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Performance of softwood plantation sawmills: The volume *vs.* value sawing strategy

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Abstract

Sawmill performance is anchored on three key indicators: timber volume recovery, timber value recovery, and log throughput. Traditionally, sawyers use the volume sawing strategy, which prioritizes maximising timber volume recovery. However, it is unclear whether this approach yields superior sawmill performance compared to the value sawing strategy. To determine the optimal sawing strategy, a study was conducted at four sawmills across three forest plantation clusters in September and October 2023. Data were collected from randomly selected logs grouped using cluster analysis. The PHP programming language was used to determine sawing patterns that maximised timber volume and/or value from each log. A paired t-test (5% significance level) was used to test the difference in timber volume and value recovery between the volume and value sawing strategies. The results showed that timber volume recovery from the volume sawing strategy was significantly higher ($p < 0.05$) than that obtained using the value sawing strategy, except in smaller logs (10-20 cm). Conversely, timber value recovery was superior to the value sawing strategy across all log sizes. The adoption of the value sawing strategy increased timber value recovery by US$ 2, 3 and 12 m^{-3} for small, medium and large logs, respectively, with a 2 % drop in sawmill timber volume recovery. Based on the findings, it is recommended that sawmills adopt the value sawing strategy, as it indicated potential for enhanced sawmill profitability.

Key words: Log throughput, timber value recovery, value sawing strategy

Introduction

Sawmills strive to maximise profits from the production and sale of sawn timber and other by-products, such as slabs, and saw dusts or wood chips (Lundahl and Grönlund, 2010). To achieve this goal, sawmills must operate efficiently by optimizing the use of manpower, machinery, and raw materials (Lundahl, 2009). According to Quebec *et al*. (2015), three key performance indicators (KPIs) are critical for sawmills to remain competitive and profitable. These KPIs include: (I) the volume of logs milled per productive hour, relative to the sawmill capacity, i.e. log throughput; (II) volume of sawn timber produced per unit volume of logs milled, i.e. timber volume recovery; and (III) monetary value of sawn timber produced per unit volume of logs milled, i.e. value recovery. By optimizing these KPIs, sawmills can remain efficient and ensure profitability.

To maximise log throughput, sawyers must identify and eliminate bottlenecks in the milling process, reduce machine breakdown through preventative maintenance, and effectively manage labour (Nwanya *et al*., 2017)**.** This optimizes the utilisation of machinery and human resources, leading to increased profit margins through reduced milling costs (Missanjo and Magodi, 2015). Maximising timber volume recovery is concerned with recovering more volumes of sawn timber, which is the most valuable and saleable sawmill product (Taube *et al*., 2020). Increasing timber volume recovery also reduces the unit cost of sawlogs, and thus the overall milling costs (Rawat *et al*., 2023). For instance, a sawmill with a milling cost of US$ 30 m^{-3}, at 30 % can halve its unit sawlog cost by doubling timber volume recovery to 60%. In contrast, timber value recovery focuses on maximising profits by sawing the most valuable sawn timber grades (Walker, 2006). According to Mendes and Pasiecznik (2015), sawn timber volume does not always reflect its true monetary value on the market. For example, a roughly sawn timber piece measuring 25 mm x 200 mm x 4.2 m attracts a premium price than 50 mm x 100 mm x 4.2 m despite having equal volumes (Mwamakimbullah, 2020). Therefore, sawyers should consider the monetary value attached to each timber size when selecting the sawing pattern for a particular log. Incidentally, it is virtually impossible to simultaneously optimise all the performance indicators in the real sawmilling environment (Lindner and Wessels, 2015; Vergara *et al*. 2015). This is because the sawing pattern that maximises log throughput may not necessarily maximise the resultant volume or value of sawn timber produced. A study by Steele *et al*. (1993) revealed that prioritising timber volume recovery would reduce the timber value by US$ 2 per log sawn. Similarly, Nordmark (2005) reported a 3% drop in timber volume recovery when adopting a value sawing strategy. While the volume sawing strategy is the most common sawing strategy used by sawmills (Missanjo and Magodi, 2015; Ngobi, 2019), it is not evident that it is better than the value sawing strategy in ensuring the overall competitiveness and profitability of sawmills. The study aimed to investigate and determine the optimal log sawing strategy that can enable sawmills in Uganda to optimise their performance, thereby ensuring competitiveness and profitability.

