Implementation of lean construction and critical chain project management (CCPM) for waste management and work estimation on the Ciawi dam construction project

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Abstract. Project delay due to waste (non-added value activity), will increase the project costs, in this case the implementation of lean construction is used to identify waste and risks that can occur in the Ciawi Dam construction project. Waste identification is carried out based on interviews with PM and processed using the Borda method to obtain the results of critical waste, namely waiting and defects. The 5 Whys method is used to determine the root cause of the waste category. Risk identification is processed using FMEA to determine critical risk, namely land acquisition and the Covid-19 pandemic. The most common waste in projects is waiting and defects. Waste and risk identification as a reference for make a mitigation plans for waste and risk that exist in the Ciawi Dam construction project. Scheduling is carried out using the Critical Chain Project Management (CCPM) Method by eliminating additional time that can lead to activities outside the plan or waste, estimated time is obtained for 12 months on work in 2019 to June 2020 without using buffer time, but if there are activities that cause delays in development projects, then the total estimated time needed is 2 years 10 months and 10 days.

Keywords: Lean Construction, Critical Chain Project Management (CCPM), FMEA, Risk Breakdown Structure (RBS), Borda, The 5 Whys

1. Introduction
PT Brantas Abipraya is one of the State-Owned Enterprises (BUMN) which has been entrusted with completing various construction projects in the water or irrigation sector. Companies often face several problems that were identified as waste in previous projects. Waste that has occurred includes natural conditions, licensing problems such as land acquisition and blasting permits, as well as delays in sending raw materials by vendors and delays in carrying out work by sub-contracting vendors. The project carried out by PT Brantas Abipraya is located in a forest, so it can hamper the process of working both in the process of distributing raw materials to access for workers. Some of the waste that appeared in the development project carried out by PT Brantas Abipraya has caused the project work time to be longer so that it can cause losses by the company.

The evaluation of waste and risks that can occur is needed in a construction project, each waste and risk can affect each other, therefore there is a need for contingency planning related to possible
waste and risks [1]. The study also explains that companies need to make estimates before project implementation with the aim of predicting or estimating the time, costs, and resources required during project implementation by considering the impact of waste previously discussed.

The research was conducted on the construction of the Ciawi Dam by PT Brantas Abipraya. The Ciawi Dam construction project experienced problems with the sub-contractor vendors who were late or completing part of the work so that additional work time was made to meet the previously scheduled work sequence. Weather factors also influence the construction process of the Ciawi Dam, where January and February have high rainfall intensity. Based on these problems, the authors identify waste and waste management plans to reduce the effect of the waste in the project, identify risks that can be occur in the future and make a mitigation plan to reduce the probability of risks in the future, and also calculate the estimated time of work carried out in the construction of the Ciawi Dam if the company eliminates safety time and does not use buffer time that caused by waste. The method used in this study is lean construction including The 5-Why Method to identify the causes of waste, Risk Breakdown Structure (RBS) and Failure Mode Effect Analyzer (FMEA) to identify risks caused by waste, as well as Critical Chain Project Management (CCPM) to calculate the estimated time required for the construction of the Ciawi Dam.

2. Literature Review

2.1. Lean Construction

Lean Construction is a concept based on the Toyota Production System (TPS) which has been transformed into a new construction system method. This system is used to identify the root cause of losses, remove the causes with related tools and techniques, and encourage prevention of losses rather than trying to overcome the negative effects of losses [1]. Based on Bajjou [2], there are many tools that can be used in Lean Construction, one of which is Root Causes Analysis. The RCA method has many tools that can be used, one of which is the 5-Why analysis. The 5-Why can be used to classify qualitative data into different groups. Then to get quantitative data, you can use FMEA.

Taiichi Ohno (1912 – 1990), a Toyota executive, identified seven types of waste found in any process [3]:

- Transportation: Unnecessary transport of parts under production.
- Inventory: Stacks of parts waiting to be completed or finished products waiting to be shipped.
- Motion: Unnecessary movement of people working on products.
- Waiting: Unnecessary waiting by people to begin the next step.
- Over-Processing: The product with extra steps.
- Over-Production: Of products not needed.
- Defects in the product.

