Investigating the Commercial Thinning Operation and Examining a 3-m Bucking System by the Takahara Forest Owners’ Co-operative, in the Tochigi Prefecture, Japan

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Abstract: This study investigated the commercial thinning operation with normal bucking at the Takahara Forest Owners’ Co-operative, near the Nakagawa sawmill, Tochigi prefecture, Japan. The productivity and net profit of 3-m bucking were estimated based on investigations of normal bucking, to examine the possibility of extending 3-m bucking and fixed-price business to all logs. The recovery rate with 3-m bucking was estimated at 85% — a significant increase over that with normal bucking (38%); therefore, recovered volumes with 3-m bucking were also significantly higher, at 148 m³/ha, compared to that with normal bucking (67 m³/ha). Productivity regarding strip-road construction, felling, and processing with 3-m bucking were higher, in line with higher recovered volumes, whereas productivity regarding bunching, forwarding, and transportation with 3-m bucking were assumed to be identical to those with normal bucking. The total costs per cubic meter with 3-m bucking were lower, whereas total costs per hectare with 3-m bucking were higher, in line with higher recovered volumes. Recovered volumes of grade-A, B, and C wood with normal bucking were estimated at 40, 20, and 7 m³/ha; revenues were estimated at JPY10,000/m³. With 3-m bucking, recovered volumes of grade-A, B, and C wood were estimated at 59, 44, and 44 m³/ha; revenues per cubic meter were lower, at JPY8,400/m³. Generally, net profit per cubic meter with 3-m bucking was lower, in line with higher volumes of lower-quality logs, whereas net profit per hectare with 3-m bucking was twice as high, in line with higher recovered volumes.

Keywords: 3-m bucking, fixed price, harvest productivity, net profit, normal bucking

1. Introduction

The Shibukawa prefectural wood processing center in Gunma prefecture was opened in 2011. It specialized in buying all types of 3-m logs at fixed prices, such as JPY12,000/m³ of grade-A wood for saw log, JPY8,000/m³ of grade-B wood for laminated lumber, and JPY4,000/m³ of grade-C wood for wood chip (Gunma Prefectural Government, 2011). Prices were determined every three months, based on the state of the log markets. A Forest Owners’ Co-operative near the Shibukawa prefectural wood processing center conducted mainly precommercial thinning operations before establishing that wood processing center; therefore, a considerable volume of thinned wood was left in the forests. After establishing the Shibukawa prefectural wood processing center, the Forest Owners’ Co-operative started to conduct commercial thinning operations, because it was easy and efficient to buck all logs of 3-m length including defects such as sweep and rotten logs. Thus, the use of thinned wood was promoted.

The Nakagawa sawmill in Tochigi prefecture also started a business similar to that of the Shibukawa prefectural wood processing center, in 2013. However, forest owners’ co-operatives around the Nakagawa sawmill have conducted commercial thinning operations, and bucking has been normally conducted to increase revenues per cubic meter considering log prices of log auction markets excluding defects such as sweep and rotten logs. In log auction markets, saw logs were 3.00-6.00 m long, with the top-end diameter exceeding 10 cm. Therefore, the forest owners’ co-operatives have experienced difficulties in introducing 3-m bucking for all logs.

The Takahara Forest Owners’ Co-operative near the Nakagawa sawmill (unpublished) investigated and compared commercial thinning operations between normal and 3-m bucking on a 28–78-year-old plantation forests comprising Japanese cedar and cypress (Table 1). As a result, 3-m bucking led to higher recovered volumes, because the total log volume included sweep and rotten wood that had normally been left in the forest following normal bucking; by using 3-m bucking, this wood was successfully extracted for wood chips. Therefore, the productivity of felling operations was higher within the same period of time, as were production volumes. The productivity of bucking operations was also higher, while reducing operation times, excluding log-quality checking times related to normal bucking; production volumes were also higher. However, as learned during
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interviews with officials from the Takahara Forest Owners’ Co-operative, the forwarding volumes were lower, given the existence of sweep logs, with the corresponding lower productivity of the forwarding operations. Actual revenues and subsidies per cubic meter with 3-m bucking were almost identical to those with normal bucking; nonetheless, revenues per cubic meter with 3-m bucking were expected to be comparatively lower, because 3-m bucked logs included sweep and rotten wood, for which prices are usually lower. Since costs per cubic meter with 3-m bucking were lower, the net profit per cubic meter with 3-m bucking was higher. Revenues and subsidies per hectare with 3-m bucking were higher, in line with the higher recovered volumes; although the costs per hectare were also higher. However, cost increases per hectare were lower than the increases in total revenues and subsidies per hectare; therefore, the net profit per hectare with 3-m bucking was higher.