Methodology

Study area

The study was conducted in the Eastern, Central and Albertine Forest plantation clusters in Uganda in 2023. The study sites were in the districts of Mayuge, Mubende, Hoima and Masindi (Fig. 1). These districts are known to host many sawmills, and through their local leadership, were ready to participate in the study.

Sampling

Plantation clusters were selected purposively based on accessibility and potential number of sawmills. Sawmills were also purposively selected to include portable and medium sawing technologies. Logs were selected systematically, to obtain a sample (N_i) of at least 90 logs in three days for each sawmill (Table 1).

Table 1: Sampling intensities used

Sample sawmill	N_d	N_q	k	N_l
Medium band sawmill	3	500	14	106
Mobile band sawmill-A	4	60	2	98
Mobile band sawmill-B	4	60	2	100
Mobile circular sawmill	4	65	2	103

Sampling interval (k) was determined using Equation 1. The starting sample log was the first log on the sawmill log deck for the day.

$$k = \frac{N_q * N_d}{N_l} \quad \text{.......... Equation 1}$$

Where: N_q = Average number of logs sawn at sawmill per day, as obtained from the sawyers. N_d = Target number of days to be spent at a sawmill which was 3 given resource constraints; and N_l = Number of logs to be sampled ($\geq$90).

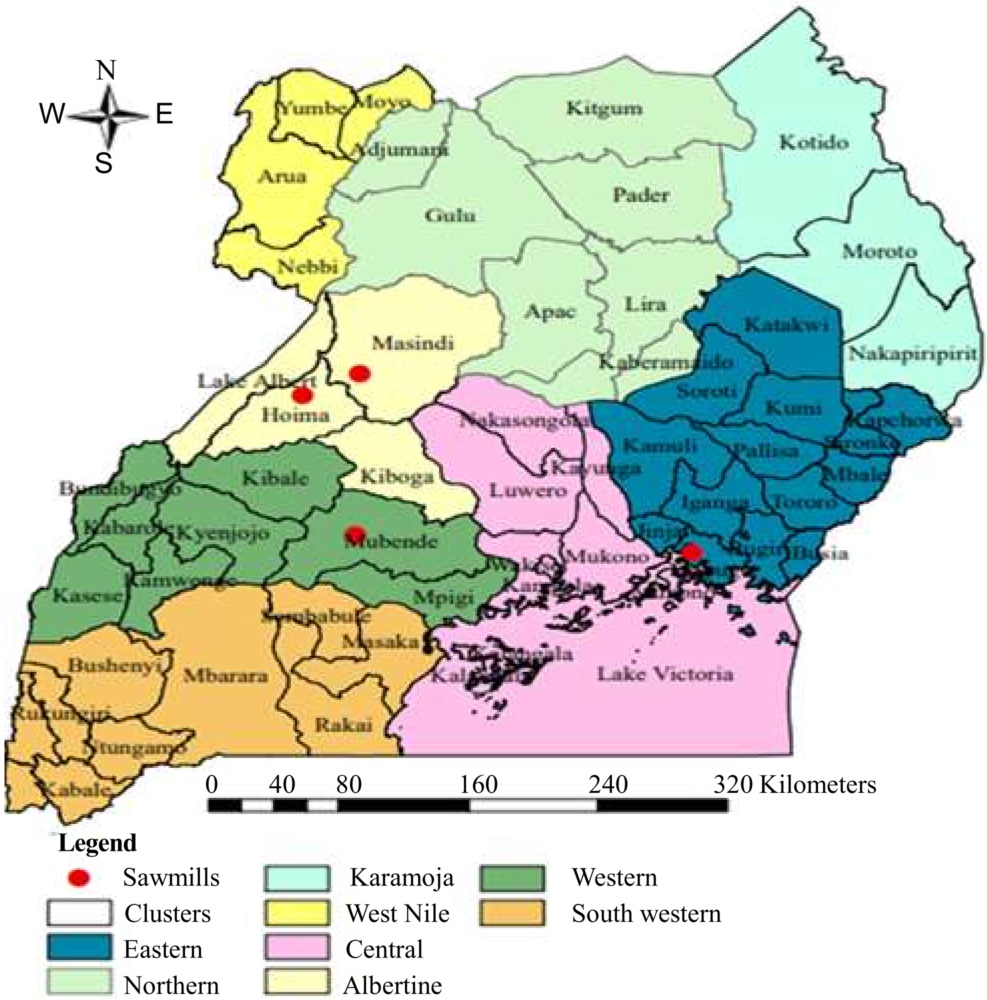

Figure 1. Map showing study area in Uganda.

