The teak log volume estimation model for Sawn Timber: Case in Forest Management Unit (FMU) Bojonegoro – Perhutani – East Java - Indonesia

L Abdulah¹, R Imanuddin², and A P Utama³

¹²Forest Research and Development Agency, Forest Research, Development and Innovation Agency. Jl. Gunung Batu No. 5, Bogor City, West Java, Indonesia
³Perhutani - Jakarta

Abstract. Cultivation of teak continues to be developed. The decision to harvest teak trees depends on the economic value. The economic value of the teak tree is the money value contained in the teak trunk which is divided into parts which are then called nodes. The determination of the part is based on the diameter size. Perhutani recognizes three classes of nodes namely A1 (10 - 19 cm), A2 (20 - 29 cm) and A3 (> 30 cm) and are expressed in the log volume table (TVL). Perhutani's TVL stated the relationship between tree circumference and log volume. This relationship is expressed in the estimator model and classified by nodes. To enter these numbers using constants that are difficult to account for. For this reason, this study aims to provide a volume estimator model for teak logs. The method used is a destructive method and regression analysis. The results showed that TVL in FMU can be explained based on the class of nodes but ignores the place of growth. The shape of the model is compound. This model works well at tree circumference intervals of 50 - 250 cm. Research like this needs to be propagated with wider tree circumference intervals.

1. Introduction
The log volume table (TVL) is an estimating tool for log production expressed in the form of sorting sizes. In this study we termed nodes as segments. Nodes are expressed based on the size of the stem tip diameter. There are three classes of segments, namely A1 (10 - 19 cm), A2 (20 - 29 cm) and A3 (> 30 cm). Nodes classes are created with the aim of determining the economic value of each segment. TVL is often used by Perhutani in estimating the amount of wood production. Perhutani as a state-owned enterprise (BUMN) with its main business is plantation forest producing logs. The log production from Perhutani from 2013 to 2018 has fluctuated. In 2013, wood production was 955,584 m³. Wood production then decreased from 2014 to 2018 which respectively amounted to 918,587 m³, 791,345 m³, 548,096 m³ and in 2018 amounted to 809,934 m³ (1).

One of Perhutani's superior plants is teak (Tectona grandis). Teak is one of the main superior types of wood because of its attractive color, strong fiber and very long durability (2). Teak production from Perhutani continues to decline from 900 thousand m³ in 2012 to 497 thousand m³ in 2017. While the area of land managed by Perhutani for planting teak reaches 1.1 million ha (3).
Table 1. Teak log production

| Year | Production (m$^3$) | Ratio (%) |
|------|-------------------|-----------|
|      | National | Perhutani |
| 2012 | 1,315,448 | 900,185 | 68 |
| 2013 | 3,432,060 | 884,257 | 26 |
| 2014 | 633,192 | 491,258 | 78 |
| 2015 | 513,378 | 505,253 | 98 |
| 2016 | 448,278 | 339,662 | 76 |
| 2017 | 539,357 | 497,408 | 92 |

Sources: (4); (5); (6); (7); (8); (9)

Based on Table 1, it shows that national teak production has continued to decline since 2013. The same thing happened to teak log production from Perhutani. In 2013, the production of teak logs from Perhutani was only 26% of the national production, but then the proportion of teak log production from Perhutani continued to increase in the following years. Changes in production data are caused by many things, one of which is the determining tool for wood production, namely the log volume table.

TVL is compiled from converting the circumference of the tree trunk at breast height to the volume of logs. This conversion can take several ways, such as expressing the correlation between circumference and stem volume or adding other variables such as soil fertility, stem length, and management factors. This technique is often referred to as a hybrid modeling technique (10); (11). This approach can be applied where there is a large bias in estimating wood volume when using the Wolf von Wulffing stand table (12). This study considers the proposals submitted by Pretsch (10) taking into account the differences in growing places. The place to grow is the location where teak trees are harvested. The place to grow is a function of the edaphic, climatic and management factors. This research is very important in estimating the volume of logs produced from standing trees.

2. Objective and

The aim of this research is a reliable and valid teak log volume estimator model for estimating production and forest planning.

