Optimization Heavy Equipment Productivity Against Costs on Un-Top Soil and Spreading Work With Linear Programming Simplex Method

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Abstract

PT Bhumi Rantau Energi is a coal mining company in Indonesia located in South Kalimantan, Indonesia. As a mining company, one of the obligations that must be carried out is land reclamation so as not to cause environmental damage. Land reclamation is carried out by planting tree seeds on ex-mining land. The stages of the process for land reclamation are Top Soil excavation. Top soil is the top layer of soil that contains the most nutrients and has the most air content among other soil layers. The excavated top soil will be spread over the ex-mining land that has been provided for reclamation. The purpose of this study is to determine the productivity, number of heavy equipment and also the costs that will be incurred for the Top Soil and Spreading excavation activities. As for determining the minimum cost, it can be analyzed using mathematical programming techniques, one of which is linear programming using the simplex method. This technique is very useful in finding the best solution for a function with more than two variables under the given constraints. Linear programming is a mathematical method that allocates limited resources to achieve a goal such as maximizing profits and minimizing costs. The research method used is a quantitative method. From the results of the study, it was found that for Top Soil and Spreading work for 8 months, 2 Excavator Units with Productivity of 182.25 m³/hour, 2 Bulldozer Units with Productivity of 181.56 m³/hour, 9 Dump Truck Units with Productivity of 39.94 m³/hour and 1 Motor Grader Unit with Productivity of 16,128 m²/hour, then the cost incurred for the work is Rp. 18,017,984,600.

Keywords
Cost, Linear Programming, Top Soil, Productivity.

1. Introduction
1.1 Background

The existence of heavy equipment currently plays a very important role in carrying out various kinds of construction activities, especially those that are mostly carried out by mechanical means. In line with the rapid development of technology, the use of heavy equipment in construction activities will be very helpful in achieving several goals, such as saving time in carrying out work, saving work execution costs, labor efficiency, and obtaining results in accordance with standards. (Satriawan, 2019)

PT Bhumi Rantau Energi is a coal mining company located in Lokpaikat District, Tapin Regency, South Kalimantan Province, Indonesia. Mining business activities often cause environmental damage, resulting in a decrease in environmental quality, thus it is necessary to have an activity as an effort to preserve the environment so that further damage does not occur, and one way that can be done is to do land reclamation. One of the land reclamation works that require special attention and handling is the un-top soil and spreading process. Top soil is a type of soil that has many benefits. This can be seen from its fertile nature, its presence in the top layer, and also its substance contents. One of the benefits of this top soil can be felt in agriculture, which requires a lot of fertile soil. Some of the benefits of top soil include improving soil structure, improving the air in the soil, as a nursery medium.

As much as 684,797 m³ of top soil volume which is spread and leveled on land that will be used for reclamation and replanting or revegetation in 2021 by PT Bhumi Rantau Energi. The use of heavy equipment in its implementation must be considered so that its use can be optimal, namely achieving minimal costs without neglecting the target time for carrying out the work.

As for determining the minimum cost, it can be analyzed using mathematical programming techniques, one of which is linear programming using the simplex method. This technique is very useful in finding the best solution for a function with more than two variables under the given constraints.
1.2 Aims and Objectives
1. Calculating the productivity of heavy equipment used in the process of un-top soil and spreading.
2. Analyzing the number of heavy equipment needed and the optimal combination for un-top soil and spreading work using the simplex linear programming method.
3. Analyzing the minimum cost of using heavy equipment needed in the un-top soil and spreading process.

2. Literature Review
2.1 Earthmoving Process
1. Stripping top soil (un-top soil)
   Topsoil is the most surface layer that contains nutrients as a medium for plant growth above the soil surface and usually has a thickness of ± 30 cm. The topsoil is peeled off using a bulldozer, and loaded using an excavator into a dump truck to then be transported and placed in a certain area which will be used later for reclamation activities later.
2. Hauling
   Hauling of material or soil by means of conveyance is carried out using a dump truck, scrapper motor or wheel loader (load and carry) or can be used with a bulldozer if the transport distance is less than one hundred meters (direct dozing). In hauling using dump trucks on the hauling road, road maintenance must be carried out which is usually carried out by motor graders, bulldozers, and compactors and assisted by water sprayer trucks.
3. Dumping
4. Land Leveling
   Land leveling consists of the work of stockpiling, leveling, forming, and spreading topsoil over the overburden disposal that has been backfilled, so that the ex-mining area can be replanted for environmental restoration (reclamation).