Data collection

For each sampled log, bark thickness and log length were measured using a measuring tape. The small and butt end diameters were measured using a vernier caliper. The thickness of saw blades used at each sample sawmill was measured using a vernier caliper. The unit price of each timber size produced, and the sawing method were also recorded.

Data analysis

For each log, timber volume recovery and value recovery of each sawing pattern were calculated using Equations 2 and 3, respectively, as follows:

$$T_y = \frac{P_y}{V_l} \times 100\% \quad \text{Equation 2}$$

$$R_y = \frac{\sum_i P_i N_{iy}}{V_l} \quad \text{Equation 3}$$

Where: T_y = timber volume recovery obtained from a log using sawing pattern y; R_y = timber value recovery obtained from a log sawn using sawing pattern y; V_l = log volume (m^3) obtained from log volume table of *Pinus caribaea* based on top diameter and length; P_y = timber volume (m^3) produced from a log using sawing pattern y, obtained using nominal dimensions as according to Kambugu *et al*. (2005); P_i = price per timber piece (given in Uganda shillings, converted to US$) of size i; and N_i = number of pieces of timber of size i produced using sawing pattern y.

A sawing pattern was a combination of timber size as centre piece/s and any corresponding extractable timber as either side, top or bottom pieces; or a combination of them. For each log, possible sawing patterns were developed, following the sawing method (cant sawing) used by the study sawmill. The study adapted and/or modified mathematical algorithms from Maness and Adams (1991) and Ngobi (2019); and developed sawing patterns in three steps indicated below.

Step 1: Determining the maximum number of center pieces. For each timber size, the maximum number of pieces that could be obtained from the log cant was obtained from Equation 4 as according to Maness and Adams (1991).

$$n = \frac{2\{r^2 - (0.5 \times cw)^2\}^{0.5} + s}{ch + s} \quad \text{Equation 4}$$

Where: s = kerf width (mm) obtained as described by Ngobi (2019); n = maximum number of pieces of timber with width (cw) and thickness (ch). n was rounded off, down to the nearest whole number, when found to be floating figure since the number of timber pieces must be an integer.

Timber width (cw) was constrained by the top diameter of the log under the bark (Equation 5).

$$c_w < t \quad \text{Equation 5}$$

Timber thickness (ch) was subject to the highest rectangle of width (cw) that could fit into a circle representing the top diameter under the bark (Equation 6) as described by Maness and Adams (1991).

$$c_h \leq 2\{r^2 - (0.5 \times C_w)^2\}^{0.5} \text{ .... Equation 6}$$

Where: r = radius of the log (mm) obtained by halving log top diameter t.

Step 2: Determining possible side pieces to be extracted. The study assumed minimal log eccentricity, so that the two resulting side slabs after extracting the centre piece/s were of equal size. The timber size that could be extracted from the side slabs as side piece(s), was constrained by its thickness (S_h) and width (S_w); width of the centre piece (c_w) and radius of small log end diameter (r) as in Equation 7.

$$\{(0.5 \times cw + p * s + S_{h_{r-1}} + S_{h_r})^2 + \left(0.5 \times S_{w_r}\right)^2\}^{0.5} < r \text{ .... Equation 7}$$

p represented the position of side piece, i.e. 1 for inner most side piece extracted next to centre piece; 2 for second sidepiece extracted after the inner most piece; and 3 for third sidepiece, etc. Equation 7 was explained in Ngobi (2019).

Step 3: Determining possible top and bottom pieces in each sawing pattern. Timber pieces which were narrower and/or thinner than centre pieces and could be extracted from the top and bottom slabs as top and bottom pieces, were subjected to similar constraints as side pieces above. However, the planes of centre pieces were reverted, as explained in Ngobi (2019).

PHP programming language was used to code the mathematical algorithm and generate possible sawing patterns for each sampled log. For each log, the sawing pattern that yielded the highest timber volume recovery (T_{max}) from Equation 2, was identified as the volume pattern and the resulting volume recovery was the recovery considered under the volume sawing strategy. The corresponding value recovery (R_a) of volume pattern, was obtained using a similar approach as in Equation 3. On the other hand, the sawing pattern that yielded the highest timber value recovery (R_{max}), as obtained in Equation 3, was the value pattern and was considered under the value sawing strategy. The corresponding volume recovery (T_a) of the value pattern was obtained using a similar approach as in Equation 2.

