The Economic and Environmentally Friendly Tree Felling Techniques in Natural Forest

S Suhartana* and Yuniawati
Forest Products Research and Development Centre,
Jl. Gunung Batu No. 5, Bogor 16610, Indonesia

*email : sona.suhartana@gmail.com

Abstract. Improper tree felling techniques may reduce productivity and log supply. This leads to an increase in production cost. Timber Utilization Efficiency (TUE) in natural forests has not been optimally implemented, thus leaving residual stands with tremendous damages. This study was carried out in late 2015 in PT Inhutani II, North Kalimantan to investigate the implementation of felling techniques and to analyze felling productivity, TUE, production cost, and residual stands damage. Productivity, felling cost, and TUE data were tabulated and averaged. Results revealed that: (1) tree felling techniques implemented on the site were the reduced impact logging (RIL) technique; (2) the average felling productivity and production cost were 3,808 m³/hour and IDR 13,935.10/m³, respectively; (3) the average TUE was 92%, with only 8% generated-wastes; and (4) the average destruction of residual stands was 13.54%, which comprised of canopy damage, broken/cracked, stem injury, and leaning.

1. Introduction

Tree felling or tree logging presents an initial step in realizing the production of timber from the inside forest. The felling in natural forests uses chainsaws numerously that comprise of several types and varying machine power. The logging process cannot be separated from productivity and production costs aspects.

[1] alleged that there were several factors that could affect how large or small the cost and productivity would be at any activities, and also could render the harvest to be more efficient and effective, among others: (1) Moving duration for chainsawmen, roads and undergrowths should not be necessarily cleaned to shorten working duration for the chainsawmen in their movement from one tree to another; (2) Establishing the cutting steps; (3) Tree diameter, it can affect the productivity as the smaller the diameter then the shorter would be the cutting duration or the faster the cutting work; and (4) kind and specification of tools, a chainsaw with high rotating speed (rpm) could accelerate the felling work (or shorten wood-cutting duration) to fell down one tree.

Efficiency closely relates to the logging wastes, which are simply the residuals that consist mostly of cut-wood pieces abandoned in the exploited forests. These wastes are merely organic stuff- which does not pose any harmful threats to the environments, but their enormous amounts could indicate inefficiency degree in the forest logging. Tree stems are not entirely removed from forests, but some part of them is uncontrolled stay inside as wood wastes. Wood wastes of logging, according to [2] are defined as wood stuff that was not or still not utilized that resulted from the forest logging. Those wastes could come from allowable cut trees that composed of residues from stem division (trimming), stumps, twigs, and end portion, whereby their generation could occur on the felling sites, loading point (TPn), and log yard (TPK).

Logging efficiency is mostly affected by the systems and techniques for such logging activities. Logging techniques should not neglect the stages in the tree felling that present the essential components
in the logging activities; and should not either disregard activities in determining the tree-felling direction, tree-felling implementation, bucking, log skidding, log-bark peeling, and hauling. Conducted properly felling techniques usually owe the precise direction in tree-felling downing, as low as possible, could supposedly reduce or minimize the degree of timber damages at the felling sites.

[3] asserted that activities of logging at natural forests should implement the techniques in such a way able to reduce the residual stands damage in maintaining their potency to secure the sustainability of natural forests. Activities in logging at natural forests which are indicatively potential to cause the residual stands damage are in tree felling activities and log skidding. Techniques of tree felling which are performed carefully in determining the felling direction and preparing the cutting steps are supposedly able to reduce the residual stands damage.

Residual stands refer to the stands after their tree origins have been selectively felled down. Those stands could become essential assets for further endeavors, which consist of nurtured trees and accompanying trees [4]. Nurtured trees pertain to the trees that should be taken care after being selectively cut, which consist mainly of young and healthy commercial trees. Meanwhile, the accompanying trees refer to the trees that make up other stands than nurtured trees. The degree of residual stands damage in natural forests could be affected by the techniques which are implemented for logging.

According to [5] the degree of residual tree stands damage was figured-out based on the ratio between the number of trees which were damaged due to the activities of timber logging and the number of trees that already existed in the forest area subtracted by the number of trees which were harvested. Residual stands that must be available according to the regulation endorsed by TPTI (Tebang Pilih Tanam Indonesia / Selective Tree Cutting for Indonesia’s Planting) should in number correspond to 2000 measuring plots/ha. Forty percent (40%) out of those 2000 plots or be numbering to 800 plots must contain “seedlings”; or in other way, 1000 plots (out of 2000 plots) are available with minimal 400 plots (of 1000 plots) spared, and 60% of them (or 240 plots) contains stakes. As such, minimally 100 plots (out of 400 plots) should also be available, whereby 75% of them or 75 plots contain poles and the remaining (25 plots) contains entirely the core trees (100%).

Further, [6] alleged that forest governance in Indonesia should abide strictly by the sustainability principles that attempt earnestly to obtain the results which were maximally kept. Such sustainability principles desire to get the results continuously and if possible increasing either qualitatively or quantitatively. Meanwhile, maximal principles serve as a base which is adopted to utilize forest resources optimally. Sustainability principles can be assured should the volume of timber in the felled tree in particular duration can be more or less equal to the wood volume which grows in the same duration.

Contemplating those backgrounds and other previously narrated aspects, this scientific writing intends to look into and assess the tree-felling techniques as adopted, felling productivity, costs of felling production, and the residual stands damage in natural forests.