2.2 Heavy Equipment
In civil engineering, heavy equipment is used to assist humans in carrying out the construction work of a building structure. Currently, heavy equipment is an important factor in projects, especially large-scale construction projects. The purpose of using heavy equipment is to make it easier for humans to do their work so that the expected results can be achieved more easily in a relatively shorter time. Heavy equipment commonly used in construction projects include dozers, excavators such as backhoes, front shovels, clamshells; transportation equipment such as loaders, trucks and conveyor belts, soil compactors such as rollers and compactors, and others. (Fatena, 2008)
1. Bulldozer
   The bulldozer is a tool that uses a tractor as the main driver, meaning that the tractor is equipped with a dozer attachment, in this case the attachment is a blade. (Fatena, 2008)
2. Excavator
   The factors that need to be considered in the selection of an excavator are in terms of bucket capacity, working conditions, can dig in soft to hard areas, but not native soil in the form of hard rock. If hard rock needs to be ripping or blasting first. For hard soils, if the operator has poor skills, it will result in excessive hydraulic pressure. This will result in damage or short tool life. The surface height of the excavation, for the backhoe can reach 6 meters, while for the loading shovel it can reach 10 meters. (Andi, 2003)
3. Motor Grader
   For the purpose of leveling the soil, a grader is used, in addition to forming the desired surface. This can be done because the blade of the grader can be adjusted in such a way. (Andi, 2003)
4. Dump Truck
   Dump trucks are long-distance conveyances, so that the haul roads traversed can be in the form of flat roads, inclines and derivatives. To drive a dump truck on hilly terrain requires operator or driver skills. (Rochmanhadi, 1992a)

2.3 Heavy Equipment Productivity
Productivity is the capacity for production, the state of being a productive force, the effectiveness of the production effort, especially in industry, the production effort per unit. In theory, productivity is output divided by input. For the productivity of a tool, the output is measured from the work that can be completed by the tool concerned per unit time, for example m³ per hour. While the input is the tool itself. Therefore, there are two types of productivity, namely the productivity of individual tools, when the work is completed by the tool alone, and
the second is group productivity/group of tools, when the work is completed by a group of tools. There is a direct relationship between individual tool productivity and tool group productivity, but it is not linear. (Fatena, 2008)

Productivity affects the success of management as measured by the results (output), this can be generated by getting the optimal point of productivity. If the research output produces positive capacity, it means getting more workers than the objectives achieved in the project. This explains the high productivity, a rare phenomenon in the construction industry.

2.4. Cost Planning

Cost planning is done by looking at the components of the project cost. The costs involved in carrying out the construction including direct cost and indirect cost. Direct costs are elements of costs that are directly related to the project being worked on. The costs included in direct costs are labor costs (wages), material costs, subcontractor costs and equipment/equipment costs. And Indirect costs are a number of expenses that are a substantial portion of direct costs and consist of overhead costs, contingency costs and profit.

3. Methodology

The research method used is by the mathematical model obtained based on the formulation of the problem contains the objective and constraint functions. After using the model, data analysis will be carried out using a linear program using the simplex method. The analysis process is carried out by entering the results of the mathematical model into the table.

