree of PipeLine End Manifold]

**Figure 6.** The fault tree of the delayed process because of Pipe Line End Manifold (PLEM)
Table 8. The explanation of the fault tree of the delayed process because of Pipe Line End Manifold (PLEM)

| Event or Gate | Note |
|---------------|------|
| T             | PLEM data was not matched with work item details |
| G1            | There were PLEM design differences between owner and engineering company |
| P1            | Miscalculation in designing PLEM by engineering company |
| S1            | Lack of coordination in designing PLEM between owner and engineering company |
| S2            | Engineering company didn’t pay attention to the contract content properly |

The top event of potential failure risk in this process was because of PLEM data was not matched with work item details. Based on the minimal cut set determination, the basic event or undeveloped events caused the potential risks were miscalculation in designing PLEM by engineering company, lack of coordination in designing PLEM between owner and engineering company and engineering company didn’t pay attention to the contract content properly. After making a Fault Tree Analysis (FTA) chart on the five potential failures or risks that have been determined, the next step was to conduct a quantitative analysis.

The probability value of each potential failure or risk can be calculated using the probability number for each component that has been set. The value of basic event (P) is 0.01, the value of conditioning event (C) is 0.5 and the value of undeveloped event (S) is 0.001. These are the probability value of each potential failure risks:

1. The delayed process because of Long Lead Item (LLI)
   \[
   T = P1 + P2 + P3 + S1 + S2 + S3 \\
   = 0.01 + 0.01 + 0.01 + 0.001 + 0.001 + 0.001 \\
   = 0.033
   \]

2. The delayed process because of design Process Flow Diagram (PFD)
   \[
   T = P1 + P2 + P3 + S1 + S2 \\
   = 0.01 + 0.01 + 0.01 + 0.001 + 0.001 \\
   = 0.032
   \]

3. The delayed process because of Subsea Valve fabrication
   \[
   T = P1 + P2 + P3 + S1 + S2 + S3 \\
   = 0.01 + 0.01 + 0.01 + 0.001 + 0.001 + 0.001 \\
   = 0.033
   \]

4. The delayed process because of tidal wave
   \[
   T = P1 + P2 \\
   = 0.01 + 0.01 \\
   = 0.02
   \]

5. The delayed process because of PLEM data
   \[
   T = P1 + S1 + S2 \\
   = 0.01 + 0.01 + 0.001 \\
   = 0.021
   \]

The probability of top events were low because the probability value was almost zero.