Cluster analysis was used to group logs into classes based on top diameter. For each log class, timber volume recovery (T_r) and value recovery (R_r), under the volume sawing strategy, were calculated using Equations 8 and 9.

$$T_r = \frac{\sum T_{max}}{N_r} \quad \text{.......... Equation 8}$$

$$R_r = \frac{\sum R_{av}}{N_r} \quad \text{.......... Equation 9}$$

Where: N_r = number of logs in the log class r, and R_{av} = value recovery of volume pattern for log v in class r.

Timber value recovery and volume recovery, under the value sawing strategy, were also calculated using a similar approach as in Equations 8 and 9, respectively.

The weighted timber volume recovery (T_s) and value recovery (R_s) of each sawmill under the volume sawing strategy, were calculated using Equations 10 and 11, respectively.

$$T_s = \sum_r T_r * \frac{V_r}{V} \quad \text{.......... Equation 10}$$

$$R_s = \sum_r R_r * \frac{V_r}{V} \quad \text{.......... Equation 11}$$

Where: V_r = Total volume of logs (m^3) in log class r, and V = Total volume of logs (m^3) sampled at the sawmill.

The weighted timber volume and value recovery of each sawmill under the value sawing strategy, were calculated using a similar approach as in Equations and 10 and 11, respectively.

The difference in timber volume recovery between the volume and value sawing strategy, was tested using a paired t-test at 5% significance level. A paired t-test was also used to test the difference in timber value recovery between the volume and value sawing strategy.

Results

Timber volume recovery

Timber volume recovery under the volume sawing strategy was higher than that of the value sawing strategy, except for smaller logs (Table 2). Timber volume recovery increased with log diameter across both sawing strategies. The medium band sawmill had the highest volume recovery under both sawing strategies, while the mobile circular sawmill recorded the lowest. Compared to the value sawing strategy, the volume sawing strategy yielded 3% increase in timber volume recovery for the medium band sawmill; 2% increase for the mobile band sawmills and 1% increase for the mobile circular sawmills (Table 3).

Table 2. Characteristics of logs sawn by sampled sawmills

Sawmill category	Log diameter class			Weighted average
	10-19cm	20-25cm	>26cm	
1	18	22	28	25
2	19	21	26	19
3	20	21	25	19
4	19	22	28	18
Average	16	22	27	20

1=Medium band sawmill, 2=Mobile band sawmill-A, 3=Mobile band sawmill-B, 4=Mobile circular sawmill

Table 3. Timber volume recovery for volume strategy (V) and value strategy (R)

Sawmill type	10-19cm		20-25cm		>26cm		Weighted average	
	V	R	V	R	V	R	V	R
1	34	34	41	40	50	49	49	46
2	36	36	43	42	48	46	39	37
3	36	36	43	42	48	46	38	36
4	33	33	41	40	43	42	31	30
Average	34	34	42	41	48	46	39	37

1=Medium band sawmill, 2=Mobile band sawmill-A, 3=Mobile band sawmill-B, 4=Mobile circular sawmill.

A paired t-test indicated a significant difference ($p < 0.05$) in timber volume recovery between sawing strategies (Table 4). Notably, timber volume recovery was significantly different across all log classes and sawmills, except for smaller logs (10 -19 cm).

Table 4. Paired samples test on volume recovery between volume and value strategy

Sawmill category	Log class	Mean	Std. Deviation	Std Error.	95% C. I Lower	95% C. I Upper	t	df	Sig (2-tailed)
1	10-19	0.00	2.33	0.7	-0.2	0.3	1.94	10	0.70
	20-25	0.00	0.9	0.52	0.39	0.23	3.71	86	0.00
	>26	0.00	0.95	0.75	0.19	0.48	4.49	158	0.00
2	10-19	0.00	1.0	0.21	0.7	0.32	2.21	18	0.20
	20-25	0.62	2.01	0.3	0.09	1.29	2.41	64	0.02
	>26	1.22	1.53	0.32	0.1	2.43	2.34	13	0.04
3	10-19	0.00	1.34	0.31	0.67	0.34	2.33	18	0.30
	20-25	0.69	2.41	0.29	0.93	1.29	2.31	64	0.02
	>26	1.21	1.92	0.52	0.10	2.33	2.35	13	0.04
4	10-19	0.00	1.74	0.24	1.23	0.23	0.682.99	48	0.10
	20-25	1.42	2.37	0.36	0.68	2.14	3.92	42	0.00
	>26	1.00	0.88	0.16	0.68	1.31	6.43	31	0.00