2. Materials and methods

2.1 Time, location and materials for research

The research was conducted at a forest concession administered by PT Inhutani II (the State Forest Company in Indonesia), which belonged to the working site of Sei Tubu’s Unit, Malinau Regency, Province of North Kalimantan. The research was carried out in late 2015. Materials used were paints, paint brushes, and plastic ropes. Equipment employed in this study comprises of chainsaws and meter-measuring devices, writing utensils, and computers.
2.2 Research procedure

The research was carried out through collecting primary and secondary data with details in the following:

2.2.1. Determining the location for research in order to represent the physical condition of local environments;

2.2.2. To prepare 10 research plots that entirely occupied one-hectare area, which each measured approximately 100 m by 100 m (Figure 1)

![Figure 1. Study Plots map](image)

2.2.3. The first research plot was determined purposively; and the further plots (second, third, fourth, etc) were determined later successively and systematically, whereby the spacing distance between plots was equal to 50 m;

2.2.4. At each of the research, plots were conducted inventories on the tree stands with their diameter equal to 20 cm or greater; and then diameter at breast height (dbh) and the height of trees vertically up to the point free of branches (clear bole) were measured.

2.2.5. Conducting the tree felling

2.2.6. The practical scheme regarding wastes and timber that could be utilized is presented in Figure 2
Remarks: A = Stump wastes; B = Lower-end waste; C = Usable portion of wood; D = Upper-end waste; E = Clear bole

**Figure 2** Size measurements on usable wood-portions and tree felling wastes.

### 2.3. Primary data.

Measuring the diameter of wood stem portion (round shape), and its length starting from the lower cut-portion all the way until the first branch-free portion (Figure 2); Conducting bucking, using chainsaw; measuring the size of the wastes, generated from the tree felling. In this study, logging wastes referred to the portion of stems or portion of trees that were allowed to be cut, but not utilized and then just laid in the forest land. Those wastes in shape could consist of stumps and branch-free stems (due to their shape, size, and objectionable conditions, unable to be utilized). In general, the portion of trees is composed of two groups, namely stumps and branch-free stems.

Stumps pertain to the lower portions of trees with their position beneath the so-called felling cut and back cut. The stump dimension as measured comprises of diameter and height. In this research, the procedures for measuring the allowed stump height were referred to the RIL’s technical guidelines [7]. Clear bole refers to the main stems starting from the buttress up to the first branch-free portion. Wastes from the clear bole can consist of short-cut wood pieces or logs. Short-cut pieces imply the part of main stems that contain defect or damages and therefore need to be cut. Short-cut pieces can also include twisted defects, crocodile-shaped knots, decays (rots), holes, and breakages.

Recording the damages that occurred to the residual stands. The definition of tree is the forest plants that exhibit their diameter equal to or greater than 20 cm. To estimate the tree damages, it uses the criteria enacted by [4], which mentioned: Tree canopy damages physically reach greater than (> ) 30%, or there occur broken branches (or broken big branches); Stem injury occurs greater than (> ) one fourth (1/4) of the stem circumference, with its length ≥ 1.5 m; Stem injury occurs greater than (> ) one fourth (1/4) of the stem circumference, with its lateral length ≥ 0.15 m; The cut root or one third (1/3) of the buttress is physically damaged.

Relevantly, the trees are regarded as damaged, if it could abide by one or more of those three criteria (a, b, c) stipulated as above. Measurement of productivity, production cost, TUE, is as follows: a). Felling productivity is calculated by recording the duration for tree- felling that uses the so-called null-stop method, and figuring-out the volume of timber from the felled trees; b). The production cost of tree felling is by recording all the incurred expenses such as fuel, lubricating oils, wages, productivity, and depreciation costs, maintenance/repairment costs, interests, insurances, taxes, and salary costs; and c). TUE is obtained by recording diameter of the stem at the lower end portion, diameter of the stem at the upper-end portion, tree height, stem length, and stump height, together with other supporting data.
2.4. Secondary data.
Secondary data were obtained from literature and by recording the plan and realization of annual production for five-year duration of the company.

2.5. Data analysis
Data analysis was conducted by arranging them in tabulation form. Parameter for the analysis as implemented was the average values (means). Processing results led to the acquisition of quantitative information about felling productivity, the production cost of the felling, TUE, and residual stands damage.

2.5.1. Timber volume (Formula 1):

\[ V = \frac{1}{4} \pi D^2 \times L \]  

where: \( V \) = timber volume (m\(^3\)); \( D \) = average timber diameter (m) (by averaging-out the diameter at upper portion of the stem and diameter at lower portion of the stem; \( \pi \) = phi constant (22/7); and \( L \) = length of stem (m).

2.5.2. Felling productivity (Formula 2):

\[ Pt = \frac{V}{t} \]  

where, \( Pt \) = felling productivity (m\(^3\)/hour); \( V \) = volume of timber, (m\(^3\)); \( t \) = felling duration (hours)

2.5.3. Production cost of the tree felling (Formula 3):

\[ Bt = \frac{Bm}{Pt} + U \]  

where: \( Bm \) = machine-operation cost (IDR / hour; IDR = Indonesian currency), calculated using the formula adopted by [8]; \( Pt \) = tree felling productivity (m\(^3\)/hour); \( U \) = wages (Rp/m\(^3\)).