The determination of critical waste using the Borda method is carried out by giving weight to the alternative options. Calculation using the AHP method requires excessive calculation, in this case the Borda Method can be chosen as the appropriate method [4]. Although the Rating Method is also an easy-to-use method, it can cause some double calculations at the end, making the results less useful.

2.2. Risk Management

The risk evaluation that can occur in a project is determined based on critical waste and is grouped with the Risk Breakdown Structure (RBS). The purpose of implementing RBS is to explain the importance of each risk and improve understanding of organizational or project risks in the context of a logical, systematic and structured framework, besides that RBS also helps to compare projects and compile lessons to be learned related to future projects [5].

FMEA helps in identifying and addressing weak points in the early stages of developing product and service concepts. Risk Priority Number (RPN) and Risk Score Value (RSV) are measurements used in FMEA risk assessment. [6] This method sorts risk factors based on the identification of risk categories, identification of potential risks, the value of severity of the impact of each failure mode
(S), the probability of failure (O), and the difficulty of detecting each reason causing the failure mode (D), calculates the RPN and RSV values of each risk, and concludes the order of all risk factors. Here is the RPN formula:

\[ RPN = S \times O \times D \]

The greater the RPN value, the greater the failure or risk mode, and the greater the impact of the specific failure mode or risk on the project so that appropriate prevention and remedies must be taken [7]. To get the Risk Score Value (RSV), Severity and Occurrence values are needed so that the formula for the RSV value is:

\[ RSV = S \times O \]

2.3. Critical Chain Project Management

Critical Chain Project Management (CCPM) is a method for project planning and management that emphasizes the resources needed for project implementation. This method is different from PERT and CPM methods. CCPM focuses on resource grading, but requires resources to be flexible at startup time. In the use of CCPM, if there is a delay for 2 days, you can use the project buffer time so that the work is still declared according to the schedule, while in CPM if there is a delay it will cause loss [8]. Project buffer is placed at the end of the critical chain while feeding buffer is placed at the non-critical end. Buffer time is determined by Cut and Paste Method (C&PM) and Root Square Error Method (RSEM) [9]. C&PM is done by cutting the time 80%, 50%, or 20% of the safety time on every job determined by the company. Here is the formula for calculating the buffer:

\[
B = 2 \times \sqrt{\left(\frac{S_1 - A_1}{2}\right)^2 + \left(\frac{S_2 - A_2}{2}\right)^2 + \cdots + \left(\frac{S_n - A_n}{2}\right)^2}
\]

There are 3 stages that must be considered in carrying out Critical Chain Project Management (CCPM), the 3 stages are identify the critical chain, determine how to exploit the critical chain by reducing the duration of each activity, and subordinate other work to the schedule by entering the buffer time.

3. Research Methodology

This study used quantitative methods through the study of literature on Lean Constructions and Critical Chain Project Management (CCPM). First, the data is collected from discussions, brainstorming, and questionnaires related to research. There are several tools that can be used in Lean Construction to reduce or even remove causes of losses or waste in the project. To determine the causes of waste in this study, the author using Root Cause Analysis (RCA) including The-5 Whys Method to find the root causes that can be known through (2). Second, determine the risk that can be occurring in the future based on the data of waste that happened before using Risk Breakdown Structure (RBS) to indicate the risks, Failure Mode and Effect Analysis (FMEA) to determine the causes and effects of the risk, and also make a risk mitigation plan to reduce the causes of the risk or even to remove them. Third, the last stage of this study is to calculate the estimated time to finish the project for jobs in january 2019 until june if the company eliminates safety time and does not use buffer time caused by waste in the project. This calculation using Critical Chain Project Management (CCPM) that can be known through [8].