3. Methodology

This research was conducted by two parties, namely FMU Perhutani Bojonegoro and the Forest Research and Development Agency (FORDA). The research was conducted by measuring the circumference of the tree at breast height and then cutting it down. The log volume is based on the perimeter of the nodes and uses the Smallian formula.

3.1. Data collecting

Data collection is based on felled reports submitted in the form of felled tabulated data. Data were collected from five locations in this study called compartments. The location is in Bojonegoro district, East Java Province. The research location belongs to the monsoon forest ecosystem type.

Table 2. Number of trees at each compartment

| Compartment | A1 | A2 | A3 | Total |
|-------------|----|----|----|-------|
| Pradok      | 124| 124| 248|
| Bubulan     | 169| 147| 316|
| Dander      | 348| 335| 316|
| Gondang     | 263| 263| 526|
| Deling      | 758| 757| 669|
| Total       | 1106| 1648| 1388| 4142|
Based on Table 2, the amount of data collected was 4,142 divided into three nodes, namely A1 as much as 1.106, A2 as much as 1.648 and A3 as many as 1.388. The highest amount of data is in Deling and the smallest amount of data is in Pradok. However, nodes A1 was not found in the three compartments namely Pradok, Bubulan, and Gondang.

Table 3. Description of tree round (cm)

| Compartmen t | A1 | A2 | A3 |
|--------------|----|----|----|
| Pradok       | 120| 196| 295|
| Bubulan      | 70 | 137| 245|
| Dander       | 50 | 106| 185|
| Gondang      | 95 | 158| 228|
| Deling       | 67 | 132| 248|
| Total        | 50 | 124| 248|

Table 3 shows that in nodes A1, the average tree circumference is 124 cm, while in nodes A2 it is 137 cm and A3 is 141 cm. Meanwhile, the average volume for nodes A1 is 0.173 m³ and 0.359 m³ for nodes A2 and 1,061 m³ for nodes A3.

Table 4. Description of volume (m³)

| Compartmen t | A1  | A2  | A3  |
|--------------|-----|-----|-----|
| Pradok       | 0.049| 0.305| 0.305|
| Bubulan      | 0.034| 0.389| 0.389|
| Dander       | 0.033| 0.179| 0.179|
| Gondang      | 0.031| 0.359| 0.359|
| Deling       | 0.011| 0.167| 0.167|
| Total        | 0.011| 0.173| 0.179|

Figure 1. Scatter plot volume per nodes
Figure 2 shows the pattern of tree volume distribution to the tree circumference at each node. The shape of the tree volume distribution on nodes A3 can be said to be almost linear. However, the log volumes on nodes A2 and A1 form a clustered pattern. This of course will affect the shape of the estimator model.

Based on Table 5, it can be seen that the difference in the mean value between the circumference of the tree and the nodes is very significant. This means that each node has a different circumference of the tree. The same can be seen in the mean difference between the volume of trees for each node.

3.2. Data Analysis
The data analysis used the non-linear regression principle. Researchers subjectively determine four forms of regression models, namely:

a) Linier regression
   \[ V = \alpha + \beta \cdot \text{Round} \]
   \[ V = \alpha + \beta \cdot (\ln R) \]  
   Logarithmic regression

b) Compound regression
   \[ V = \alpha \cdot \beta^R \]

3) Exponential regression
   \[ V = \alpha \cdot \exp(\beta \cdot R) \]

There stages of data analysis: (a) filtering outlier data for each node and compartment. The outlier’s data are then deleted; (b) divide into two parts, namely data on model compilers and data validation. The model compiler data is determined at 80% and the rest is for validation; (c) Perform fit regression; (d) Choose the best model. Selection of the best model by some criteria like the lowest error, value of each model coefficient has a significant effect and has the largest coefficient of determination \( R^2 \); (e) Model simulation and (f) performing the mean difference test between the model simulation data and the validation data. The test criteria are:

\[ H_0: \text{there is no difference between the validation data and the data model (p-value} \geq \alpha, 5\% \]
\[ H_1: \text{There is a difference between the validation data and the data model (p-value} \geq \alpha, 5\%). \]