2.5.4. Timber utilization efficiency (TUE) (Formula 4):

\[ Ef = \frac{Vp}{Vm} \times 100\% \]  

where: \( Ef \) = efficiency of utilization (%); \( Vp \) = volume of timber as acquired (logged) (m\(^3\)); \( Vm \) = volume of timber that should have been utilized (m\(^3\))

2.5.5. The degree of residual stands damage (Formula 5) as adopted from [9]:

\[ KP = \frac{RP}{Pt} \times 100\% \]  

where: \( KP \) = degree of residual stands damage (%); \( RP \) = number of trees which were damaged (trees/ha); \( P \) = number of trees with diameter equal to or greater than 20 cm, before being felled; \( Pt \) = number of trees felled.
3. Results and Discussion

3.1 Felling productivity

Activities of tree felling signified as the initial stage in timber harvest with the aim to obtain raw material to supply wood-processing industries in adequate amount and with qualities satisfying the desired requirement. Table 1 depicts that average felling productivity afforded by PT Inhutani II reached 38.303 m$^3$ (of the corresponding timber) with average volume of the felled trees equal to 6.735 m$^3$ in 10.5-minute duration.

Average productivity in this research was greater than that performed by [10], whereby the average felling productivity in the natural forest that used Stihl chainsaw reached 26.1 m$^3$/hour, with average felling duration equal to 4.57 minutes per tree, and average volume of the felled trees as much as 1.900 m$^3$ (of equivalent timber). Research results by [11] conducted in Turkey’s natural forest brought out the productivity of tree felling at 19.19 m$^3$/hour, with average felling duration 5.69 minutes and average felling volume equal to 1.82 m$^3$.

Although the average felling productivity in this research was greater than those performed by [10] and [11] the average felling duration in this study, however, was also longer. Such duration could happen as the topography condition of the research area belonged to the category as predominantly steep, thereby causing the machine operators to take a longer time to move from one tree to another. Also, the area condition brought about additional difficulty to the operators in determining the tree-felling direction. Besides those factor hindrances, the skills afforded by operators should be better in the understanding (learning) stage. In addition, the health and safety of the operators should be taken as a priority. Moreover, such high productivity of felling in this research owed to the obtained volume of timber (from the tree felling) which was greater than from the two other research results.

The research area which was dominated by steep topography could affect the average timber productivity from the tree felling. [12] asserted that activity of causing inconvenience, exhaustion, and unsafe feeling due to working under the worry condition that occurred almost frequently during their work. Accordingly, this could end up with the decreasing felling-productivity.

Several factors that could affect the productivity of felling in the natural forest were among others: 1) Determining the felling direction: it would be better before the felling work to determine or approximate the direction of the trees to be felled down. If the felling direction were right, proper, and precise, then it could minimize the working-accident risk and also reduce the residual stands damage; 2) Preparing the felling-cut: as such there was requirement regarding the depth in preparing the felling-cut which consisted of two main items, consecutively cut base and cut roof. The cut base should be prepared earlier with the depth about 1/5 – 1/3 of tree diameter (at dbh). Afterwards, the cut roof could be made at angle 45° to the cut base. In this way, it brought out pieces which were so-called cut mouth. If the preparation of felling-cut did not follow the regulation, then breakage could occur to the lower end of the tree stems, thereby generating a higher amount of wastes. Besides, the felling-cut which was made too deep could cause the trees to fall down prematurely before their intended time; and there would also occur the so-called barber chair in that wood fibers would project or protrude out above the stumps due to a mistake in preparing the felling-cut; and 3) Preparing the back cut: the height of back cut was approximately 1/10 of the tree diameter beginning from the line along the base cut. The back cut was made by cutting the tree horizontally at the height above up to the so-called hinge wood. The function of hinge wood was as a drive in controlling and orienting the direction of the felled trees [12].
| Sampling plot for the research | Tree No | Timber volume of felled trees (m³) | Felling duration, (minutes) | Timber productivity from the tree felling, (m³/hour) |
|-------------------------------|---------|-----------------------------------|-----------------------------|--------------------------------------------------|
| I                             | 1       | 9.464                             | 15.0                        | 37.855                                           |
|                               | 2       | 11.462                            | 17.0                        | 40.455                                           |
|                               | 3       | 9.125                             | 14.0                        | 39.106                                           |
| II                            | 4       | 7.078                             | 11.8                        | 35.991                                           |
|                               | 5       | 7.063                             | 11.7                        | 36.220                                           |
|                               | 6       | 5.444                             | 8.0                         | 40.833                                           |
|                               | 7       | 5.815                             | 8.2                         | 42.547                                           |
|                               | 8       | 3.956                             | 6.8                         | 34.909                                           |
|                               | 9       | 7.219                             | 11.9                        | 36.398                                           |
|                               | 10      | 4.171                             | 7.0                         | 35.752                                           |
| III                           | 11      | 2.703                             | 4.0                         | 40.539                                           |
|                               | 12      | 4.008                             | 6.2                         | 38.789                                           |
|                               | 13      | 4.963                             | 7.5                         | 39.704                                           |
|                               | 14      | 9.625                             | 15.1                        | 38.247                                           |
|                               | 15      | 12.140                            | 18.1                        | 40.244                                           |
|                               | 16      | 5.440                             | 8.0                         | 40.804                                           |
|                               | 17      | 4.338                             | 6.0                         | 43.379                                           |
| IV                            | 18      | 9.585                             | 15.2                        | 37.836                                           |
|                               | 19      | 7.544                             | 10.5                        | 43.108                                           |
|                               | 20      | 4.447                             | 6.6                         | 40.423                                           |
|                               | 21      | 11.965                            | 17.5                        | 41.022                                           |
|                               | 22      | 4.753                             | 7.4                         | 38.541                                           |
|                               | 23      | 2.508                             | 4.1                         | 36.705                                           |
|                               | 24      | 4.780                             | 7.3                         | 39.289                                           |
| V                             | 25      | 6.243                             | 9.1                         | 41.160                                           |
|                               | 26      | 4.667                             | 6.5                         | 43.078                                           |
|                               | 27      | 6.325                             | 10.0                        | 37.949                                           |
|                               | 28      | 15.116                            | 21.1                        | 42.984                                           |
|                               | 29      | 7.530                             | 11.1                        | 40.702                                           |
|                               | 30      | 3.492                             | 6.2                         | 33.797                                           |
| VI                            | 31      | 11.588                            | 18.1                        | 38.414                                           |
|                               | 32      | 2.798                             | 4.4                         | 38.154                                           |
|                               | 33      | 7.424                             | 11.5                        | 38.735                                           |
|                               | 34      | 3.961                             | 6.3                         | 37.725                                           |
|                               | 35      | 7.478                             | 11.6                        | 38.677                                           |
|                               | 36      | 3.832                             | 6.5                         | 35.375                                           |
|                               | 37      | 2.453                             | 4.3                         | 34.230                                           |
| VII                           | 38      | 7.823                             | 11.1                        | 42.286                                           |
|                               | 39      | 3.003                             | 5.5                         | 32.759                                           |
|                               | 40      | 6.251                             | 10.0                        | 37.505                                           |
|                               | 41      | 9.975                             | 15.2                        | 39.376                                           |
|                               | 42      | 10.029                            | 17.1                        | 35.189                                           |
|                               | 43      | 3.870                             | 6.0                         | 38.699                                           |
3.2 Cost of tree felling production