4. Result and Analysis

The initial stage for identifying waste in the Ciawi Dam project based on journals and interviews via electronic message with the project manager. Table 1 shown the waste table in the construction of the Ciawi Dam:
Table 1. Waste on ciawi dam construction

| Type          | Waste in Construction Project                                                                 |
|---------------|------------------------------------------------------------------------------------------------|
| Defects       | The quality of the goods delivered by the vendor did not match the technical specifications at the time of pre-order. |
| Overproduction| Rework or redesign of development projects due to unexpected geological factors.                |
| Waiting       | - Bad weather at construction site.                                                             |
|               | - Late delivery of material on materials with special orders from vendors.                     |
|               | - The COVID-19 pandemic, which affected the provision of resource as a result of government regulations both central government and regional government. |
|               | - Land acquisition in the Ciawi Dam construction project.                                      |
| Unnecessary Motion | - Workers walk too much.                                                                      |
|               | - Rest periods that are too long as a result of work that requires human power.                |

The questionnaire was filled in to determine the ranking of each waste that was obtained from the results of the previous interview. Rank one is the most common waste in the Ciawi Dam construction project and rank four is the waste that rarely occurs in the project. Ranking is determining the priority order of waste that needs to be reduced or commonly referred to as critical waste. Table 2 shown the Borda method that used for search critical waste with multiplying the weight on each ranking with each type of waste.

Table 2. Calculation of critical waste using the Borda method

| No | Type            | Ranking | Score | Percentage |
|----|-----------------|---------|-------|------------|
| 1  | Waiting         | 2 3 1   | 12    | 40.00%     |
| 2  | Defects         | 2 2 1   | 11    | 36.67%     |
| 3  | Overproduction  | 1 3 1   | 6     | 20.00%     |
| 4  | Unnecessary Motion | 1 4 1 | 3     | 3.33%      |

The determination of critical waste is then carried out using the Pareto diagram so that waiting and defects are obtained with a cumulative percentage value of 40.00% and 76.7%. The diagram is arranged from the highest to the lowest from left to right. The left bar chart is relatively more important than the right. Figure 1 shown a Pareto chart of critical waste.
The next stage of analysis is to analyze waste using the 5-Whys Method shown in Table 3. The 5-Whys Method is used to determine the causal components based on the predetermined sub-waste until improvement plans can be made related to the causes of waste generation in the Ciawi Dam construction process.

Abbreviation: BPN is The National Land government with tasks in the land sector in accordance with the provisions of laws and regulations. PSBB is large-scale social restrictions or Indonesia’s style lockdown during Covid pandemic. BPKP is Financial and Development Supervisory Agency with task of administering government affairs in the field of state / regional financial supervision and national development. PPK is Cadastral measurement and mapping is one type of survey that is at the core of the work of the National Land Agency. This survey supports realizing the certainty of objects and subjects of land rights holders as mandated by statutory regulations.

Table 3. Waste analysis uses the 5-whys method

| Waste | Sub-waste | Why 1 | Why 2 | Why 3 | Why 4 | Why 5 |
|-------|-----------|-------|-------|-------|-------|-------|
| Waiting | Waiting for the materials to arrive | Unsuitable material / not available | Late delivery of materials | Resend due to defect material | Incorrect material delivery schedule | Lack of coordination between contractors and vendors |
| Environmental factor | Difficult access to projects such as soil texture that is difficult to pass if it rains |
| The Covid-19 pandemic | Government policy regarding social distancing | Work procedures changed or added | Provision of skilled labor from outside the project is limited |
Limited material delivery follows PSBB which is Indonesia regulation.

There is a difference between the BPN sector data and the PPK sector data.

Defects:
- Quality of goods delivered by vendors
- Quality of building materials that do not meet the requirements
- Goods shipped do not meet specifications

RBS functions to map risk into levels that shown in figure 2, all possible sources of risk have been explored or analyzed until it can be seen whether additional risk identification activities are needed or not.

