Design of Wood Pellet Trolley using Finite Element Method (FEM) and Design for Assembly (DFA) Approach at PT. Perkebunan Nusantara VIII Ciater

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Abstract. PT. Perkebunan Nusantara VIII is a company produces orthodox black tea. The wood pellets distribution in drying station still uses human power without any tools. The process is done as far as five meters with the transport time of each sack for three minutes and the weight is 30 kg. In the previous research has produced a design that used as reference in this research. The purpose of the research is to provide trolley design by applying Finite Element Method and Design for Assembly approach. The method is chosen because the trolley force should be considered so the trolley has good strength. The initially complex and inflexible designs are expected to be simpler and more efficient. The results of this research are wooden pellet trolleys on handle, platform, frame, and stairs chunk are considered safe from the results of the test. While the wheels chunk need to be re-election of material into titanium alloy because it is considered unsafe based on the test results. Then the design of wooden pellet trolleys results in a higher assembly efficiency rating of 27.77% with 127 total components and total processing time of 928.98 seconds so it can be concluded better than reference design.

Keywords: wood pellets, finite element method, assembly efficiency

1. Introduction

PT. Perkebunan Nusantara VIII Ciater, West Java is a company that produces 8 kinds of orthodox black tea [1]. The production of orthodox black tea consists of several processes as shown in figure 1. Each production process has its own room, in each room there is a Material Handling Equipment (MHE) which is used as a transportation of various types of materials or other objects. In the drying process, the decrease in water content of the tea powder uses a drying machine with heat flow to sterilize the possibility of bacteria. The drying machine requires wood pellets to fuel the machine. The need of wood pellets reached 3.6 tons/day. The wood pellet is distributed continuously every 10 minutes, which is done to maintain the stability of hot air temperature in the tea dryer which will affect the quality of tea.
In the existing process, wood pellets are distributed from the transport truck to the temporary storage inside the drying station using human power as shown in figure 2. The process of transporting wood pellets by the operator is carried out by five meters with the transport time of each sack for three minutes and the weight of each wood pellet is approximately 30 kg.

In a previous study, [2] has proposed a wood pellet trolley design as illustrated in figure 3 using the Ergonomic Function Deployment (EFD) approach to improve the productivity of the company. The result of the research is a concept of MHE design in the form of trolley which is expected to be a solution for the company to be able to increase work productivity.

In the design, the trolley frame strength must be really taken into account, so the design of the trolley is not only a good design, but also has good strength. Because if it is ignored it will be dangerous for the
operator. Therefore, with Finite Element Method (FEM), calculations that cannot be known through the calculation manually can be known as the maximum voltage, the voltage at each node, and also the magnitude of the shift or deformation can be known. Improper product design leads to inefficient design, thereby reducing product reliability and increasing the cost of the assembly process [3]. An industry needs to design the product well in order to improve its competitiveness. Using the Design for Assembly (DFA) method, product production costs can be simplified without reducing product function. Initially complex and inflexible designs, they are simpler and more capable of being used elsewhere. DFA analysis refers to minimizing the components of the product. The use of the DFA method in redesigning the wood pellet trolley in order to get the trolley design to be more efficient to operate on the PT. Perkebunan Nusantara VIII.

2. Methods

2.1. Finite Element Method (FEM)
Finite Element Method (FEM) is a method to dividing complex objects into blocks or simple elements or dividing complex objects into smaller fragments that are easier to explore, called elements [4].

2.2. Design for Assembly (DFA)
Design for Assembly (DFA) is a process to improve product design to be easily assembled and at low assembly cost, focused on functional aspects and assembly of a product [5] [6]. Quantitative methods of assessing efficiency levels by Boothroyd and Dewhurst will calculate the estimated time of assembly between product components. There are two ways to analyse the efficiency level of assembling a product:
1. Possibility to minimize components
2. Possibility to redesign every component is easy to assemble

Reducing the number of components in the assembly is a step to improve assembly efficiency of a product. This can be done by removing unnecessary components and merging several components into one component.