Average of timber productivity from the tree felling as obtained (Table 1) could be used as a divisor in the calculation of average cost for felling production. The resulting calculation regarding the cost components in tree felling and average production cost also in the tree felling is presented in Table 2. The tree-felling cost per m$^3$ of timber could be calculated through the ownership cost and tool-operation cost as follows: (1) Price of Stihl 070’s chainsaw tool was Rp. 15,950,000/unit; (2) service life of the tool lasted for one year or 1,000 hours; (3) Insurance equal to 3%/year; (4) Bank interest as much as 12%/year; (5) Taxes as high as 2%/year; (6) price of gasoline worth IDR 6.500/liter; (7) salary for operators and assistant-operators was IDR 13,000/m$^3$; (8) Working duration per day reached 8 hours; and (9) Tool power equal to 6.5 HP. From those cost data and using [8] formula, then the cost components could be calculated as presented in Table 2. Further, the values for each of the tree-felling production costs were obtained by dividing the total cost for enterprise (endeavor) by each of the felling productivities, as depicted in Table 3.

| Year | VIII  | IX  | X   | Sum  | Average |
|------|-------|-----|-----|------|---------|
| 44   | 4.089 | 6.878 | 5.777 | 3.609 | 3.752 | 7.148 | 10.401 | 3.453 | 13.680 | 9.182 | 9.530 | 9.327 | 10.457 | 4.749 | 3.571 | 7.849 | 7.189 | 404.093 | 6.735 |
| 45   | 7.6   | 10.1 | 8.5 | 6.3  | 6.0   | 12.0  | 17.5   | 6.0   | 20.0  | 15.3  | 15.1  | 15.5  | 17.1   | 7.6   | 5.2   | 12.1  | 12.0  | 630.4  | 10.5  |
| 46   | 32.285 | 40.859 | 40.776 | 34.367 | 37.518 | 35.739 | 35.660 | 34.534 | 41.039 | 36.007 | 37.866 | 36.104 | 36.690 | 37.489 | 41.200 | 38.918 | 35.945 | 2298.487 | 38.308 |
| 47   | 45    | 6.878 | 10.1 | 40.859 | 37.518 | 35.739 | 35.660 | 34.534 | 41.039 | 36.007 | 37.866 | 36.104 | 36.690 | 37.489 | 41.200 | 38.918 | 35.945 | 2298.487 | 38.308 |
| 48   | 46    | 5.777 | 32.285 | 34.367 | 37.518 | 35.739 | 35.660 | 34.534 | 41.039 | 36.007 | 37.866 | 36.104 | 36.690 | 37.489 | 41.200 | 38.918 | 35.945 | 2298.487 | 38.308 |
| 49   | 32.285 | 40.859 | 40.776 | 34.367 | 37.518 | 35.739 | 35.660 | 34.534 | 41.039 | 36.007 | 37.866 | 36.104 | 36.690 | 37.489 | 41.200 | 38.918 | 35.945 | 2298.487 | 38.308 |
| 50   | 32.285 | 40.859 | 40.776 | 34.367 | 37.518 | 35.739 | 35.660 | 34.534 | 41.039 | 36.007 | 37.866 | 36.104 | 36.690 | 37.489 | 41.200 | 38.918 | 35.945 | 2298.487 | 38.308 |
| 51   | 7.6   | 10.1 | 8.5 | 6.3  | 6.0   | 12.0  | 17.5   | 6.0   | 20.0  | 15.3  | 15.1  | 15.5  | 17.1   | 7.6   | 5.2   | 12.1  | 12.0  | 630.4  | 10.5  |
| 52   | 4.089 | 7.6   | 10.1 | 5.777 | 6.3  | 12.0  | 17.5   | 6.0   | 6.878 | 10.1  | 8.5   | 6.3   | 6.0   | 7.6   | 5.2   | 12.1  | 12.0  | 630.4  | 10.5  |
| 53   | 45    | 6.878 | 10.1 | 46    | 5.777 | 4.089 | 7.6   | 10.1  | 8.5   | 6.3   | 6.0   | 12.0  | 17.5   | 6.0   | 6.0   | 12.0  | 12.0  | 630.4  | 10.5  |
| 54   | 46    | 5.777 | 32.285 | 34.367 | 37.518 | 35.739 | 35.660 | 34.534 | 41.039 | 36.007 | 37.866 | 36.104 | 36.690 | 37.489 | 41.200 | 38.918 | 35.945 | 2298.487 | 38.308 |
| 55   | 32.285 | 40.859 | 40.776 | 34.367 | 37.518 | 35.739 | 35.660 | 34.534 | 41.039 | 36.007 | 37.866 | 36.104 | 36.690 | 37.489 | 41.200 | 38.918 | 35.945 | 2298.487 | 38.308 |
| 56   | 32.285 | 40.859 | 40.776 | 34.367 | 37.518 | 35.739 | 35.660 | 34.534 | 41.039 | 36.007 | 37.866 | 36.104 | 36.690 | 37.489 | 41.200 | 38.918 | 35.945 | 2298.487 | 38.308 |