4. Result and Discussion
4.1. Total log volume model
In general, the relationship between log volume and perimeter of the tree is positive linear. This means that as the tree ring size increases, the log volume will increase. This information is important when used in estimating the potential of standing trees.
Figure 2. Scatter plot of tree round and log volume

Figure 2 shows that the tree circumference is in the range of 50 cm - 250 cm or a diameter at breast height (DBH) of 16 cm - 80 cm. There is one tree with a circumference between 100 - 150 cm which has a log volume above 3 m³ and there is also a tree with a circumference between 100 - 150 cm which has a log volume below 1 m³. Meanwhile, the circumference of 50 - 100 cm has log volume <1 m³ and log volume at tree circumference > 200 cm is in the range of 3 m³. For example, the log volume interval will be 100-200 cm wide at the circumference of the tree.

Table 6. Model for nodes 3 volume

| Model                | Coefficient | p-value | Error   | $R^2$  | Best Model |
|----------------------|-------------|---------|---------|--------|------------|
| Linier (V)           | $\alpha$   | -1.1564 | < 0.05  | 0.312  | 76.4%      |
|                      | $\beta_1$  | 0.018   |         |        |            |
| Logarithmic (V)      | $\alpha$   | -10.031 | < 0.05  | 0.340  | 71.8%      |
|                      | $\beta_1$  | 2.32    |         |        |            |
| Compound (ln V)      | $\alpha$   | 0.139   | < 0.05  | 0.296  | 72.4%  *    |
|                      | $\beta_1$  | 1.015   |         |        |            |
| Exponential (ln V)   | $\alpha$   | 0.139   | < 0.05  | 0.296  | 72.4%      |
|                      | $\beta_1$  | 0.015   |         |        |            |

Notes: *: the best model

Table 6 shows that the compound model is a reliable model in estimating the overall log volume at FMU Bojonegoro because the flow between points to the compound regression line is closer than other models. This can be seen from the smaller error. However, the amount of data that can be explained by this model is only 72.4% or less than the linear model.

Model for total volume log is:

Figure 3. Model Simulation of total volume log
Figure 3 shows that this model will only work well with tree circumference between 50 - 200 cm. If the circumference of the tree is < 50 cm or > 200 cm then this model should be tested again. This is because the log volume will not equal 0 m³ even if the circumference of the tree is 0.

4.2. Log Volume Model at FMU Level

Modeling includes variable nodes regardless of location factors. Nodes A1 is only found in two compartments, namely Dander and Deling. This also affects the number of models that can be simulated. This model can be used as a log volume estimator model based on nodes which describes the general model described in point A.