![Figure 1: Methodology Flow Chart](image)

4. Results and Discussion

4.1. Analysis of Heavy Equipment Selection

1. Excavator Selection Analysis

<table>
<thead>
<tr>
<th>Table 1. Crawler Excavator Specification Comparison</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Brand</strong></td>
</tr>
<tr>
<td>Type</td>
</tr>
<tr>
<td>Boom Length</td>
</tr>
<tr>
<td>Arm Length</td>
</tr>
<tr>
<td>Horse Power</td>
</tr>
<tr>
<td>Operating Weight</td>
</tr>
<tr>
<td>Swing Speed</td>
</tr>
<tr>
<td>Bucket Capacity</td>
</tr>
<tr>
<td>Max. Digging Height</td>
</tr>
<tr>
<td>Max. Digging Depth</td>
</tr>
<tr>
<td>Max. Digging Reach</td>
</tr>
<tr>
<td>Max. Reach on Ground</td>
</tr>
</tbody>
</table>

To get the actual production figures, determining the efficiency must be in accordance with the actual operating conditions of the heavy equipment at work, it is assumed that the working conditions are in an average state of 75% or 0.75.
Excavator cycle time is calculated when the bucket is digging/filling (land bucket), boom swinging (swing loaded), unloading (dump bucket), and swinging back without load (swing empty). Cycle time data is obtained from direct field observations when the company uses this type of tool.

<table>
<thead>
<tr>
<th>Loading Condition</th>
<th>Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Easy</td>
<td>1.0 – 0.9</td>
</tr>
<tr>
<td>Medium</td>
<td>0.8 – 0.6</td>
</tr>
<tr>
<td>Rather Difficult</td>
<td>0.6 – 0.5</td>
</tr>
<tr>
<td>Difficult</td>
<td>0.5 – 0.4</td>
</tr>
</tbody>
</table>

Excavator cycle time is calculated when the bucket is digging/filling (land bucket), boom swinging (swing loaded), unloading (dump bucket), and swinging back without load (swing empty). Cycle time data is obtained from direct field observations when the company uses this type of tool.

<table>
<thead>
<tr>
<th>Tool Operating Condition</th>
<th>Machine Maintenance</th>
<th>Excellent</th>
<th>Good</th>
<th>Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Excellent</td>
<td>0.83</td>
<td>0.81</td>
<td>0.76</td>
<td></td>
</tr>
<tr>
<td>Good</td>
<td>0.78</td>
<td>0.75</td>
<td>0.71</td>
<td></td>
</tr>
<tr>
<td>Normal</td>
<td>0.72</td>
<td>0.69</td>
<td>0.65</td>
<td></td>
</tr>
<tr>
<td>Poor</td>
<td>0.63</td>
<td>0.61</td>
<td>0.57</td>
<td></td>
</tr>
<tr>
<td>Very Poor</td>
<td>0.52</td>
<td>0.50</td>
<td>0.47</td>
<td></td>
</tr>
</tbody>
</table>

(source: (Rochmanhadi, 1992b))

Excavator cycle time is calculated when the bucket is digging/filling (land bucket), boom swinging (swing loaded), unloading (dump bucket), and swinging back without load (swing empty). Cycle time data is obtained from direct field observations when the company uses this type of tool.

<table>
<thead>
<tr>
<th>Total Cycle Time</th>
<th>PC-200</th>
<th>PC-300</th>
<th>PC-400</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cycle Time</td>
<td>20 second</td>
<td>20 second</td>
<td>22 second</td>
</tr>
</tbody>
</table>

The capacity of the excavator bucket is very dependent on the type of material being excavated, therefore there is a correction factor in determining the capacity of the bucket so that the volume of the existing bucket is completely filled with material. The type of material to be worked on is ordinary soil type, then the bucket fill factor is taken from 0.8 to 0.6.

<table>
<thead>
<tr>
<th>Loading Condition</th>
<th>Bucket Fill Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Easy</td>
<td>1.0 – 0.9</td>
</tr>
<tr>
<td>Medium</td>
<td>0.8 – 0.6</td>
</tr>
<tr>
<td>Rather Difficult</td>
<td>0.6 – 0.5</td>
</tr>
<tr>
<td>Difficult</td>
<td>0.5 – 0.4</td>
</tr>
</tbody>
</table>

(source: (Rochmanhadi, 1992a))

From the data that has been obtained and collected, then calculate the productivity of each type of excavator and analyze the rental price.