2.3. Assembly Efficiency
Assembly efficiency is a ratio of the ideal assembly time to the actual assembly or the initial design of a product.

\[
E = \frac{N_m \times t_a}{T_m}
\]

Where,

- \(E\) = Assembly efficiency
- \(N_m\) = Theoretical minimum item count
- \(t_a\) = Actual assembly process time for the product
- \(T_m\) = Total assembly process time for all item

Calculating the efficiency of assembly can be done by finding the code and time of both handling and insertion, which is then included in the DFA analysis table. The assembly efficiency formulation is basically the ratio between ideal assembly time and real assembly time. Ideal time above is determined by the number of minimum components that become factors in minimizing costs.

2.4. Manual Assembly
Manual Assembly is an assembly activity of product components by manual, manual assembly is divided into two, namely:

a. Handling (acquiring and grasp, moving, and orienting the part)
   - Whether components can be taken with: one hand, one hand with the aid of a tool, two hands, or two hands with the help of another.
• Orienting (Part Symmetry)
  What degree of component can be rotated perpendicular to the axis (α) or in line axis (β) for its reorientation.
• Ease the components to be picked up and manipulated.
• The thickness of the product.
• Component size.

b. Insertion and Fastening
  Insertion is the activity of merging of one component with other components. Fastening is to integrate a component with other components permanently or locked. Factors that affect at the time of this merger there are three, namely:
• Components are not locked at the merge.
• Components are immediately locked at the merge
• Components require additional operations for assembly to be locked.

3. Result and Discussion

3.1. Finite Element Method (FEM)
  The trolley design is tested using Finite Element Method (FEM). The FEM test is a test aimed to detecting damage caused by stress and displacement. FEM tests are performed on handle, platform, frame, wheels, and ladder chunk. The chunk is chosen to be tested because they are receiving the most force and load when operated and are the main component of trolley. The test consisted of:
  a. von Mises
     Von Mises was done to get the biggest load on the simulation result.
  b. URES
     URES is done to see how far the displacement is.
  c. Factor of Safety
     FOS is conducted with a series of preliminary studies aimed to conduct security analysis of materials and previous research concepts.

After obtaining the value of the test for each component, then the value will be analyzed to know the strength of the product material, the summary of the test result is described in table 1. If the test result shows good result, no change of material required. However, if the test results are not in accordance with the expected, it is necessary to change the material with the constraints to be determined.

| No. | Part   | Material      | Test          | Maximum Value     | Minimum Value     | Yield Strength Value |
|-----|--------|---------------|---------------|-------------------|-------------------|----------------------|
| 1   | Handle | Stainless Steel | von Mises     | 2.087e+000N/m²    | 8.477e+004N/m²   | 1.723e+008           |
|     |        |               | FOS           | 0.000e+000mm      | 7.049e-005mm     |                      |
| 2   | Platform | Aluminum Alloy | von Mises     | 3.766e+002N/m²    | 3.091e+006N/m²   | 2.757e+007           |
|     |        |               | FOS           | 0.000e+000mm      | 1.968e-002mm     |                      |
|     |        |               | URES          | 8.92E+00          | 7.32E+04         |                      |
| 3   | Frame  | Aluminum Alloy | von Mises     | 1.056e+001N/m²    | 5.927e+006N/m²   | 2.757e+007           |
|     |        |               | FOS           | 0.000e+000mm      | 2.664e-001mm     |                      |
|     |        |               | URES          | 4.65E+00          | 2.61E+06         |                      |
|     |        |               | FOS           | 0.000e+000N/m²    | 3.151e+008N/m²   |                      |
| 4   | Wheels | Aluminum Alloy | von Mises     | 0.000e+000mm      | 1.170e+000mm     | 2.757e+007           |
|     |        |               | FOS           | 8.75E-02          | 1.00E+16         |                      |
|     |        |               | URES          | 2.764e+000N/m²    | 1.442e+007N/m²   |                      |
| 5   | Ladder | Stainless Steel | von Mises     | 0.000e+000mm      | 1.681e-002mm     | 1.723e+008           |
|     |        |               | FOS           | 1.20E+01          | 6.24E+07         |                      |
Based on the result of FEM analysis, wheel is categorized as unsafe because in von Mises test obtained maximum value exceeds yield strength value and in FOS test obtained FOS value ≤ 1. Therefore, it is necessary to re-election material on wheel. In this case selected titanium alloy because it has the best strength and is still within the limits of material selection. The material will be tested by the load. Based on the test results, test values obtained for chunk wheels with titanium alloy material as in table 2 below.