1=Medium band sawmill, 2=Mobile band sawmill-A, 3=Mobile band sawmill-B, 4=Mobile circular sawmill

Timber value recovery

The value sawing strategy yielded higher timber value recovery than the volume sawing strategy across all log classes and sawmills (Table 5). Larger logs yielded the highest timber value recovery under the value sawing strategy (US$ 72 m^{-3}), while smaller logs had the lowest value recovery (US$ 42 m^{-3}). In contrast, the volume sawing strategy resulted in lower value recovery rates of US$ 60 and 40 m^{-3} for larger and smaller logs, respectively (Table 5).

The medium band sawmill had the highest timber value recovery under both sawing strategies: US$ 98 m^{-3} (value sawing strategy) and US$ 86 m^{-3} (volume sawing strategy). Conversely, the mobile circular sawmill had the lowest timber value recoveries: US$ 28 and 26 m^{-3} for value and volume sawing strategy, respectively (Table 5).

Table 5. Value recovery (US$/m^3) for volume strategy (V) and value strategy (R)

Sawmill category	10-19cm		20-25cm		>26cm		Weighted average	
	V	R	V	R	V	R	V	R
1	65	65	76	79	93	112	86	98
2	36	36	41	43	54	69	35	39
3	35	35	41	43	54	69	34	37
4	28	31	35	37	37	38	26	28
Average	40	42	48	51	60	72	45	51

1=Medium band sawmill, 2=Mobile band sawmill-A, 3=Mobile band sawmill-B, 4=Mobile circular sawmill.

A paired t-test indicated significant difference ($p < 0.05$) in timber value recovery between sawing strategies for all log sizes at all sawmills, except for smaller logs with diameter below 20 cm (Table 6).

Table 6. Paired samples test on timber value recovery between sawing strategies

Sawmill category	Log class	Mean	Std. Deviation	Std Error.	95% C. I		t	df	Sig (2-tailed)
					Lower	Upper			
1	10-19	-2.70	4.24	1.27	-5.56	0.16	-2.11	10	0.6
	20-25	-2.31	5.59	0.60	-3.51	-1.12	-3.86	86	0.00
	>26	-19.21	13.13	1.04	-21.27	-17.16	-18.47	158	0.00
2	10-19	-0.47	1.40	0.31	-1.14	0.21	-1.45	18	0.16
	20-25	-3.38	3.33	0.39	-4.16	-2.57	-8.23	64	0.00
	>26	-15.16	13.99	3.74	-23.24	-7.02	-4.05	13	0.00
3	10-19	-0.47	1.40	0.31	-1.14	0.21	-1.46	18	0.16
	20-25	-3.38	3.33	0.39	-4.21	-2.57	-8.24	64	0.00
	>26	-15.16	13.99	3.74	-23.14	-7.07	-4.00	13	0.00
4	10-19	-2.31	2.34	0.31	-2.99	-1.64	-6.900	48	0.06
	20-25	-3.59	2.13	0.34	-4.29	-2.91	-10.00	42	0.00
	>26	0.83	1.01	0.18	-1.20	-0.47	-4.64	31	0.00

1=Medium band sawmill, 2=Mobile band sawmill-A, 3=Mobile band sawmill-B, 4=Mobile circular sawmill

Discussion

Timber volume recovery

The volume sawing strategy yielded higher timber volume recovery than the value sawing strategy (Table 3), implying that the sawing patterns that maximized timber volume did not necessarily yield maximum timber value. This finding aligns with previous studies by Steele *et al*. (1993) in hardwood sawmills and Nordmark (2005) in softwood sawmills, which reported higher timber volume recovery under the volume sawing strategy. Notably, the volume sawing strategy increased timber volume recovery by 2.4 % (Nordmark, 2005) and 3 % (Steele *et al*., 1993). However, smaller logs (10 – 19 cm) showed no significant difference in timber volume recovery between sawing strategies, suggesting that either sawing strategy can be used without negatively impacting timber volume recovery. In contrast, medium-sized logs (20-25 cm) and large logs (>26cm) had a 1 and 2 % increase in timber volume recovery, respectively, under the volume sawing strategy (Table 3). This increasing potential for the volume sawing strategy to improve timber volume recovery with log size can be attributed to greater number of applicable sawing patterns for larger logs (Kambugu *et al*. 2005; Missanjo and Magodi, 2015; Ngobi, 2019).