### a. Excavator PC-200

**Productivity:**

\[
P = \frac{3600}{\text{Cycle Time}} \times \text{Bucket Capacity} \times \text{Bucket Fill Factor} \times \text{Job Efficiency}
\]

\[
P = \frac{3600}{20} \times 1.0 \times 0.8 \times 0.75
\]

\[
P = 121.25 \text{ m}^3/\text{Hour}
\]

**Excavator Working Hours:**

\[
\frac{\text{Target Volume of Work}}{\text{Productivity}} = \frac{684.797}{121.25} = 5.636,18 \text{ Hours}
\]

**Number of Excavators:**

\[
\frac{\text{Number of effective working hours}}{\text{Number of Excavators}} = \frac{5.636,18}{2.333} = 2.41 \approx 3 \text{ Excavators}
\]

Komatsu Excavator Rental Price Type PC-200 is IDR 235,000,-/hour.

Total rental price = IDR 235,000 x 3 = IDR **705,000** / hour.

### b. Excavator PC-300

**Productivity:**

\[
P = \frac{3600}{\text{Cycle Time}} \times \text{Bucket Capacity} \times \text{Bucket Fill Factor} \times \text{Job Efficiency}
\]

\[
P = \frac{3600}{20} \times 1.5 \times 0.8 \times 0.75
\]

\[
P = 182.25 \text{ m}^3/\text{Hour}
\]

**Excavator Working Hours:**

\[
\frac{\text{Target Volume of Work}}{\text{Productivity}} = \frac{684.797}{182.25} = 3.757,45 \text{ Hours}
\]

**Number of Excavators:**

\[
\frac{\text{Number of effective working hours}}{\text{Number of Excavators}} = \frac{3.757,45}{2.333} = 1.61 \approx 2 \text{ Excavators}
\]

Komatsu Excavator Rental Price Type PC-300 is IDR 335,000,-/hour.

Total rental price = IDR 335,000 x 2 = IDR **670,000** / hour.

### c. Excavator PC-400

**Productivity:**

92
is of productivity and rental costs, the type of excavator chosen is the Komatsu Excavator Type PC because the rental fee will be cheaper than the PC-200 and PC-400 types.

2. Bulldozer Selection Analysis

<table>
<thead>
<tr>
<th>Table 5. Crawler Mounted Bulldozer Specification Comparison</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Brand</strong></td>
</tr>
<tr>
<td><strong>Type</strong></td>
</tr>
<tr>
<td><strong>Operating Weight</strong></td>
</tr>
<tr>
<td><strong>Blade Capacity</strong></td>
</tr>
<tr>
<td><strong>Min. Turning Radius</strong></td>
</tr>
<tr>
<td><strong>Coolant</strong></td>
</tr>
<tr>
<td><strong>Engine Oil</strong></td>
</tr>
<tr>
<td><strong>Fuel Tank</strong></td>
</tr>
</tbody>
</table>

When calculating bulldozer productivity, the number used for the volume of soil transported in each cycle, is taken as blade capacity. In fact, production per cycle differs with soil type, so a blade fill factor is used to adjust this figure. The material to be worked on is in the form of ordinary soil with low water content without any stones, so based on the table the blade fill factor is taken with easy/light evicton conditions with a value of 1.1-0.9.

<table>
<thead>
<tr>
<th>Table 6. Blade Fill Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Dozing Conditions</strong></td>
</tr>
<tr>
<td>Easy Dozing</td>
</tr>
<tr>
<td>Average Dozing</td>
</tr>
<tr>
<td>Rather Difficult Dozing</td>
</tr>
<tr>
<td>Difficult Dozing</td>
</tr>
</tbody>
</table>

(source: Komatsu, 2013)

To get the actual production figures, determining the efficiency must be in accordance with the actual operating conditions of the heavy equipment at work, it is assumed that the working conditions are in an average state of 75% or 0.75.