Note: *) The State Forestry Company in Indonesia

Table 2 Cost components for the tree-felling operation using chainsaw machine.

| Cost components     | Amount (IDR/hour) |
|---------------------|-------------------|
| Depreciation expenses | 14,355            |
| Insurance expenses   | 287.1             |
| Interest expenses    | 1,435.5           |
| Tax expenses         | 191.4             |
| Fuel expenses        | 4,563             |
| Oil expenses         | 456.3             |
| maintenance expense  | 14,355            |
| Machine expenses     | 35,643.3          |
| Wages expenses (IDR/m$^3$) | 13,000          |
### Table 3 Average of timber production cost from the tree felling at PT Inhutani II.

| Sampling plots for the research | Tree No. | Machine expenses (IDR/hour) | Timber productivity from the tree felling (m$^3$/hour) | Wages expenses (IDR/m$^3$) | Cost of timber production from tree felling (IDR/m$^3$) |
|--------------------------------|----------|-----------------------------|--------------------------------------------------------|-----------------------------|------------------------------------------------------|
| I                              | 1        | 35,643.3                    | 37.855                                                  | 13,000                      | 13941.57                                              |
|                                | 2        | 35,643.3                    | 40.455                                                  | 13,000                      | 13881.06                                              |
|                                | 3        | 35,643.3                    | 39.106                                                  | 13,000                      | 13911.45                                              |
| II                             | 4        | 35,643.3                    | 35.991                                                  | 13,000                      | 13990.34                                              |
|                                | 5        | 35,643.3                    | 36.220                                                  | 13,000                      | 13984.08                                              |
|                                | 6        | 35,643.3                    | 40.833                                                  | 13,000                      | 13872.90                                              |
|                                | 7        | 35,643.3                    | 42.547                                                  | 13,000                      | 13837.74                                              |
|                                | 8        | 35,643.3                    | 34.909                                                  | 13,000                      | 14021.03                                              |
|                                | 9        | 35,643.3                    | 36.398                                                  | 13,000                      | 13979.27                                              |
|                                | 10       | 35,643.3                    | 35.752                                                  | 13,000                      | 13996.96                                              |
| III                            | 11       | 35,643.3                    | 40.539                                                  | 13,000                      | 13879.23                                              |
|                                | 12       | 35,643.3                    | 38.789                                                  | 13,000                      | 13918.90                                              |
|                                | 13       | 35,643.3                    | 39.704                                                  | 13,000                      | 13897.73                                              |
|                                | 14       | 35,643.3                    | 38.247                                                  | 13,000                      | 13931.92                                              |
|                                | 15       | 35,643.3                    | 40.244                                                  | 13,000                      | 13885.68                                              |
|                                | 16       | 35,643.3                    | 40.804                                                  | 13,000                      | 13873.52                                              |
|                                | 17       | 35,643.3                    | 43.379                                                  | 13,000                      | 13821.67                                              |
| IV                             | 18       | 35,643.3                    | 37.836                                                  | 13,000                      | 13942.05                                              |
|                                | 19       | 35,643.3                    | 43.108                                                  | 13,000                      | 13826.84                                              |
|                                | 20       | 35,643.3                    | 40.423                                                  | 13,000                      | 13881.76                                              |
|                                | 21       | 35,643.3                    | 41.022                                                  | 13,000                      | 13868.88                                              |
|                                | 22       | 35,643.3                    | 38.541                                                  | 13,000                      | 13924.82                                              |
|                                | 23       | 35,643.3                    | 36.705                                                  | 13,000                      | 13971.07                                              |
|                                | 24       | 35,643.3                    | 39.289                                                  | 13,000                      | 13907.21                                              |
| V                              | 25       | 35,643.3                    | 41.160                                                  | 13,000                      | 13865.97                                              |
|                                | 26       | 35,643.3                    | 43.078                                                  | 13,000                      | 13827.41                                              |
|                                | 27       | 35,643.3                    | 37.949                                                  | 13,000                      | 13939.24                                              |
|                                | 28       | 35,643.3                    | 42.984                                                  | 13,000                      | 13829.22                                              |
|                                | 29       | 35,643.3                    | 40.702                                                  | 13,000                      | 13875.71                                              |
|                                | 30       | 35,643.3                    | 33.797                                                  | 13,000                      | 14054.63                                              |
| VI                             | 31       | 35,643.3                    | 38.414                                                  | 13,000                      | 13927.87                                              |
|                                | 32       | 35,643.3                    | 38.154                                                  | 13,000                      | 13934.20                                              |
|                                | 33       | 35,643.3                    | 38.735                                                  | 13,000                      | 13920.18                                              |
|                                | 34       | 35,643.3                    | 37.725                                                  | 13,000                      | 13944.82                                              |
|                                | 35       | 35,643.3                    | 38.677                                                  | 13,000                      | 13921.56                                              |
|                                | 36       | 35,643.3                    | 35.375                                                  | 13,000                      | 14007.58                                              |
|                                | 37       | 35,643.3                    | 34.230                                                  | 13,000                      | 14041.29                                              |
| VII                            | 38       | 35,643.3                    | 42.286                                                  | 13,000                      | 13842.91                                              |
|                                | 39       | 35,643.3                    | 32.759                                                  | 13,000                      | 14088.05                                              |
Table 3 shows that the average cost of timber production from the tree-felling reached IDR 13,935.10/m³, with the machine cost worth IDR 35,643.3/hour and the average felling productivity equal to 38.3058 m³/hour. Average timber production that resulted from this study was greater than the results by [13], who performed his research regarding felling productivity in natural forest in North Kalimantan using Stihl 070’s chainsaw as well. Meanwhile, average tree-felling productivity that implemented the RIL (Reduced Impact Logging)’s techniques corresponded to 45.56 m³/hour with the average cost of tree-felling productivity worth IDR 956.58/m³. Such high cost of felling productivity in this research was caused by several factors, such as: 1) Low average felling productivity as achieved: tree-felling productivity affected timber-production cost, whereby the greater the felling productivity, then the lower would be the production cost; 2) The topography condition of the research area which was very steep could slow down the tree-felling process, thereby prolonging the felling duration; and 3) Despite using chainsaw with the same type, in fact, the skills afforded by the operators differed from one to others.