| Compartment | Model          | Coefficient | p-value | Error | R²  | Best Model |
|-------------|----------------|-------------|---------|-------|-----|------------|
| Pradok      | Linier (V)     | α -2.4      | < 0.05  | 0.455 | 76.5% |            |
|             |                | β1 0.025    |         |       |     |            |
|             | Logarithmic (V)| α -22.4     | < 0.05  | 0.503 | 71.4% |            |
|             |                | β1 4.7      |         |       |     |            |
|             | Compound (ln V)| α 0.354     | < 0.05  | 0.185 | 74.7% |            |
|             |                | β1 1.01     |         |       |     |            |
|             | Exponential (ln V)| α 0.354 | < 0.05  | 0.185 | 74.7% |            |
|             |                | β1 0.01     |         |       |     |            |
| Bubulan     | Linier (V)     | α -1.198    | < 0.05  | 0.331 | 77.3% |            |
|             |                | β1 0.018    |         |       |     |            |
|             | Logarithmic (V)| α -7.68     | < 0.05  | 0.410 | 66.7% |            |
|             |                | β1 1.89     |         |       |     |            |
|             | Compound (ln V)| α 0.042     | < 0.05  | 0.381 | 81.6% |            |
|             |                | β1 1.024    |         |       |     |            |
|             | Exponential (ln V)| α 0.042 | < 0.05  | 0.381 | 81.6% |            |
|             |                | β1 0.024    |         |       |     |            |
| Dander      | Linier (V)     | α -0.986    | < 0.05  | 0.324 | 64.9% |            |
|             |                | β1 0.018    |         |       |     |            |
|             | Logarithmic (V)| α -12.2     | < 0.05  | 0.324 | 65.5% |            |
|             |                | β1 2.78     |         |       |     |            |
|             | Compound (ln V)| α 0.331     | < 0.05  | 0.177 | 68.3% |            |
|             |                | β1 1.011    |         |       |     |            |
|             | Exponential (ln V)| α 0.331 | < 0.05  | 0.177 | 68.3% |            |
|             |                | β1 0.011    |         |       |     |            |
| Gondang     | Linier (V)     | α 0.208     | < 0.05  | 0.439 | 8%   |            |
|             |                | β1 0.006    |         |       |     |            |
|             | Logarithmic (V)| α -2.27     | < 0.05  | 0.438 | 9.3% |            |
|             |                | β1 0.68     |         |       |     |            |
|             | Compound (ln V)| α 0.310     | < 0.05  | 0.526 | 10.8% |            |
|             |                | β1 1.009    |         |       |     |            |
|             | Exponential (ln V)| α 0.31 | < 0.05  | 0.526 | 10.8% |            |
|             |                | β1 0.009    |         |       |     |            |
| Deling      | Linier (V)     | α -0.926    | < 0.05  | 0.202 | 77.4% |            |
|             |                | β1 0.016    |         |       |     |            |
|             | Logarithmic (V)| α -8.57     | < 0.05  | 0.21  | 75.6% |            |
|             |                | β1 2        |         |       |     |            |
|             | Compound (ln V)| α 0.153     | < 0.05  | 0.203 | 74.8% |            |
|             |                | β1 1.015    |         |       |     |            |
|             | Exponential (ln V)| α 0.153 | < 0.05  | 0.203 | 74.8% |            |
|             |                | β1 0.015    |         |       |     |            |
Table 7 shows that the total tree volume estimation model will differ if it is differentiated by location. The difference also occurs in the error and coefficient of determination. However, the model reliably describes log volume.

| Nodes | Model         | Coefficient | p-value | Error | R²   | Best Model |
|-------|---------------|-------------|---------|-------|------|------------|
|       |               | α           |         |       |      |            |
| A1    | Linier (V)    | 0.142       | < 0.05  | 0.076 | 0.7% |            |
|       | β₁            | 0           |         |       |      |            |
|       | Logarithmic (V) | α      | < 0.05  | 0.077 | 0.3% | *          |
|       | β₁(ln R)      | 0.014       |         |       |      |            |
| A2    | Linier (V)    | 0.439       | < 0.05  | 0.164 | 0.9% |            |
|       | β₁            | 0           |         |       |      |            |
|       | Logarithmic (V) | α      | < 0.05  | 0.165 | 0.1% | *          |
|       | β₁(ln R)      | -0.024      |         |       |      |            |
|       | Compound (ln V) | α     | < 0.05  | 0.568 | 0.5% |            |
|       | β₁            | 0.999       |         |       |      |            |
|       | Exponential (ln V) | α  | < 0.05  | 0.568 | 0.5% |            |
|       | β₁            | -0.001      |         |       |      |            |
| A3    | Linier (V)    | -2.233      | < 0.05  | 0.321 | 80%  | *          |
|       | β₁            | 0.021       |         |       |      |            |
|       | Logarithmic (V) | α      | < 0.05  | 0.34  | 77.4%|            |
|       | β₁(ln R)      | 3.2         |         |       |      |            |
|       | Compound (ln V) | α     | < 0.05  | 0.587 | 66.2%|            |
|       | β₁            | 1.027       |         |       |      |            |
|       | Exponential (ln V) | α  | < 0.05  | 0.587 | 66.2%|            |
|       | β₁            | 0.027       |         |       |      |            |

In nodes A1, the best model is logarithmic. Although based on the criteria for selecting the best model, the linear model has a smaller error and a large R2. However, if you choose the linear model, then the tree circumference is 0 cm, the log volume will reach 0.142 m3. This is certainly not acceptable. Meanwhile for A2 nodes, the best model is logarithmic model. The reason for choosing is that it has a low error even though R2 is smaller than other models. The error value is the main selection criteria for the best model. In nodes A3, the best model is the linear model. The linear model has a very small error and also a large R2. Coefficient R2 in nodes A3 is bigger than nodes A1 and A2.