From the data that has been obtained and collected, then calculate the productivity of each type of bulldozer and analyze the rental price.

d. Bulldozer D-31

Productivity:

\[
P = \frac{\text{Production Per Cycle} \times \text{60} \times \text{Job Efficiency}}{\text{Cycle Time}}
\]

\[
P = \frac{1771 \times 60 \times 0.75}{2.12} = 62.26 \text{ m}/\text{Hour}
\]

Bulldozer Working Hours:

\[
\text{Bulldozer Working Hours} = \frac{\text{Target Volume of Work}}{\text{Productivity}} = \frac{684.797}{62.26} = 10.998,98 \text{ Hours}
\]

Number of Bulldozers:

\[
\text{Number of Bulldozers} = \frac{\text{Number of effective working hours}}{2.33} = \frac{10.998,98}{4.71} \approx 5 \text{ Bulldozers}
\]

Komatsu Bulldozer Rental Price Type D-31 is IDR 150,000./hour.

Total rental price = IDR 150,000 x 5 = IDR 750.000 / hour.

e. Bulldozer D-85

Productivity:

\[
P = \frac{\text{Production Per Cycle} \times \text{60} \times \text{Job Efficiency}}{\text{Cycle Time}}
\]

\[
P = \frac{220 \times 60 \times 0.75}{205} = 276,136 \text{ m}^3/\text{Hour}
\]

Total rental price = IDR 800.000 / hour.

Based on the analysis of productivity and rental costs, the type of excavator chosen is the Komatsu Excavator Type PC-300 because the rental fee will be cheaper than the PC-200 and PC-400 types.
\[ P = \frac{3.74 \times 60 \times 0.75}{1.64} \]

**P = 181.56 m³/Hour**

Bulldozer Working Hours = \( \frac{\text{Target Volume of Work}}{\text{Productivity Bulldozer Working Hours}} = \frac{684.797}{181.56} = 3.771,73 \text{ Hours} \)

Number of Bulldozers = \( \frac{\text{Number of effective working hours}}{2.333} = \frac{3.771.73}{2.333} = 1.6 \approx 2 \text{ Bulldozers} \)

Komatsu Bulldozer Rental Price Type D-85 is IDR 318.000,-/hour.

Total rental price = IDR 318.000 x 2 = IDR 636.000 / hour.

f. **Bulldozer D-155**

Productivity:

\[ P = \frac{\text{Production Per Cycle} \times 60 \times \text{Job Efficiency}}{\text{Cycle Time}} \]

\[ P = \frac{5.06 \times 60 \times 0.75}{1.92} \]

**P = 203.30 m³/Hour**

Bulldozer Working Hours = \( \frac{\text{Target Volume of Work}}{\text{Productivity Bulldozer Working Hours}} = \frac{684.797}{203.30} = 3.368,40 \text{ Hours} \)

Number of Bulldozers = \( \frac{\text{Number of effective working hours}}{2.333} = \frac{3.368.40}{2.333} = 1.4 \approx 2 \text{ Bulldozers} \)

Komatsu Bulldozer Rental Price Type D-85 is IDR 460.000,-/hour.

Total rental price = IDR 460.000 x 2 = IDR 920.000 / hour.

Based on the analysis of productivity and rental costs, the type of bulldozer chosen is the **Komatsu Bulldozer Type D-85** because the rental fee will be cheaper than the D-31 and D-155 types.

3. **Dump Truck Selection Analysis**

<table>
<thead>
<tr>
<th>Table 7. Dump Truck Specification Comparison</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Brand</strong></td>
</tr>
<tr>
<td>Type</td>
</tr>
<tr>
<td>Maximum Speed</td>
</tr>
<tr>
<td>Climbing</td>
</tr>
<tr>
<td>Min. Turning Radius</td>
</tr>
<tr>
<td>Capacity</td>
</tr>
<tr>
<td>Empty Weight</td>
</tr>
<tr>
<td>Total Vehicle Weight</td>
</tr>
</tbody>
</table>

To get the actual production figures, determining the efficiency must be in accordance with the actual operating conditions of the heavy equipment at work, it is assumed that the working conditions are in an average state of 75% or 0.75.