### 3.3 Timber utilization efficiency (TUE)

Optimation of wastes generated from timber harvest presents one of the several indicators toward sustainable forest management. That inducement became a reference for PT Inhutani II’s attempt to minimize timber harvesting wastes by utilizing them, based on their dimension. Tree-felling wastes which were measured in this research pertained to the residues or portion of the felled trees regarded in as of no-economic values in the process of felling production and therefore were just abandoned on sites.
after the logging operation finished. Those wastes related to the TUE very closely. The average TUE at PT Inhutani II is presented in Table 4.

| Sampling plots for the research | Tree No. | Total volume of timber (m³) | Volume of generated wastes (m³) | TUE |
|--------------------------------|----------|-----------------------------|-----------------------------|-----|
| I                              | 1        | 9.984                       | 0.520                       | 0.95|
|                                | 2        | 11.973                      | 0.510                       | 0.96|
|                                | 3        | 9.557                       | 0.433                       | 0.95|
| II                             | 4        | 8.371                       | 1.292                       | 0.85|
|                                | 5        | 8.470                       | 1.407                       | 0.83|
|                                | 6        | 6.345                       | 0.901                       | 0.86|
|                                | 7        | 7.101                       | 1.286                       | 0.82|
|                                | 8        | 4.638                       | 0.682                       | 0.85|
|                                | 9        | 7.404                       | 0.185                       | 0.97|
|                                | 10       | 4.439                       | 0.268                       | 0.94|
| III                            | 11       | 3.269                       | 0.566                       | 0.83|
|                                | 12       | 4.461                       | 0.453                       | 0.90|
|                                | 13       | 5.205                       | 0.242                       | 0.95|
|                                | 14       | 10.416                      | 0.790                       | 0.92|
|                                | 15       | 13.983                      | 1.843                       | 0.87|
|                                | 16       | 6.494                       | 1.053                       | 0.84|
|                                | 17       | 4.596                       | 0.258                       | 0.94|
| IV                             | 18       | 9.891                       | 0.306                       | 0.97|
|                                | 19       | 7.747                       | 0.203                       | 0.97|
|                                | 20       | 4.603                       | 0.156                       | 0.97|
|                                | 21       | 12.794                      | 0.829                       | 0.94|
|                                | 22       | 4.905                       | 0.152                       | 0.97|
|                                | 23       | 2.585                       | 0.077                       | 0.97|
|                                | 24       | 4.943                       | 0.163                       | 0.97|
| V                              | 25       | 6.679                       | 0.437                       | 0.93|
|                                | 26       | 5.119                       | 0.452                       | 0.91|
|                                | 27       | 6.504                       | 0.179                       | 0.97|
|                                | 28       | 16.357                      | 1.241                       | 0.92|
|                                | 29       | 8.288                       | 0.758                       | 0.91|
|                                | 30       | 3.793                       | 0.301                       | 0.92|
| VI                             | 31       | 12.839                      | 1.251                       | 0.90|
|                                | 32       | 2.979                       | 0.181                       | 0.94|
|                                | 33       | 8.047                       | 0.622                       | 0.92|
|                                | 34       | 4.729                       | 0.768                       | 0.84|
|                                | 35       | 8.168                       | 0.690                       | 0.92|
|                                | 36       | 4.519                       | 0.687                       | 0.85|
|                                | 37       | 2.604                       | 0.150                       | 0.94|
| VII                            | 38       | 8.150                       | 0.327                       | 0.96|
|                                | 39       | 3.165                       | 0.162                       | 0.95|
|                                | 40       | 6.524                       | 0.273                       | 0.96|
Table 4 reveals that average total volume of harvested timber and volume of the generated wastes were consecutively 7.305 m$^3$ and 0.569 m$^3$, thereby leading to as much 0.92 or 92% of the timber as utilized, while the rest (8%) presented as the generated wastes which were abandoned. From the 10 plots prepared as the research sample, it disclosed that the range of timber utilization was 0.81-0.97. This indicated that the lowest TUE occurred at plots II and X which reached 0.82 and 0.81, respectively. When assessed from their topography, those two plots belonged to the steep areas, thereby causing a lot of tree portions to sustain technical damages due to the high number of stumps abandoned on sites, broken stems, and some of the felled trees accidentally falling down into deep ravines.