| Test            | Minimum Value | Maximum Value       |
|-----------------|---------------|---------------------|
| von Mises       | 3.766e+002N/m² | 3.091e+006N/m²     |
| URES            | 0.000e+000mm  | 1.968e-002mm        |
| Factor of Safety | 8.921e+000    | 7.321e+004          |

3.2. Design for Assembly (DFA)

3.2.1. Reference Design. The reference design of wood pellet trolley has three components as base part, 14 components as main part, and 10 components as fastener. As well as having seven subassemblies, namely platform sub assembly, wheels sub assembly, frame sub assembly, ladder sub assembly, bottom frame sub assembly, top frame sub assembly, and final sub assembly. The number of assembly operations for reference design is described in table 3 below.

| No. | Sub Assembly | Number of Assembly Operations |
|-----|--------------|-------------------------------|
| 1   | Platform     | 14                            |
| 2   | Wheels       | 4                             |
| 3   | Frame        | 12                            |
| 4   | Ladder       | 26                            |
| 5   | Bottom Frame | 4                             |
| 6   | Top Frame    | 1                             |
| 7   | Final        | 2                             |
|     | Total        | 63                            |

3.2.2. Proposed Design. In planning the proposed design (Figure 4), evaluation and identification of components may be combined, modified or eliminated. Proposed design changes are obtained through a benchmarking process to existing trolleys that already on the market to ensure design changes can be applied to the proposed design. The number of assembly operations for proposed design is described in table 4 below.

**Figure 4. Proposed Design of Wood Pellet Transport Trolley**
Table 4. Assembly Operations Total for Proposed Design

| No. | Sub Assembly     | Number of Assembly Operations |
|-----|------------------|------------------------------|
| 1   | Platform         | 14                           |
| 2   | Wheels           | 4                            |
| 3   | Frame            | 3                            |
| 4   | Ladder           | 26                           |
| 5   | Bottom Frame     | 4                            |
| 6   | Top Frame        | 1                            |
| 7   | Final            | 2                            |
|     | **Total**        | **54**                       |

After the proposed design assembly process is known, the next step is to calculate the efficiency value of assembly on the proposed design using DFA analysis table. Filling the table is done by identifying manual handling code and manual insertion code for each component. Calculations are performed to determine the overall assembly process time resulting in assembly efficiency values. Calculation of total assembly process time and its efficiency value can be seen in Table 5.