From the data that has been obtained and collected, then calculate the productivity of each type of dump truck and analyze the rental price.

g. **Dump Truck FG-235**

Productivity:

\[ P = \frac{\text{Production Per Cycle} \times 60 \times \text{Job Efficiency}}{\text{Cycle Time}} \]

\[ P = \frac{9.45 \times 60 \times 0.75}{1.663} \]

**P = 29.10 m³/Hour**

Number of Dump Trucks = \( \frac{\text{Excavator Productivity}}{\text{Dump Truck Productivity}} = \frac{182.25}{29.10} = 6.26 \approx 7 \text{ Dump Trucks} \)

Hino Dump Truck Rental Price Type FG-235 is IDR 200.000,-/hour.

Total rental price = IDR 200.000 x 7 = IDR 1.400.000 / hour.

h. **Dump Truck FM-260**

Productivity:

\[ P = \frac{\text{Production Per Cycle} \times 60 \times \text{Job Efficiency}}{\text{Cycle Time}} \]

\[ P = \frac{14.85 \times 60 \times 0.75}{16.73} \]

**P = 39.94 m³/Hour**

Number of Dump Trucks = \( \frac{\text{Excavator Productivity}}{\text{Dump Truck Productivity}} = \frac{182.25}{39.94} = 4.56 \approx 5 \text{ Dump Trucks} \)

Hino Dump Truck Rental Price Type FM-260 is IDR 225.000,-/hour.

Total rental price = IDR 225.000 x 5 = IDR 1.125.000 / hour.

94
Based on the analysis of productivity and rental costs, the type of dump truck chosen is the Hino Dump Truck Type D-85 because the rental fee will be cheaper than the FG-235 type.

4. Motor Grader Selection Analysis

Table 8. Motor Grader Specification Comparison

<table>
<thead>
<tr>
<th>Brand</th>
<th>Caterpillar</th>
<th>Komatsu</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type</td>
<td>120K</td>
<td>GD705</td>
</tr>
<tr>
<td>Base Power</td>
<td>125 HP</td>
<td>260 HP</td>
</tr>
<tr>
<td>Blade Length</td>
<td>4.27 m</td>
<td>4.32 m</td>
</tr>
<tr>
<td>Fuel Tank</td>
<td>305 L</td>
<td>408 L</td>
</tr>
<tr>
<td>Cooling System</td>
<td>30 L</td>
<td>24.5 L</td>
</tr>
<tr>
<td>Ripper Depth Max</td>
<td>262 mm</td>
<td>380 mm</td>
</tr>
<tr>
<td>Max. Speed Forward</td>
<td>45.7 km/Hour</td>
<td>42.5 km/Hour</td>
</tr>
<tr>
<td>Max. Speed Reverse</td>
<td>36.1 km/Hour</td>
<td>34.1 km/Hour</td>
</tr>
<tr>
<td>Turning Radius</td>
<td>7.3 m</td>
<td>7.6 m</td>
</tr>
</tbody>
</table>

To get the actual production figures, determining the efficiency must be in accordance with the actual operating conditions of the heavy equipment at work, it is assumed that the working conditions are in an average state of 75% or 0.75.

Motor graders are used in top soil and spreading work to support the smooth hauling of top soil, namely road maintenance. So theoretically, the standard speed of the motor grader for regular road repairs is 2-6 km/hour.

Table 9. Average motor grader speed

<table>
<thead>
<tr>
<th>Job</th>
<th>Speed (km/hour)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regular Road Repair</td>
<td>2 - 6</td>
</tr>
<tr>
<td>Trens</td>
<td>1.6 - 4</td>
</tr>
<tr>
<td>Cliff Trimming</td>
<td>1.6 – 2.6</td>
</tr>
<tr>
<td>Snow Removal</td>
<td>7 – 25</td>
</tr>
<tr>
<td>Terrain Leveling</td>
<td>1.6 - 4</td>
</tr>
<tr>
<td>Levelling</td>
<td>2 - 8</td>
</tr>
</tbody>
</table>

(source: (Rochmanhadi, 1992b)

From the data that has been obtained and collected, then calculate the productivity of each type of motor grader and analyze the rental price

i. Motor Grader 120K
Productivity:
P = \(1000 \times (L_e - L_o) \times \text{Speed} \times \text{Job Efficiency}\)
P = \(1000 \times 3.36 \times 6 \times 0.75\)
P = **16.128 m²/jam**