Table 1. Economic balances investigated by the Takahara forest owners’ co-operative.

|                | Normal (JPY/m³) | 3-m (JPY/m³) | Normal (JPY/ha) | 3-m (JPY/ha) |
|----------------|-----------------|--------------|-----------------|--------------|
| Revenue        | 7,021           | 7,076        | 410,087         | 547,036      |
| Subsidy        | 7,389           | 7,130        | 431,600         | 551,176      |
| Cost           | −12,411         | −11,239      | −724,880        | −868,901     |
| Net Profit     | 2,000           | 2,966        | 116,807         | 229,311      |

In order to more examine the possibility of extending 3-m bucking and fixed-price business to all logs, this study investigated the commercial thinning operation with normal bucking, as undertaken by the Takahara Forest Owners’ Co-operative. Then, the productivity and net profit of 3-m bucking were estimated based on an investigation of normal bucking. The study should investigate commercial thinning operation with 3-m bucking and compare the two bucking systems, but there was not an actual investigation or comparison between the two bucking systems. This study showed preliminary results.

2. Study Site and Method

The study site was located in Nasushiobara, Tochigi prefecture, Japan. The study site comprised Japanese cedar and cypress plantation forests with ages ranging between 39 and 61 years (Table 2). The area of the study site was 5.59 ha, its average slope angle was 5 degrees, and the strip road network density was 310 m/ha (Figure 1).

Table 2. Study site.

|                |            |            |
|----------------|------------|------------|
| DBH (cm)       | 22         |            |
| Height (m)     | 18.9       |            |
| Stem volume (m³/stem) | 0.43    |            |
| Stand density (stems/ha) | 1,633  |            |
| Stem volume of thinned wood (m³/stem) | 0.26    |            |
| Thinning rate of stem (%) | 31      |            |
| Thinning rate of volume (%) | 25      |            |
| Recovered volume of thinned wood (m³/ha) | 36.6    |            |
| Recovered volume of removed wood (m³/ha) | 30.3    |            |

Operation systems included strip-road construction by mini backhoe, chainsaw felling and processing, mini grapple-loader bunching and loading to forwarder, forwarder extraction, truck unloading and loading, and secondary transportation by trucks. Recovered volumes with 3-m bucking were assumed that bucking continued until the small-end diameter reached 5 cm. The stem diameter d (cm) at height h (m) above the ground was estimated using the following taper curve formula (Inoue and Kurokawa, 2001).
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Figure 1. Study site.

\[ d = \frac{(a(1.0 - 1.2/H) - 0.9a + 1.8)(1.0 - h/H)}{(a(1.0 - 1.2/H) - 0.9a + 1.8)(1.0 - 1.2/H)} D \]

where \( H \) denotes the tree height (m) and \( D \) denotes the diameter at breast height (cm). Coefficient \( a \) was estimated as follows.

\[ a = \frac{(18.0 - 21.6/H) - 12.6\sqrt{7/10}f}{(2.0 - 2.4/H) + (0.7 - 8.4/H)\sqrt{7/10}f} \]

where \( f \) denotes the breast height form factor, estimated as follows.

\[ f = 4V_n/(HD^2\pi/10,000) \]

where \( V_n \) denotes the stem volume (m\(^3\)).

Operation times with 3-m bucking were estimated while assuming the absence of log-quality checking times, during which chainsaw workers consider bucking length in terms of log prices and quality.

Costs were estimated with labor expenses of JPY1,300/h, and machinery expenses (i.e., chainsaw, JPY241/h; mini backhoe and mini grapple-loader, JPY3,257/h; forwarder, JPY1,926/h; and truck, JPY5,783/h). In addition, handling fees for the Takahara Forest Owners’ Co-operative were estimated as 5% of revenues. Logs with normal bucking were assumed to be sold in a log market, whereas logs with 3-m bucking were assumed to be sold to the Nakagawa sawmill. In the log market, handling fees were estimated as 5% of revenues, and piling fees were estimated as JPY700/m\(^3\).