Table 5. Manual Assembly Proposed Design

| Item ID | Item name                     | Number of items | Total operation time, s | Figures for min. parts |
|---------|--------------------------------|-----------------|-------------------------|------------------------|
| 1       | Platform Sub Assembly         |                 |                         |                        |
| 1.1     | Hydraulic Base Sheet          | 4               | 29.20                   | 2                      |
| 1.2     | Hydraulic Arm                 | 8               | 58.40                   | 4                      |
| 1.3     | Hydraulic Spiner              | 2               | 7.90                    | 1                      |
| 1.4     | Hydraulic Pin 1               | 8               | 60.00                   | 4                      |
| 1.5     | Hydraulic Pin 2               | 8               | 57.04                   | 4                      |
| 1.6     | Hydraulic Nut                 | 2               | 23.00                   | 1                      |
| 1.7     | Hydraulic Rod                 | 2               | 23.00                   | 1                      |
| 1.8     | Socket Set Screw              | 10              | 125.70                  | 5                      |
| 1.9     | Platform Base (Base Part)     | 1               | -                       | -                      |
| 1.10    | Platform                      | 1               | 13.00                   | 1                      |
| 1.11    | M10 Bolt                      | 8               | 82.40                   | 4                      |
| 1.12    | M10 Nut                       | 8               | 79.44                   | 2                      |
| 2       | Wheels Sub Assembly           |                 |                         |                        |
| 2.1     | Wheels Bracket(Base Part)     | 4               | -                       | -                      |
| 2.2     | Wheels                        | 4               | 26.52                   | 4                      |
| 2.3     | Wheels Connector              | 4               | 12.52                   | 4                      |
| 3       | Frame Sub Assembly            |                 |                         |                        |
| 3.1     | Main Frame (Base Part)        | 1               | -                       | -                      |
| 3.2     | Frame Door                    | 1               | 10.50                   | 1                      |
| 3.3     | Storage Container Door        | 1               | 12.10                   | 1                      |
| 3.4     | Frame Door Lock               | 1               | 3.50                    | 1                      |
| 4       | Ladder Sub Assembly           |                 |                         |                        |
| 4.1     | Ladder Pillar                 | 12              | 37.56                   | 12                     |
| 4.2     | Connecting Rubber             | 14              | 53.20                   | 14                     |
| 4.3     | Step Footing                  | 6               | 21.00                   | 6                      |
| 5       | Bottom Frame Sub Assembly     |                 |                         |                        |
| 5.1     | Platform Sub Assembly (Base Part) | 1     | -                       | -                      |
| 5.2     | Wheels Sub Assembly           | 4               | 10.92                   | 4                      |
| 5.3     | M10 Nut                       | 16              | 158.88                  | 8                      |
| 6       | Top Frame Sub Assembly        |                 |                         |                        |
| 6.1     | Frame Sub Assembly (Base Part) | 1     | -                       | -                      |
| 6.2     | Ladder Sub Assembly           | 1               | 6.10                    | 1                      |
| 6.3     | Handle                        | 1               | 6.10                    | 1                      |
### Table 6. Manual Assembly Proposed Design (cont.)

| Item ID | Item name                                      | Number of items | Total operation time, s | Figures for min. parts |
|---------|------------------------------------------------|-----------------|-------------------------|------------------------|
| 7       | Final Sub Assembly                             |                 |                         |                        |
| 7.1     | Bottom Frame Sub Assembly (Base Part)          | 1               | -                       | -                      |
| 7.2     | Top Frame Sub Assembly                         | 1               | 11.00                   | 1                      |
|         | **Total**                                      | **127**         | **928.98**              | **86**                 |

#### 3.3. Comparison

The proposed design has fewer number of components i.e. 127 components, compared to the reference design that has 185 components. The proposed design requires less total assembly operation time of 928.98 seconds, compared to the reference design that requires total assembly operation time of 1475.93 seconds. The proposed design has a higher assembly efficiency value of 27.77%, compared to the reference design of the trolley having an assembly efficiency value of 22.97%. It can be concluded that by using the proposed design can minimize the number of components and assembly operation time with the principles of Design for Assembly (DFA) Boothroyd and Dewhurst method. Comparison of number of components, total assembly operation time, and efficiency value in each design can be seen in the table 6.

### Table 7. Comparison

| No. | DFA Goals                          | Reference Design | Proposed Design |
|-----|------------------------------------|------------------|-----------------|
| 1   | Number of Components (pcs)         | 185              | 127             |
| 2   | Total Assembly Operation Time (sec)| 1475.93          | 928.98          |
| 3   | Efficiency Value (%)               | 22.97            | 27.77           |

### 4. Conclusion

Based on the results of research, can be obtained some conclusion that is expected to be problem solving in company. The conclusions that can be taken include:

1. Test results of the main components of the wood pellet trolley using Finite Element Method (FEM), handles, platforms, frames and ladders chunk are categorized safe and can operate well based on stress, displacement and factor of safety tests. As for the wheel chunk is categorized as unsafe so it needs to be re-election of material into titanium alloy.
2. After comparison of reference design with proposed design using Design for Assembly (DFA) approach, proposed design has better assembly system with assembly efficiency value of 27.77% which increased from the previous design by 22.97%. Then the proposed design has a shorter total processing time that is 928.98 seconds down from the previous design that is for 1475.93 seconds.

### 5. References

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