Caterpillar Motor Grader Rental Price Type 120K is **IDR 370.000,/hour.**

j. Motor Grader GD705
Productivity:
P = \(1000 \times (L_e - L_o) \times \text{Speed} \times \text{Job Efficiency}\)
P = \(1000 \times 3.42 \times 6 \times 0.75\)
P = **16.416 m²/jam**

Komatsu Motor Grader Rental Price Type GD705 is **IDR 480.000,/hour.**

Based on the analysis of productivity and rental costs, the type of motor grader chosen is the Caterpillar Motor Grader Type 120K because the rental fee will be cheaper than the Komatsu GD705 Type.

5. Linear Programming Analysis Simplex Method Solving Method

1) Mathematical Modeling
Heavy equipment is used as a variable in this problem as follows:
X₁ = Excavator , X₂ = Bulldozer , X₃ = Dump Truck , X₄ = Motor Grader

2) Goal Setting
k. Excavator as X₁, Total Cost: Equipment rental + operator + fuel = IDR 566.000/Hour.
l. Bulldozer as X₂ , Total Cost: Equipment rental + operator + fuel = IDR 549.000/Hour.
m. Dump Truck as X₃ . Total Cost: Equipment rental + operator + fuel = IDR 303.000/Hour.

95
n. Motor Grader as $X_1$. Total Cost: Equipment rental + operator + fuel = IDR 468,000/Hour. From the calculation above, the objective equation is to minimize costs.

$$Z = 566,000X_1 + 549,000X_2 + 303,000X_3 + 468,000X_4$$

3) Limiting determination

o. Cost Limit. Costs incurred for the hourly land clearing work: IDR 1,116,456/Hour. Costs incurred for the hourly top soil and spreading work: IDR 6,952,417/Hour. Then, the cost constraint equation is:

```
Land Clearing: 566,000X_1 + 549,000X_2 ≤ 1,116,456
Top Soil and Spreading: 566,000X_4 + 549,000X_2 + 303,000X_3 + 468,000X_4 ≤ 6,952,417.
```

p. Time Limit.

```
\frac{3.757.45}{X_1} ≤ 2.333 = 2.333X_1 ≥ 3.757,45
\frac{3.771.73}{X_2} ≤ 2.333 = 2.333X_2 ≥ 3.771,73
\frac{17.145.64}{X_3} ≤ 2.333 = 2.333X_3 ≥ 17.145,64
\frac{2.333}{X_4} ≤ 2.333 = 2.333X_4 ≥ 2.333
```

q. Heavy Equipment Quantity Limit.

```
X_1 ≤ 3 , X_2 ≤ 3 , X_3 ≤ 14 , X_4 ≤ 2
```

r. Heavy Equipment Productivity Limit

```
182.25X_1 ≥ 293,52
181,56X_2 ≥ 293,52
39.94X_3 ≥ 293,52
16.128X_4 ≥ 16.128
```

6. Determination of Optimum Solution

Minimize : $R = R_3 + R_4 + R_5 + R_6 + R_{11} + R_{12} + R_{13} + R_{14}$

Against constraints:

```
566,000X_1 + 549,000X_2 + S_1 = 1,116,456
566,000X_1 + 549,000X_2 + 303,000X_3 + 468,000X_4 + S_2 = 6,952,417
2.333X_1 + S_3 + r_3 = 3.757.45
2.333X_2 + S_4 + r_5 = 3.771.73
2.333X_3 + S_5 + r_7 = 17.145.64
2.333X_4 + S_6 + r_6 = 2.333
X_1 + S_7 = 3
X_2 + S_9 = 3
X_3 + S_0 = 14
X_4 + S_{10} = 2
182.25X_1 + S_{11} + r_{11} = 293,52
181,56X_2 + S_{12} + r_{12} = 293,52
39.94X_3 + S_{13} + r_{33} = 293,52
16.128X_4 + S_{14} + r_{14} = 16.128
```