![Risk Breakdown Structure of Ciawi Dam Project]

**Figure 2.** Risk breakdown structure of ciawi dam project

Risk identification is carried out to determine the risk of causes of project failure in the future. Table 4 shown the identification of possible risks.

| Source of Risk    | Category          | Risk                                                                 |
|-------------------|-------------------|----------------------------------------------------------------------|
| **Internal**      | Procurement       | Late delivery of materials                                           |
|                   |                   | The material is difficult to find                                     |
|                   | Quality Control   | Delay in subcontract vendor work                                     |
|                   | Legal             | There are defective items after delivery                             |
|                   |                   | Damage to tools, materials, and physical buildings                    |
|                   |                   | Long process of land acquisition                                      |
| **External**      | Natural Environment | Bad weather                                                           |
|                   | Cultural          | Natural disasters                                                     |
|                   |                   | The Covid-19 pandemic                                                 |
Risk analysis using the FMEA method that shown in table 5 which is carried out to obtain a risk priority number (RPN) value that focuses on potential project failures.

| Code | Risk                                      | Severity (S) | Occurance (O) | Detection (D) | RPN (O×S×D) | RSV (O×S) | Critical Ranking |
|------|-------------------------------------------|--------------|---------------|---------------|--------------|-----------|------------------|
| R1   | Long process of land acquisition          | 4.8          | 4.2           | 2             | 40.32        | 20.16     | 1                |
| R2   | Natural disasters                         | 5.0          | 1.6           | 4.8           | 38.40        | 8.00      | 2                |
| R3   | The Covid-19 pandemic                     | 4.2          | 3.2           | 2.8           | 37.63        | 13.44     | 3                |
| R4   | There are defective items after delivery  | 3.8          | 3.0           | 2.2           | 25.08        | 11.40     | 4                |
| R5   | Bad weather                               | 4.4          | 2.8           | 2             | 24.64        | 12.32     | 5                |
| R6   | Delay in subcontract vendor work          | 3.4          | 3.4           | 1.8           | 20.81        | 11.56     | 6                |
| R7   | Damage to tools, materials, and physical buildings | 4.0        | 2.8           | 1.8           | 20.16        | 11.20     | 7                |
| R8   | Late delivery of materials                | 3.8          | 2.6           | 2             | 19.76        | 9.88      | 8                |
| R9   | The material is hard to find              | 3.4          | 2.2           | 2.6           | 19.45        | 7.48      | 9                |

Pareto chart and scatter plots are used to determine high risk. The results of the 80/20 Pareto principle and quadrant 1 in scatter plot found that the long process of land acquisition (R1) and the Covid-19 pandemic (R3) are the highest risks in the Ciawi Dam development project. High risk or priority risk is determined as a suggestion so that the company can pay more attention to these priority risks. Table 6 shown the mitigation plan that aims to reduce the possibility or even eliminate the risk of occurring in the future.

| Category          | Risk                                      | Causes                                      | Effects                                      | Mitigation Plans                                      |
|-------------------|-------------------------------------------|---------------------------------------------|---------------------------------------------|-------------------------------------------------------|
| **Procurement**   | Late delivery of materials                 | There are special orders that require extra time | Worker productivity decreases due to waiting for materials to arrive | Place orders at two factories on this particular material and continue with the rest of the work |
|                   | The material is hard to find               | Scarcity of raw materials                   | The development process is hampered          | Analyzing the material requirements needed before the project is executed |
|                   | Delay in subcontract vendor work          | Lack of field workers                       | Will interfere with the other work          | Give warning letter (SP) 1 & 2 to the vendor concerned 1 month in advance |
|                   | There are defective items after delivery  | Goods do not comply with the technical specifications in the PO, purchase order | Items that are defective are returned, goods are not allowed to enter the stockpile area | Check before delivery in order to deliver according to the specifications on the PO |
| **Quality Control**| Damage to tools, materials, and physical buildings | Bad weather or unwanted natural disasters | Tools and materials cannot be used because they may not conform to technical specifications. | Regular maintenance and maintenance |
The building frame can be destroyed or damaged. Update work procedures and qualification of materials used.