4.3. Model Log Volume at Nodes A3

Nodes A3 start around the tree> 95 cm. However, around the tree between 90 - 95 cm there is a volume of log A3 with a short log size. Around the trees that enter the class of nodes A3 there are also nodes A2 and A1 with the largest proportion of log length is at nodes A3 or A1.

| Compartment | Model         | Coefficient | p-value | Error | R²   | Best Model |
|-------------|---------------|-------------|---------|-------|------|------------|
|             | α             | < 0.05      |         | 0.428 | 78.1%|            |
| Pradok      | β₁            | < 0.05      |         |       |      |            |
| Logarithmic (V) | α      | < 0.05      |         | 0.470 | 73.5%|            |
|             | β₁(ln R)      | 4.852       |         |       |      |            |
| Compound (ln V) | α     | < 0.05      |         | 0.251 | 72.5%| *          |
|             | β₁            | < 0.05      |         |       |      |            |
| Exponential (ln V) | α  | < 0.05      |         | 0.251 | 72.5%|            |
|             | β₁            | < 0.05      |         |       |      |            |
Based on the results of the model analysis shown in Table 9, it can be seen that the form of the log volume estimator model on nodes A3 is linear, logarithmic and compound. The best model for estimating log volume A3 in Pradok is compound. Meanwhile, the linear model can be found in the Bubulan and Deling compartments. In the Gondang compartment, the best model is logarithmic. This difference can occur because the volume of logs at the same circumference of the tree varies.

4.4. Model Log Volume at Nodes A2

The volume of log nodes A2 tends to be very difficult to predict with the regression approach. This is because the log volume tends to be the same even though the circumference of the tree is different. This trend indicates that the tree circumference> 95 cm and is included in the class A3 nodes, has a log volume A2 which may be equal to or smaller than the tree circumference 62 - 95 cm.

### Table 10. Model for log volume at A2.

| Compartment | Model         | Coefficient | p-value | Error | R²     | Best Model |
|-------------|---------------|-------------|---------|-------|--------|------------|
| Pradok      | Linier (V)    | α           | >0.05   | 0.135 | 2.2%   |            |
|             |               | β₁          | -0.001  |       |        |            |
|             | Logarithmic (V) | α          | >0.05   | 0.134 | 2.9%   |            |
|             |               | β₁         | -0.137  |       |        |            |
|             | Compound (ln V) | α          | >0.05   | 0.546 | 2.5%   |            |
|             |               | β₁         | 0.097   |       |        |            |
|             | Exponential (ln V) | α        | >0.05   | 0.546 | 2.5%   |            |
|             |               | β₁         | -0.003  |       |        |            |
Bubulan  
| Model          | α   | β₁  | p-value | Error  | R²    |
|----------------|-----|-----|---------|--------|-------|
| Linier (V)     | 0.361 | 0   | > 0.05  | 0.121  | 0.2%  |
| Logarithmic (V)| 0.15 | 0.05| > 0.05  | 0.171  | 0.4%  |
| Compound (ln V)| 0.364 | 1   | > 0.05  | 0.548  | 0     |
| Exponential (ln V)| 0.364 | 0   | > 0.05  | 0.548  | 0     |

Dander  
| Model          | α   | β₁  | p-value | Error  | R²    |
|----------------|-----|-----|---------|--------|-------|
| Linier (V)     | -0.026 | 0.003| < 0.05  | 0.134  | 19.3% |
| Logarithmic (V)| -1.369 | 0.362| < 0.05  | 0.131  | 22.3% |
| Compound (ln V)| 0.07 | 1.103| < 0.05  | 0.568  | 17.3% |
| Exponential (ln V)| 0.07 | 0.013| < 0.05  | 0.568  | 17.3% |