The equation:

```
r_3 = 3.757.45 - 2.333X_1 + S_3
r_4 = 3.771.73 - 2.333X_2 + S_4
r_5 = 17.145.64 - 2.333X_3 + S_5
r_6 = 2.333 - 2.333X_4 + S_6
r_{11} = 293,52 - 182.25X_1 + S_{11}
r_{12} = 293,52 - 181,56X_2 + S_{12}
r_{13} = 293,52 - 39.94X_3 + S_{13}
r_{14} = 16.128 - 16.128X_4 + S_{14}
```

From the results of the simplex table analysis phase 2, it was found in the solution column that:

```
X_1 (Excavator) = 1, 5696 ≈ 2
X_2 (Bulldozer) = 1, 4500 ≈ 2
X_3 (Dump Truck) = 8, 3491 ≈ 9
X_4 (Motor Grader) = 1 ≈ 1
```

7. Cost Analysis
### Table 10. Total Cost

<table>
<thead>
<tr>
<th>No.</th>
<th>Description</th>
<th>Total Cost (IDR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Direct Cost (DC)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Preparatory Work</td>
<td>887,218,000</td>
</tr>
<tr>
<td></td>
<td>Top Soil Stripping Work</td>
<td>9,230,400,000</td>
</tr>
<tr>
<td></td>
<td>Spreading Top Soil Work</td>
<td>4,881,600,000</td>
</tr>
<tr>
<td></td>
<td>Direct Cost Total Amount</td>
<td>14,999,218,000</td>
</tr>
<tr>
<td>II</td>
<td>Indirect Cost (IDC)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Salary</td>
<td>583,520,000</td>
</tr>
<tr>
<td></td>
<td>Tools</td>
<td>714,648,000</td>
</tr>
<tr>
<td></td>
<td>Preparation and Completion</td>
<td>82,600,000</td>
</tr>
<tr>
<td></td>
<td>Indirect Cost Total Amount</td>
<td>1,380,768,000</td>
</tr>
<tr>
<td></td>
<td>Total I + II</td>
<td>16,379,986,000</td>
</tr>
<tr>
<td></td>
<td>VAT 10%</td>
<td>1,637,998,600</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>18,017,984,600</td>
</tr>
</tbody>
</table>

#### 5. Closing

**5.1. Conclusion**

Based on the results of the productivity analysis, the number of tools and costs incurred for Top Soil and Spreading work, it can be concluded as follows:

1. The productivity of heavy equipment to achieve the 8-month work target is:
   - Excavator : 182.25 m³/hour
   - Bulldozer : 181.56 m³/hour
   - Dump Truck : 39.94 m³/hour
   - Motor Grader : 16,128 m²/hour

2. The number of each optimized heavy equipment is:
   - Excavators : 2 Units
   - Bulldozer : 2 Unit
   - Dump Truck : 9 Units
   - Motor Grader : 1 Unit

3. The result of cost analysis for top soil and spreading work is Rp. 18,017,984,600 (Eighteen Billion Seventeen Million Nine Hundred Eighty Four Six Hundred Rupiah) including 10% VAT.

#### 6. Suggestion

Based on the analysis and calculation results for top soil and spreading work, suggestions that can be put forward are as follows:

4. It should be taken into account for rainy times and slippery times in calculating heavy equipment productivity.

5. In the analysis of the selection of heavy equipment, it is necessary to reconsider the achievement of the target work time.

#### References


#### Biography

**Maulvi Ratri Adinda Putri** is an undergraduate student majoring civil engineering in Mercu Buana University Jakarta. She has completed her diploma studies at Diponegoro University Semarang majoring civil engineering diploma at 2019. She is passionate with coal mining industries, therefore she works on coal mining company based in Jakarta.
Irriene Indah Susanti, S.T., M.T. She was born on January 15, 1983. She is active in construction management project civil in Indonesia and also lecturer in Construction Management at Faculty of Civil Engineering, Mercu Buana University, Jakarta. Completed her Master Degree in Civil Engineering with concentration Infrastructure Management from Bandung Institute Technology with title of her thesis, “Application of Failure Mode and Impact Analysis (FMEA) on Airport Infrastructure.”