Revenues were estimated with the use of log prices and log-quality rates which were the rates of grade-A, B, and C wood to total recovered volumes, and gathered from personal communications with officials from the Takahara Forest Owners’ Co-operative (Table 3).

Table 3. Log prices and log quality.

| Log quality                  | A    | B    | C    |
|------------------------------|------|------|------|
| Log prices (JPY/m\(^3\))    | 12,000 | 8,000 | 4,000 |
| Log quality rates with normal bucking (%) | 60   | 30   | 10   |
| Log quality rates with 3-m bucking (%)    | 40   | 30   | 30   |
Subsidies for thinning operations were estimated using standard unit costs multiplied by area, assessment coefficients (1.7), and the subsidy rate (0.4) of the Tochigi Prefectural Government (2011). To promote the extraction of thinned wood, subsidies were higher, in line with recovered volumes (Table 4). To help finance thinning operations, common subsidies in Japan for strip-road construction were used. The standard unit costs for strip-road construction were determined using the average slope angle and road width; then, subsidies (Table 5) were estimated using standard unit costs multiplied by length, assessment coefficients (1.7), and the subsidy rate (0.4) of the Tochigi Prefectural Government (2011).

Table 4. Subsidies for thinning operations (JPY/ha).

| Recovered volume (m³/ha) | 10– | 20– | 30– | 40– | 50– | 60– | 70– | 80– | 90– |
|-------------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Subsidies (JPY/ha)      | 132,150 | 180,031 | 226,954 | 273,876 | 321,757 | 368,680 | 415,603 | 463,483 | 510,406 |

Table 5. Subsidies for strip road establishment (JPY/m).

| Average slope angle | Width |
|---------------------|-------|
| Gradual (−15 degrees) | 102 |
| Medium (15−30 degrees) | 203 |
| Steep (30− degrees) | 501 |

3. Results and Discussion

3.1 Recovered Volumes

With normal bucking, recovered volumes from ten thinned trees and nine removed trees along strip roads were measured. The average stem volume of thinned trees was 0.28 m³. Only 31% of thinned-tree volume (0.09 m³/stem) was extracted because of log-specification requirements in log auction markets, which were 3.00-6.00 m long, with the top-end diameter exceeding 10 cm. The rests were cut in a certain length easily to remove while log extractions if the rests were obstacles. On the other hand, the average stem volume of removed trees along strip roads was 0.38 m³. In all, 55% of removed-tree volume along strip roads (0.21 m³/stem) was extracted. The recovery rate of removed trees was higher than that of thinned trees because of stem volumes. These low recovery rates usually happened for such small-sized thinned trees. Since thinned-tree volumes and removed-tree volumes along strip roads were 119 m³/ha and 55 m³/ha, respectively, recovered volumes from thinned trees and removed trees along strip roads were estimated at 37 m³/ha and 30 m³/ha, using the recovery rates (i.e., 31% for thinned trees and 55% for removed trees along strip roads). Since the total felled-tree volumes and recovered-tree volumes were 174 m³/ha and 67 m³/ha, respectively, the recovery rate with normal bucking was 38%. In order to examine 3-m bucking, the stem diameter d (cm) at height h (m) above the ground was estimated using the taper curve formula [1]. The average root mean square error (RMSE) between the measured and estimated stem diameters was 2.5 cm. Log diameters were normally rounded to 2 cm; therefore, the RMSE was almost within allowable ranges. Using estimated stem diameters, recovered volumes with 3-m bucking were estimated at 84% of thinned-tree volume (0.24 m³/stem) and 88% of removed-tree volume along strip roads (0.33 m³/stem). Recovered volumes of thinned trees and removed trees along strip roads were estimated at 100 m³/ha and 48 m³/ha, respectively, using the recovery rates (i.e., 84% for thinned trees and 88% for removed trees along strip roads). Recovered volumes with 3-m bucking, especially of thinned trees, were significantly higher, in line with the higher recovery rates. Since the total felled-tree volumes and recovered-tree volumes were 174 m³/ha and 148 m³/ha, respectively, the recovery rate with 3-m bucking was 85%.
3.2 Productivity