The abandoned wastes in this research amounted to 8%, with average timber production from those wastes per year equal to 3,275 m$^3$ [14]. The efficiency of timber utilization from such particular amount of the generated wastes (8%) implied that the Company (PT Inhutani II) would gain additional profit as production increase which corresponded to 8% multiplied by 3,275 m$^3$ or equal to 262 m$^3$/year. Assuming that the timber price was IDR 1,000,000 per m$^3$ and the feasible profit for the Company corresponded to 20% (or equal to IDR 200,000 / m$^3$), and therefore the Company itself would gain as much 262 m$^3$/year multiplied by IDR 200,000/m$^3$ or equal to IDR 52,400,000/year as an additional profit. Such high additional profit would supposedly occur just at this study that covered an area of 2,041.04 ha. Accordingly, when accounted for the entire area of production forests managed by the Company, then a significant reduction would occur in the amount of generated wastes and therefore deserve thorough consideration.

TUE related closely to the annual allocated production (AAP) in the forest enterprise (entrepreneurship). The AAP value could be calculated using the related formula: $V = L \times P \times 0.92$ or 0.80, where $V =$ volume of the logged/harvested timber that could be felled per year; $L =$ actual area of the forest from which its tree stands could be felled per year; $P =$ potency of forest logging in accordance with the diameter limit related to the forest function (m$^3$/ha); 0.92 = ...
efficiency of timber utilization as acquired in this research (Table 4); and 0.80 = security factor. Using the
data which were quoted from the AWP (Annual Working Plan) book in the year 2016 owned by the
Company (PT Inhutani II), then the forest area that could be felled reached 2,041.04 ha/year; and the
logging potency in accordance with the diameter limit corresponded to 112.555 m$^3$ per ha. In this way,
therefore the AAP value would be 2,041.04 multiplied by 112.555 by 0.92 or 0.80 = 169,080.73 m$^3$/year.
Further, if the efficiency value for timber utilization or exploitation factor complied with the regulation
enacted by the Ministry of Forestry (MOF) which corresponded to 0.70, then the AAP value would be
128,648.39 m$^3$/year. As such, a difference would occur in AAP values between efficiency value of
timber utilization as stipulated by the MOF and the efficiency value obtained in these research results,
which would be 169,080.73 - 128,648.38 or equal to 40,432.35 m$^3$/ year.

Research results by [15] regarding the exploitation factor in East Kalimantan and Central Kalimantan
which corresponded to 0.82 would bring about an impact on the national AAP value from the average
value as much as 8.756 million m$^3$/year to the other average value (10.052 m$^3$/year) or being equivalent
to additional production of round timber approximately 1.077 million m$^3$/per year.

Results of this research were greater than those conducted by [2] a natural forest area in West
Sumatera and Central Kalimantan, which disclosed that TUE in those two respective areas reached
consecutively 0.75 and 0.74. This implied from their research that the degree of timber utilization
starting from the standing trees until they were removed from the forest corresponded to 74-75%, while
the residual (24-25%) signified as wood wastes abandoned in the forest.

3.4 Residual stands damage

Activities of the tree felling could bring about various kinds of damages to the residual stands. According
to Elias (2008), kinds of the damaged that occurred to the abandoned residual stands could be among
others damaged canopies, shattered barks, ruptured stems, broken stems, leaning stands, trees felled
down, and damaged buttresses. Such damages were due to being hit by the felled trees, either hit by
canopies, stems or hit by the stem of the felled down trees. In relevant, the average damages that
occurred to the residual tree stands at PT Inhutani II, as conducted in this research are disclosed in Table 5.

| Plot No. | Trees / ha$^3$ | felled trees | Residual stands damage |
|----------|----------------|--------------|------------------------|
|          | (trees)        | (trees)      | Canopy | Broken | Stem injury | Felling down | Sum |
| Plot 1   | 49             | 3            | 1      | 2      | 0          | 1            | 4   | 8.70 |
| Plot 2   | 57             | 8            | 2      | 2      | 1          | 3            | 8   | 16.33 |
| Plot 3   | 55             | 7            | 2      | 2      | 1          | 1            | 7   | 14.58 |
| Plot 4   | 55             | 7            | 3      | 2      | 1          | 1            | 7   | 14.58 |
| Plot 5   | 53             | 6            | 1      | 2      | 0          | 3            | 6   | 12.77 |
| Plot 6   | 57             | 7            | 0      | 3      | 1          | 3            | 7   | 14.00 |
| Plot 7   | 49             | 5            | 2      | 2      | 1          | 1            | 6   | 13.64 |
| Plot 8   | 57             | 8            | 2      | 3      | 1          | 2            | 8   | 16.33 |
| Plot 9   | 50             | 6            | 2      | 1      | 2          | 1            | 6   | 13.64 |
| Plot 10  | 49             | 3            | 1      | 1      | 1          | 2            | 5   | 10.87 |
| Average  | 53.1           | 6.0          | 1.6    | 2      | 1          | 1.8          | 6.4 | 13.54 |