Gondang  
| Model          | α   | β₁  | p-value | Error  | R²    |
|----------------|-----|-----|---------|--------|-------|
| Linier (V)     | 0.759 | -0.003| < 0.05  | 0.155  | 14.5% |
| Logarithmic (V)| 2.395 | -0.405| < 0.05  | 0.154  | 15.2% |
| Compound (ln V)| 0.985 | 0.993| < 0.05  | 0.560  | 9.7%  |
| Exponential (ln V)| 0.985 | -0.007| < 0.05  | 0.560  | 9.7%  |

Deling  
| Model          | α   | β₁  | p-value | Error  | R²    |
|----------------|-----|-----|---------|--------|-------|
| Linier (V)     | 0.59 | -0.001| < 0.05  | 0.145  | 3.5%  |
| Logarithmic (V)| 0.987 | -0.111| < 0.05  | 0.146  | 2.1%  |
| Compound (ln V)| 0.622 | 0.997| < 0.05  | 0.43   | 3.2%  |
| Exponential (ln V)| 0.622 | -0.003| < 0.05  | 0.43   | 3.2%  |

Notes: * = the best model

Table 10 shows the complexity of applying the regression method to estimate the volume of log nodes A2. Volume logs in Pradok are not found for the best model. This is because the model does not significantly represent the relationship between tree circumference and log volume. The same thing happened in the Bubulan compartment. However, the best estimator models are formed in three other compartments, such as Dander, Gondang and Deling, with the consecutive logarithmic, linear and compound forms. The compound model formed in the Deling compartment has a small R² value, in contrast to the linear and logarithmic forms in the other two compartments.

4.5. Model Log Volume at Nodes A1
The construction of the log nodes A1 log volume estimator model is more complicated. This is because the tree circumference starts from the smallest to the largest. At a circumference under 62 cm, there is one log volume A1. The volume of log A1 will be very large if the circumference of the tree is also large. This is due to the construction of the teak tree branches. If no pruning is done, log A1 volume will be bigger than log A3 volume.

Table 11. Model for log volume at A1

| Compartment | Model     | Coefficient | p-value | Error  | R²    | Best Model |
|-------------|-----------|-------------|---------|--------|-------|------------|
| Pradok      | Linier (V)| α           | -0.048  | < 0.05 | 0.091 | 14.5%      | *          |
Table 11 shows that the volume of log A1 in Gondang and Deling is difficult to establish. This can be seen from the model formed which does not significantly explain the relationship between tree circumference and log volume. Meanwhile, the estimator models in Pradok, Bubulan and Dander compartments are linear, linear and compound respectively.

### 4.6. Model Validation

The validation test is carried out only for the log-volume model at the FMU level. More detailed model testing is carried out if the model at the FMU level is valid. Based on Figure 4, it can be seen that the log-volume model spreads out following the forming data. However, this graphical trend is different from the validity test data.
Based on the boxplot between the log volume data vs the log-volume model shown in Figure 5, it can be seen that the mean value of the log volume data is greater than the log volume model. Furthermore, the distribution of volume log data appears narrower. Volume log data ranges from 0.1 m$^3$ - 2.5 m$^3$ per log. While the log model ranges from 0.3 m$^3$ - 2.3 m$^3$ per log. These results clearly indicate that the log volume model has not been able to explain other data besides the model compiler data. Thus, the volume log model is invalid. The mean difference test shows that the t-statistic value $<\alpha$ (5%).

5. Discussion
The research results have produced the best model for log volume with tree circumference. The pattern of making this model is deductive, meaning that the general model is then differentiated based on compartment and eliminates the influence of the nodes class. Another alternative is to build a generic model with nodes in mind but ignore compartment. This research also finally tries to analyze the relationship model between log volume and tree perimeter by including compartment variables and class nodes. It can be said that this study adopts the modeling suggestions presented by Pretsch regarding hybrid regression but is modified. Modifications occur to consider the effect of location and perimeter of the tree but not as independent variables in one model.