3.3. Critical Path Method (CPM)

Based on CPM analysis with Primavera P6 software, the critical path activities in the project can be seen. There were 25 activities in the critical path. The details of critical path activities can be found in Table 9.
| Activity Name                             | Original Duration | Early Start | Early Finish | Late Start | Late Finish | Total Float |
|------------------------------------------|------------------|-------------|--------------|------------|-------------|-------------|
| Project                                  | 499              |             |              |            |             |             |
| Operational Acceptance                   | 0                | -           | 28-Jun-19    | -          | 28-Jun-19   | 0           |
| Contract Award                           | 0                | 15-Feb-18   | -            | 15-Feb-18  | -           | 0           |
| Process Flow Diagram SPM 3 to DPPU Facility | 49               | 15-Feb-18   | 4-Apr-18     | 15-Feb-18  | 4-Apr-18    | 0           |
| Data Sheet for Subsea Check Valve        | 14               | 5-Apr-18    | 18-Apr-18    | 5-Apr-18   | 18-Apr-18   | 0           |
| Data Sheet for Subsea Ball Valve         | 14               | 5-Apr-18    | 18-Apr-18    | 5-Apr-18   | 18-Apr-18   | 0           |
| Requisition for Subsea Valve             | 7                | 19-Apr-18   | 25-Apr-18    | 19-Apr-18  | 25-Apr-18   | 0           |
| RFQ - PO for Subsea Valve                | 45               | 26-Apr-18   | 9-Jun-18     | 26-Apr-18  | 9-Jun-18    | 0           |
| Process Welding for Subsea Valve         | 20               | 16-Jan-19   | 4-Feb-19     | 16-Jan-19  | 4-Feb-19    | 0           |
| Process Assembly for Subsea Valve        | 30               | 17-Dec-18   | 15-Jan-19    | 17-Dec-18  | 15-Jan-19   | 0           |
| Ordering Raw Material Subsea Valve (By Vendor) | 145            | 25-Jul-18   | 16-Dec-18    | 25-Jul-18  | 16-Dec-18   | 0           |
| Delivery for Subsea Valve                | 45               | 5-Feb-19    | 21-Mar-19    | 5-Feb-19   | 21-Mar-19   | 0           |
| Approval Vendor Document for Subsea Valve | 45              | 10-Jun-18   | 24-Jul-18    | 10-Jun-18  | 24-Jul-18   | 0           |
| Testing for PLEM                         | 3                | 29-Mar-19   | 31-Mar-19    | 29-Mar-19  | 31-Mar-19   | 0           |
| PLEM Assembly                            | 7                | 22-Mar-19   | 28-Mar-19    | 22-Mar-19  | 28-Mar-19   | 0           |
| Load Out PLEM & Transportation           | 5                | 1-Apr-19    | 5-Apr-19     | 1-Apr-19   | 5-Apr-19    | 0           |
| PLEM Installation                        | 25               | 9-Apr-19    | 3-May-19     | 9-Apr-19   | 3-May-19    | 0           |
| Crane Barge Rig Up                       | 3                | 6-Apr-19    | 8-Apr-19     | 6-Apr-19   | 8-Apr-19    | 0           |
| Spool Installation                       | 7                | 5-May-19    | 11-May-19    | 5-May-19   | 11-May-19   | 0           |
| Diver Metrology                          | 1                | 4-May-19    | 4-May-19     | 4-May-19   | 4-May-19    | 0           |
| SPM Installation                         | 28               | 15-May-19   | 11-Jun-19    | 15-May-19  | 11-Jun-19   | 0           |
| SPM hook Up                              | 3                | 12-May-19   | 14-May-19    | 12-May-19  | 14-May-19   | 0           |
| Precommissioning Offshore                | 3                | 12-Jun-19   | 14-Jun-19    | 12-Jun-19  | 14-Jun-19   | 0           |
| Mechanical Completion                    | 0                | -           | 14-Jun-19    | -          | 14-Jun-19   | 0           |
| Filling Jet A1                           | 7                | 15-Jun-19   | 21-Jun-19    | 15-Jun-19  | 21-Jun-19   | 0           |
| Soak Test                                | 7                | 22-Jun-19   | 28-Jun-19    | 22-Jun-19  | 28-Jun-19   | 0           |
The value of Total Float was obtained from the reduction between Late Start (LS) with Early Start (ES) or Late Finish (LF) with Early Finish (EF). Total float value in Table 7 was obtained with analyzing data using Primavera P6 software where the date values of each ES and EF were all same. All those activities were categorized as critical path activities because its total float values were all zero. The total duration of critical path was 499 days. The critical path activities should be finished on time otherwise the project will be delayed.

3.4. **Crashing Project**

Crashing project method was conducted to accelerate some project activities duration in order to reduce the total project duration. Acceleration was conducted on critical path activities. Not all of the activities can be accelerated, so the expert judgement was needed to determine which activities that will be accelerated. Activities that were accelerated can be found at Table 10.

| Activity Code | Activity ID | Activity Name | Original Duration (days) | Crash Time (days) | Normal Cost (Rp) | Crash Cost (Rp) | Cost Slope (Rp) | Crash By | Crashing Cost (Rp) |
|---------------|-------------|---------------|--------------------------|------------------|-----------------|----------------|----------------|---------|------------------|
| A             | PRC-PFD-1010 | Process Flow Diagram SPM 3 to DPPU Facility | 49.00 | 44.00 | 39.200.000 | 41.842.697 | 533.333 | 5 | 2.642.697 |
| B             | PROC-OFF-1604 | Process Assembly for Subsea Valve | 30.00 | 27.00 | 32.000.000 | 34.157.303 | 719.101 | 3 | 2.157.303 |
| C             | PROC-OFF-1605 | Process Welding for Subsea Valve | 20.00 | 18.00 | 30.000.000 | 32.022.072 | 1.000.000 | 2 | 2.022.472 |

Based on the analysis using Critical Path Method, the duration needed to finish the project was 499 days. The duration can be accelerated using crashing project method in order to get project finished in 489 days with the additional cost of manpower Rp. 6.822.472,-

4. **Conclusion**

Based on FMEA and FTA, the highest risks on offshore EPC project based on RPN value are the delayed of Long Lead Item (LL1) procurement process, the delayed of Process Flow Diagram (PFD) design process, the delayed of subsea valve fabrication, tidal wave and Pipe Line End Manifold (PLEM) data was not matching with work item details. Based on CPM Method, there were 25 activities in the critical path with the total duration was 499 days. Based on Crashing Method, the total of project duration can be reduced 10 days with additional cost Rp. 6.822.472,-

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