With normal bucking, the productivity associated with felling, processing, and bunching of removed trees along strip roads was higher than that of thinned trees, given the larger operational space along strip roads (Table 6). The log-quality checking time with normal bucking was 1.5 and 3.7 s/stem for thinned and removed trees, respectively (Table 7). These were small amounts, relative to the cycle times for chainsaw felling and processing operations with normal bucking (i.e., 414.0 and 528.0 s/stem for thinned and removed trees). Operation times with 3-m bucking were estimated while assuming the absence of log-quality checking times. The number of logs per stem with normal bucking was 2.5, whereas that with 3-m bucking was estimated at 5.3; however, the number of crosscuts with normal bucking was 6.9 cuts/stem, whereas that with 3-m bucking was 5.3 cuts/stem. Therefore, 4.4 crosscut logs/stem with normal bucking were left behind in the forests. Crosscutting times with 3-m bucking could be reduced relative to that seen with normal bucking, given the reduced number of crosscuts. However, because crosscutting times per cut could not be investigated in this study, crosscutting times with 3-m bucking were assumed to be identical to those with normal bucking. Under this assumption, the productivity associated with felling and processing operations with 3-m bucking were higher, at 2.1 m$^3$/h (compared to 1.0 m$^3$/h with normal bucking), given the higher recovered volumes (Table 6). The operation times for strip-road construction with 3-m bucking were also the same as those with normal bucking; therefore, productivity with respect to strip-road construction would be greater, in line with higher recovered volumes.

|                                      | Thinned tree | Removed tree | Total  |
|--------------------------------------|--------------|--------------|--------|
|                                       | Normal 3-m   | Normal 3-m   | Total 3-m   |
| Strip road construction              | 3.8 10.3     | 3.1 5.0      | 3.5 7.7     |
| Felling and processing               | 0.8 2.1      | 1.4 2.2      | 1.0 2.1     |
| Bunching                             | 13.1 13.1    | 24.6 24.6    | 16.6 15.7   |
| Forwarding                           | 8.7 8.7      | 8.7 8.7      | 8.7 8.7     |
| Transportation                       | 9.5 9.5      | 9.5 9.5      | 9.5 9.5     |
| Total                                | 0.5 1.1      | 0.8 1.1      | 0.6 1.1     |

Table 7. Cycle time of felling and processing (s/stem).

|                              | Thinned tree | Removed tree |
|------------------------------|--------------|--------------|
| Moving                       | 228.8        | 259.0        |
| Face and back cut            | 36.5         | 50.5         |
| Hang-ups                     | 14.7         | 7.5          |
| Deliming and crosscut        | 114.9        | 143.3        |
| Log quality check            | 1.5          | 3.7          |
| Others                       | 17.6         | 64.0         |
| Total                        | 414.0        | 528.0        |

On the other hand, the operational time associated with bunching, forwarding, and transportation with 3-m bucking were larger, in line with the higher recovered volumes. Furthermore, the operational times associated with forwarding and transportation were also higher, given the lower loading volumes pertaining to sweep logs. Therefore, the productivity of those operations would be lower than those seen with normal bucking. However, as this study did not investigate actual loading volumes with 3-m bucking, we assumed them to be the same as those with normal bucking; subsequently, productivity associated with bunching, forwarding, and transportation with 3-m bucking were assumed to be identical to that with normal bucking. Although bunching productivity for thinned trees and removed trees with 3-m bucking were identical to that with normal bucking (Table
6), bunching productivity for all trees with 3-m bucking differed from that with normal bucking, given the different recovered volumes associated with thinned and removed trees with normal and 3-m bucking.

3.3 Net Profit

Costs per cubic meter of strip-road construction, felling, and processing with 3-m bucking were lower, as a result of higher recovered volumes; meanwhile, costs per hectare with 3-m bucking were identical to those with normal bucking (Table 8). Costs per cubic meter of bunching, forwarding, and transportation with 3-m bucking were identical to those with normal bucking, whereas costs per hectare with 3-m bucking were relatively higher, as a consequence of the higher recovered volumes. Total costs per cubic meter with 3-m bucking were lower, whereas total costs per hectare with 3-m bucking were higher, in line with higher recovered volumes.