Note : $^*$ Number of tree stands with their diameter (Ø) equal to or greater than 20 cm before felling
Table 5 reveals that the average number of tree stands with diameter greater than 20 cm corresponded to 53 trees per ha, with the number of the felled trees in the range of 3-8 trees/ha or on average of 6 trees/ha. The tree felling inflicted the damages on the abandoned residual stands, which reached 6.4 trees/ha on average (13.54%). This implied for every one tree being felled, it left with roughly one residual tree stands damaged. In general, the damages to the residual stands, which could comprise damaged canopy, ruptured tree stems, stem injury, and felling down, revealed specifically as many as 1.6 trees with destroyed canopies (1.6/6.4 x 100% = 25%), 2 trees with ruptured stem (2/6.4 x 100% = 31.25%), 1 tree with injured stem (1/6.4 x 100% = 15.63%), and 1.8 trees felling down (1.8/6.4 x 100% = 28.13%).

Experiment results in this research brought about the residual stands damage (13.54%) which was lower than those found by [3] the latter revealed that the residual stands damage at the trees due to felling in the tropical peat natural forest reached 20%. Meanwhile, research results by [16] disclosed that the tree felling in a natural forest in Iran numbered to 5.1 trees per ha, in that as much 17.3 m³/ha. As such, the damages that occurred to residual stands corresponded to 9.8 trees.

4. Conclusion and suggestions

The tree-felling techniques as implemented typified as the felling techniques which brought about low impacts or so-called RIL (Reduced Impact Logging) technique. Average tree-felling productivity reached 38.308 m³/hour, with average felling production worth Rp 13,897.44/m³. Average TUE corresponded to 92%, with the concurrently generated wastes as abandoned equal to 8%. The average of residual stands damage due to the tree felling reached 13.54%, which comprised of canopy damage, ruptured/broken tree stem, stem injury, and tree felling down. The tree-felling techniques adopting the RIL (Reduced Impact Logging) techniques indicatively were able to come up with convenient results/expectation (e.g. high felling productivity, low felling cost, high TUE, and low portion of the generated wastes) provided by paying meticulous attention to the field condition (e.g. steepness of topography, types of forests, dimension of the logged, buttresses/canopy/branch-free stems, and residual stands damage) and the affecting factors (e.g. chainsaw machine, type and specification, operators, their health, and skills); and therefore this deserves thorough consideration in the commercial implementation.

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References

[1] Sitohang W R M, Muhdi and Afifuddin Y 2016 https://jurnal.usu.ac.id/index.php/PFJS/article/view/14163. Access on April 30, 2019.
[2] Matangaran J R, Partiani T and Purnamasari D R 2013 J. Bumi Lestari 13 384-393
[3] Suwarna U, Matangaran J R and Harmawan F 2014 J. Manusia dan Lingkungan 21 83-9
[4] Directorate General of Forest Entrepreneurship 1994 Pedoman dan Petunjuk Teknis Pelaksanaan Sistem Silvikultur Tebang Indonesia (TPTI) (Jakarta: Departemen Kehutanan)
[5] Elias 1998 Reduced Impact Timber Harvesting in the Indonesian Selective Cutting and Planting System (Bogor: IPB Press)
[6] Idris M M and Sukanda 2012 J. Penelitian Hasil Hutan 30 269-278
[7] Ruslandi 2013 Petunjuk Teknik Penerapan Pembalakan Berdampak Rendah Karbon (RIL-C) pada Izin Usaha Pemanfaatan Hasil Hutan Kayu Hutan Alam (IUHHK-HA) (Jakarta: The Nature Conservancy)

[8] FAO 1992 Cost control in forest harvesting and road construction (FAO Forestry Paper No 99) (Rome: FAO)

[9] Thaib J and Suhartana S 1991 J. Penelitian Hasil Hutan 9 144-9

[10] Behjou F K, Majnounian B, Dvorak J, Namiranianl M, Saeed A and Feghhi J 2009 J. of For.Sc. 55 96-100

[11] Akay E, Erdas O, Buyuksakall H and Akar D S 2015 Proc.of the 48th FORMEC Symp. Ed C Kanzian, G Erber and M Kuhmaier (Austria: Institute of Forest Engineering) 77-80

[12] Suhartana S and Yuniawati 2006 Peronema For Sci J 2 37-44

[13] Muhdi 2016 Int.J of Sci and Res 5 141-3

[14] Inhutani II 2015 Rencana Kerja Tahunan IUPHHK-HA Inhutani II Unit Sei Tubu, Kabupaten Malinau, Provinsi Kalimantan Utara (Malinau: Inhutani II)

[15] Idris M M, Dulsalam, Sukanda and Soenarno 2012 Proc Ekspose Hasil-Hasil Penelitian (Bogor: Pusat Litbang Hasil Hutan)

[16] Behjou F K and Mollabashi O G 2012 BioResources 7 4867-74