The higher timber volume recovery obtained by the medium band sawmill (49 %) can be attributed to the relatively large log sizes that were sawn by the sawmill (Table 2). Furthermore, the medium band sawmill used optimising edgers and resaws, which enables the recovery of narrower, thinner, and/or shorter sawn timber pieces. Conversely, the mobile circular sawmill had the lowest timber volume recovery (31 %) due to the relatively small diameter log sizes that it sawed. Moreover, the mobile circular sawmill had the thickest saw blade which resulted into a wide saw-kerf. According to Kambugu *et al*. (2005), sawmills with thick saw blades are inefficient and thus inappropriate for use in conversion of small diameter logs.

Timber value recovery

Timber value recovery obtained under the value sawing strategy was higher than that obtained under the the volume sawing strategy (Table 5), indicating that sawing patterns that maximized timber value recovery did not maximise timber volume recovery. The value sawing strategy increased timber value recovery across all log sizes i.e., US$ 2, 3 and 12 m^{-3} for small, medium and large logs, respectively. This resulted in a mean increase of 8% in timber value recovery, surpassing the 3% reported by Todoroki and Ronnqvist (1999) when the value sawing strategy was considered.

The medium band sawmill had the highest timber value recovery under both sawing strategies for all log sizes, and this can be attributed to the relatively higher volume of timber recovered from the logs and the higher prices attached to the sawn timber. In contrast, the mobile circular sawmill showed a minimal increase in timber value recovery (US$ 1 m^{-3}) for large logs under the value sawing strategy. This can be attributed to the fact that timber pricing is not only dictated by the corresponding timber volume but also the prevailing timber demand, log requirement, present stock and production costs (Kant, 2010). Attaching premium prices to wider timber pieces milled from larger logs might explain the higher increase in timber value recovery obtained at the medium band sawmill (US$ 19 m^{-3}) and mobile band sawmills (US$ 15 m^{-3}).

Assuming harvesting and milling cost of US$ 39 m^{-3} (FAO, 2020), zero cost for saw logs since the sawmills owned the forest plantations, and timber value recovery obtained in Table 5, net revenues from sale of sawn timber at the medium band sawmill under the volume sawing strategy were: US$ 26, 37 and 54 m^{-3} for small, medium and large logs, respectively. Under the value sawing strategy, timber value recovery remained US$ 26 m^{-3} for small logs but increased by US$ 3 and 19 m^{-3} for medium and large logs, indicating the value sawing strategy's potential to increase profits from medium and large logs at the medium band sawmills with a 1 % drop in timber volume recovery (Table 3). Similar trends were observed at the mobile band sawmills with increased timber value recovery of US$ 2 and 15 m^{-3} for medium and large logs but with a 2 % drop in timber volume recovery. However, the net revenue from sale of sawn timber from small logs remained negative even with the value sawing strategy (Table 5). For the mobile circular sawmill, the net revenue from sale of sawn timber was negative across all log sizes for either sawing strategies suggesting that the sawmill did not realise any profits unless significant revenues were obtained from sale of by-products such as billets, slabs or saw dust.

Conclusion

The volume sawing strategy had no significant effect on timber volume recovery for smaller logs but increased timber volume recovery by 1 and 2% for medium and large logs. However, this came at a cost of reduced timber value recovery by US$ 2, 3 and 12 m^{-3} for small, medium and large logs, respectively. Compared to the value sawing strategy, the volume sawing strategy yielded 3% increase in volume recovery for the medium band sawmill, 2% increase for the mobile band sawmills, and 1% increase for the mobile circular sawmill.

The value sawing strategy increased timber value recovery by US$ 2, 3 and 12 m^{-3} for small, medium and large logs. Timber volume recovery did not drop in small logs but reduced in medium and large logs by 1 and 2 %. The medium band sawmill and mobile circular sawmill had the highest and lowest timber value recovery (US$ 98 and 28 m^{-3}). The value sawing strategy indicated potential to maximise sawmill profits at the medium and mobile band sawmills i.e., increased net revenue for medium and large logs by US$ 3 and 19 m^{-3} at the medium band sawmill and US$ 2 and 15 m^{-3} at the mobile band sawmills.

Considering its potential to improve overall profitability, adopting the value sawing strategy is recommended for all log sizes at all sawmills. Future research should investigate the impact of the two sawing strategies on log throughput for the different sawmills.

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