### Legal
- Long process of land acquisition
- Waiting for the deliberative process and BPN validation
- The building process can be hampered and stalled
- Speed up the verification process for administrative documents to be released
- Legal process and BPN validation
- The building process can be hampered and stalled
- Speed up the verification process for administrative documents to be released
- Analyze the weather regularly with the help of information from the local Meteorology and Geophysics Agency (BMKG)

### Natural Environment
- The rainy season is prolonged or erratic
- Work pending
- Landslides, earthquakes, forest fires
- The construction carried out can be damaged
- Prepare an emergency plan if this happens
- Natural disasters
- Analysis of weather with the help of information from the local Meteorology and Geophysics Agency (BMKG)

### Cultural
- There is a government policy regarding social distancing
- Provision of labor from outside is reduced
- Delivery of construction materials is limited
- Create a schedule and work method in accordance with central and local government regulations
- The Covid-19 pandemic

Scheduling is done using Microsoft Project as a calculation tool using the Critical Chain Project Management (CCPM) Method. The calculation starts by determining the order of work on a given project schedule. The data used in calculations is from January 2019 to June 2020. Data processing produces critical chains and non-critical chains. Each line reduces the duration by 50% and calculates the buffer time in the form of feeding buffer and project buffer time is placed at the end of the chain. Table 7 shows the result of feeding buffer.

#### Table 7. Feeding Buffer

| Jenis Feeding Buffer | Feeding Buffer (Month) |
|----------------------|------------------------|
| Feeding Buffer 1     | 9.513                  |
| Feeding Buffer 2     | 20.530                 |
| Feeding Buffer 3     | 12.757                 |
| Feeding Buffer 4     | 21.875                 |
| Feeding Buffer 5     | 14.274                 |
| Feeding Buffer 6     | 9.539                  |
| Feeding Buffer 7     | 9.950                  |
| Feeding Buffer 8     | 9.487                  |

The result of buffer feeding will be placed at the end of each non-critical chain. The calculated feeding buffer is the spare time that can be used to protect non-critical chains against critical chains. Table 8 shows the result of project buffer.

#### Table 8. Project Buffer

| Project Buffer | 23.32 |

The project buffer results will be placed at the end of the critical chain. The calculated buffer time results included in the CCPM Method scheduling therefore the total duration according to schedule with the buffer time is 2 years 10 months 10 days, while the duration without the buffer time is 12 months.
5. Conclusion
Waste identification is carried out by analyzing using Borda and the 80/20 Pareto diagram provisions. The processed data are in the form of a questionnaire that has been obtained regarding the types of waste that occur in the project. Based on the analysis conducted, it was found that waiting and defects as critical waste with high percentage of waste often occur. The results of critical waste in this project must be considered by the company. Based on the data that has been collected before, in the waiting category there are major jobs in it, include waiting for the distribution of materials, equipment, even project workers. If this problem is ignored by the company, it can cause time loss which can affect costs.

Risk identification is carried out using FMEA based on the results of a questionnaire. Determination of the level of importance of critical risk is carried out using the 80/20 pareto diagram analysis and scatter plot, so that two high risks need to be paid more attention to, namely the land acquisition process and the Covid-19 pandemic. The two high risks can be prevented from carrying out mitigation planning so as not to interfere with the project in the future. The mitigation plan that is made is used as a proposed actions that can be taken by the company to reduce the chance of future risks or even prevent future risks based on the waste that has occurred before.

The total duration produced after reducing the duration and adding the buffer time for the Ciawi Dam construction project schedule for 2019-2020 is 2 years 10 months 10 days, while the total duration after reducing the duration without additional buffer time for the Ciawi Dam construction project schedule for 2019-2020 is for 12 months. By carrying out the waste and risk management that has been proposed previously, the company does not need to use buffer time or safety time so that the project work time for work in January 2019 to June 2020 is 6 months faster than the previous schedule. So that the company can reduce the costs incurred for project work.

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