Log volume models in general without considering the location and class of nodes produce reliable models. Unfortunately, this model is invalid. This is because the log volume variation is very wide so that there is a difference in the mean between the data and the model. This model should only be used at 50 cm - 250 cm tree circumference intervals. Another drawback is that this model ignores log length. The log length is not a consideration for Perhutani in estimating production. If log length data is
available, analysis techniques can be used by comparing the length of the segment. The length of the segment can explain the size of the perimeter of the tree \((13)\). In estimating standing tree volume, tree height variables are the main consideration \((14); \(15)\).

This estimation of log volume in general leaves a question if it is differentiated by commercial units, namely nodes. So far, Perhutani has used a weight that represents the volume of each log \((16)\). Nodes A1 is cheaper than nodes A2 and nodes A3. Likewise, the price of A2 nodes is cheaper than A3 nodes. Class nodes are made for the purposes of furniture and construction raw materials. The measure of the sustainability of tea plantations if used is based on the demand for the furniture and construction industry \((17)\). This measure can result in a decline or stagnation of teak cultivation in the form of tea plantations \((18)\). This is because the harvest time is very long. For this reason, it is necessary to modify the processing technology for small teak logs to increase with a greater economic value than large circumference.

The form of the model with consideration of location produces a good predictive model, although it is not valid. Location may not have much effect on log volume. The correlation between tree circumference and log volume at each location tends to be positive. However, if the class size of the nodes is entered the correlation is low. This is indicated by the low R2 value. The relationship between tree perimeter and location and class of nodes has been generated. There are three general models, namely linear, logarithmic and compound. If linear and logarithmic models are selected, the error will be low and R2 is also large. However, if the compound model is selected, the error is small, while R2 is also small. This shows that the log volume tends to increase according to the circumference of the tree but at large circumference the increase tends to be lower than the circumference of a small tree. The linear regression form is an option in tree volume modeling. However, it takes a time variable to explain this linear trend \((14)\).

The modeling approach used in this research is individual trees. The use of tree circumference parameters at breast height is considered insufficient. Single tree base modeling should be considered as a system \((19)\). This is also a weakness of individual-based tree modeling because it negates the influence of various factors on productivity \((11)\). Some of the suggested modeling techniques include simultaneous regression or multistage regression \((11); \(15)\). In research that has been applied multistage, the opinion \((19)\) cannot be proven. This is because this study estimates log volume and not tree volume.

This study has broken down the effect of a single variable, the circumference of the tree, on the volume of the logs. On a general scale, this effect is clearly visible. However, if the variables for location and commercial size are included, this relationship becomes less significant. This is due to the absence of some information such as the silvicultural technique applied, the age of the trees, as well as the management by Perhutani and the type of climate. Climate affects 59% of the yield potential variance of tea plantations \((2)\) because the climate will affect the growth rate and quality of teak \((20)\). Individual tree-based plantation forest management will work well if it is completed with records regarding spacing, fertilization, pruning, thinning and supervision.

However, TVL which consists of various information makes TVL very complex and difficult to implement. Single variable consideration of tree circumference at breast height is better because it is simple and practical. The considerations for soil, climate, silvicultural techniques and management are used as variables in compiling the stand table. Based on the above research results, TVL can be arranged systematically. At the first level, TVL explains the total log volume with the equation:

\[
V_{total} = 0.135 \times 1.015^R 
\]  

5)

Meanwhile, at the second level, log volumes can be distinguished by nodes. The equations used are:

\[
V_{A3} = -2.23 + 0.021R \]  
6)

\[
V_{A2} = 0.492 - 0.024 \ln (R) \]  
7)

\[
V_{A1} = 0.015 + 0.014R \]  
8)

The model above is reliable but invalid. For this reason, modeling at the FMU level needs to be considered by involving broader data collection so that environmental effects can be ignored. Deviation
from the model to the data can be caused by environmental and management variations. There needs to be a correction to the overall standing volume (12).