Recovered volumes of grade-A, B, and C wood through normal bucking were estimated at 40, 20, and 7 m³/ha, respectively, using the cumulative recovered volume (67 m³/ha) and log-quality rates (Table 3); in this way, revenue per cubic meter with normal bucking was found to be JPY 10,000/m³ (Table 9). Recovered volumes of grade-A, B, and C wood with 3-m bucking were estimated at 59, 44, and 44 m³/ha, respectively, using the cumulative recovered volume (148 m³/ha) and log-quality rates (Table 3). Revenue per cubic meter with 3-m bucking was found to be lower, at JPY 8,400/m³ (Table 9). However, revenues per hectare with 3-m bucking were found to be higher, as a result of with higher recovered volumes. Overall, the net profit per cubic meter with 3-m bucking was lower, which resulted from the higher volume of lower-quality logs; likewise, the net profit per hectare with 3-m bucking was twice as large, in line with higher recovered volumes.

Table 8. Costs.

|                      | Normal (JPY/m³) | 3-m (JPY/m³) | Normal (JPY/ha) | 3-m (JPY/ha) |
|----------------------|-----------------|--------------|-----------------|--------------|
| Strip road construction | 1,836           | 828          | 122,734         | 122,734      |
| Felling and processing | 2,140           | 974          | 143,051         | 144,371      |
| Bunching             | 382             | 406          | 25,533          | 60,082       |
| Forwarding           | 759             | 759          | 50,752          | 112,498      |
| Transportation       | 902             | 902          | 60,275          | 133,608      |
| Subtotal             | 6,020           | 3,870        | 402,345         | 573,293      |
| Other*               | 1,700           | 420          | 113,624         | 62,225       |
| Total                | 7,720           | 4,290        | 515,969         | 635,518      |

*Other: Handling fees of the forest owners’ co-operative were estimated as 5% of revenues. In addition, handling fees of a log market were estimated as 5% of revenues and piling fees were estimated as 700 yen/m³ for normal bucking.

Table 9. Economic balance.

|                      | Normal (JPY/m³) | 3-m (JPY/m³) | Normal (JPY/ha) | 3-m (JPY/ha) |
|----------------------|-----------------|--------------|-----------------|--------------|
| Revenue              | 10,000          | 8,400        | 668,376         | 1,244,495    |
| Subsidy              | 5,519           | 3,444        | 368,680         | 510,406      |
| Cost                 | -7,720          | -4,290       | -515,969        | -635,518     |
| Net Profit           | 7,799           | 7,554        | 521,087         | 1,119,383    |
4. Conclusions

This study investigated the commercial thinning operation with normal bucking, as undertaken by the Takahara Forest Owners’ Co-operative near the Nakagawa sawmill. Then, based on investigations of normal bucking, the various types of productivity as well as the net profit of 3-m bucking were estimated to examine the possibility of using 3-m bucking and fixed-price business for all logs. The recovery rate with 3-m bucking was estimated at 85%, a figure significantly higher than that with normal bucking, 38%. Therefore, recovered volumes with 3-m bucking (148 m$^3$/ha) were also significantly higher than those with normal bucking (67 m$^3$/ha). Productivity related to strip-road construction, felling, and processing with 3-m bucking were higher than those seen with normal bucking, in line with relatively higher recovered volumes. On the other hand, in the current study, productivity related to bunching, forwarding, and transportation with 3-m bucking were assumed to be the same as those with normal bucking. However, on the basis of interviews with officials from the Takahara Forest Owners’ Co-operative, forwarding productivity with 3-m bucking was lower, given the same operation times and lower forwarding volumes owing to working with sweep logs. Therefore, actual loading volumes with 3-m bucking should be investigated in future research.

Total costs per cubic meter with 3-m bucking were lower than those with normal bucking, whereas total costs per hectare with 3-m bucking were higher, both in line with relatively higher recovered volumes. Revenues per cubic meter with 3-m bucking were also lower, whereas revenues per hectare with 3-m bucking were higher. Overall, the net profit per cubic meter with 3-m bucking was lower, in line with higher volumes of lower-quality logs; meanwhile, the net profit per hectare with 3-m bucking was higher, in line with higher recovered volumes. These findings align with those of the Takahara Forest Owners’ Co-operative. However, revenues were estimated with the use of log prices and log-quality rates, by referencing information gathered from interviews with officials from the Takahara Forest Owners’ Co-operative. Log prices and log-quality rates differ from site to site, and so log prices and log-quality rates should also be investigated in future research.

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