6. Conclusion
The shape of the log volume model at FMU Bojonegoro is compound. This model works well if it is simulated at intervals of the circumference of the tree at breast height of 50 cm - 250 cm. Commercial size and location considerations will help clarify TVL but are limited to class A3 nodes with and or without considering location. It is good to estimate log volumes for A2 and A1 if the location factor is ignored.

Acknowledgement

The author would like to thank Perhutani for providing sponsorship and data support.

References
[1] Ministry of Environment and Forestry [MoEF]. Statistic of Environment and Forestry at 2018 [Internet]. 1st ed. Jakarta: Ministry of Environment and Forestry; 2018. 0–13 p. Available from: http://www.dephut.go.id/index.php
[2] Pandey D, Brown C. Teak: a global overview. Unasylva. 2000; 51:3–13.
[3] Pumomo H, Abdullah L, Irawati RH. A system dynamic approach to balancing wood supply and demand for sustaining the future industry. In: MODSIM 2011 - 19th International Congress on Modelling and Simulation - Sustaining Our Future: Understanding and Living with Uncertainty [Internet]. 2011. Available from: http://www.scopus.com/inward/record.url?eid=2-s2.0-84858819643&partnerID=MN8TOARS
[4] Central Bureau of Statistics. Forestry Production Statistic. Jakarta: Central Bureau of Statistics; 2012.
[5] Central Bureau of Statistics. Forestry Production Statistic. Jakarta: Central Bureau of Statistics; 2013.
[6] Central Bureau of Statistics. Forestry Production Statistic. Jakarta: Central Bureau of Statistics; 2014.
[7] Central Bureau of Statistics. Forestry Production Statistic. Jakarta: Central Bureau of Statistics; 2015.
[8] Central Bureau of Statistics. Forestry Production Statistic. Jakarta: Central Bureau of Statistics; 2016.
[9] Central Bureau of Statistics. Forestry Production Statistic. Jakarta: Central Bureau of Statistics; 2017.
[10] Pretzsch H. The course of tree growth. Theory and reality. For Ecol Manage [Internet]. 2020;478(August):118508. Available from: https://doi.org/10.1016/j.foreco.2020.118508
[11] Monserud R a. Evaluating forest models in a sustainable forest management context. For Biometry, Model Inf [Internet]. 2003;1(1):35–47. Available from: http://cms1.gre.ac.uk/conferences/iufro/fbmis/Abstracts/3_1_MonserudR_1_abstract.html
[12] Putri AL. Pengujian ketelitian penggunaan tabel tegakan Wof Von Wulfing di KPH Cianjur Perum Perhutani Unit III. IPB University; 2006.
[13] Abdulah L, Sutiyono S. Model Taper Bambu Betung. J Penelit Hutan Tanam. 2019;16(1):47–57.
[14] Bermejo I, Cañellas I, San Miguel A. Growth and yield models for teak plantations in Costa Rica. For Ecol Manage. 2004;189(1–3):97–110.
[15] Goodwin AN. A cubic tree taper model. Aust For. 2009;72(2):87–98.
[16] Perum Perhutani. Harga jual kayu bulat jati dan rimba tahun 2020. Vol. 2020. Jakarta: Perum Perhutani; 2020.
[17] Kartheek. Furniture Market - Segmented by Category (Domestic Furniture, Office Furniture, Hotel/restaurant furniture, and Others), Furniture Material (Wood, Metal, and Others),
Distribution Channel (Offline retail stores and Online retail stores), and Geography - G. Mordor Intell [Internet]. 2019;367–71. Available from: https://www.mordorintelligence.com/industry-reports/furniture-market

[18] Purnomo H, Guizol P, Muhtaman DR. Governing the teak furniture business: A global value chain system dynamic modelling approach. Environ Model Softw [Internet]. 2009;24(12):1391–401. Available from: http://dx.doi.org/10.1016/j.envsoft.2008.04.012

[19] Hasenauer H, Monserud RA, Gregoire TG. Using simultaneous regression techniques with individual-tree growth models. For Sci. 1998;44(1):87–95.

[20] Seppänen P, Mäkinen A. Comprehensive yield model for plantation teak in Panama. Silva Fenn. 2020;54(5).