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CHANGE IN THE PRODUCTION LINE FOR BETTER OPERATIONAL PERFORMANCE IN MACHINING *Eucalyptus spp.* WOOD

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Resumo

Alteração da linha de produção para melhor desempenho operacional na usinagem de madeira de Eucalyptus spp. O presente estudo tem como objetivo avaliar o efeito da alteração do layout sobre a eficiência operacional, produtividade e rendimento em duas linhas de usinagem de pranchas, vigas, caibros, tábuas e ripas de *Eucalyptus* spp. Foram coletadas informações diárias de produção nas duas linhas de usinagem de peças de madeira durante um período de 21 dias, antes e após a alteração de layout. Para o cálculo de eficiência operacional, produtividade e rendimento, foram utilizados os dados do volume de matéria prima e produto final. A eficiência operacional média da linha um teve aumento de 0.1534 $m^3.op.h^{-1}$ e a linha dois de 0.1850 $m^3.op.h^{-1}$ após a alteração do layout. A produtividade da linha um e dois aumentou após a reestruturação das linhas, obtendo uma diferença de 0.1364 $m^3.op.h^{-1}$ e 0.1099 $m^3.op.h^{-1}$. O rendimento da usinagem da madeira não diferiu para as duas linhas. Os resultados indicaram homogeneização na produção e um ganho de desempenho na usinagem da madeira.
Palavras-chave: Madeira serrada; Desdobro; Produtividade; Eficiência Operacional; Rendimento.

Abstract

The present study aims to evaluate the effect of layout modification on operational efficiency, productivity, and yield in two wood machining lines for planks, beams, rafters, boards, and battens of *Eucalyptus* spp. Daily production data was collected from the two machining lines over a period of 21 days, before and after the layout modification. For the calculation of operational efficiency, productivity, and yield, data on raw material volume and final product was used. The average operational efficiency of line one increased by 0.1534 $m^3.op.h^{-1}$, and line two by 0.1850 $m^3.op.h^{-1}$ after the layout modification. The productivity of lines one and two also increased after the restructuring, with differences of 0.1364 $m^3.op.h^{-1}$ and 0.1099 $m^3.op.h^{-1}$, respectively. The wood machining yield did not differ between the two lines. The results indicated production homogenization and performance improvement in wood machining.
Keywords: Sawn timber; Sawing; Productivity; Operational Efficiency; Yield.

INTRODUCTION

Wood machining faces significant challenges due to variations among species and their anatomical and physical characteristics, which make each operation unique. However, accurately assessing operational efficiency, productivity, and yield remains one of the primary challenges for the success of these operations. The lack of standardization among species and the different responses of wood during processing complicate the implementation of consistent and efficient practices. These parameters, although widely used, these parameters often do not provide a comprehensive view of the challenges faced in the machining process, particularly concerning wood variability and tool wear, which necessitate continuous adjustments and rigorous monitoring (FORGHANI *et al.*, 2024; JUIZO; ROCHA; BILA, 2014; MELO *et al.*, 2017; PRASETYO *et al.*, 2019; SALVADOR *et al.*, 2020; SERPE; FILHO; ARCE, 2018).

Operational efficiency is a key tool for analyzing a company's performance, as it enables the evaluation of the volume of inputs used per hour or shift. Productivity, in contrast, measures an industry's output, allowing for the assessment of the volume produced per hour or shift and establishing the operational production capacity of a machining line. Yield, in turn, is an essential metric for measuring the percentage of raw material converted into final product during wood machining. In the industry, these three metrics are considered essential components of operational management (ANJOS; FONTE, 2017; CONTADOR, 2017; MUHDI, 2022; ROZAS *et al.*, 2023; SUN; MARCILLE; DANIELS, 2021).

Moreover, one of the critical factors in the production process of a machining center is the spatial organization of the machines. Poorly planned layouts can lead to waste of raw materials and low operational performance. A well-organized spatial arrangement of machines can reduce production costs and increase productivity (SANTOS; REIS, 2019; VALE; SABLOWSKI, 2006).

Thus, the selection and organization of machines will result in a volume of machined wood within a given time interval, which in turn will serve as the basis for evaluating operational performance and guiding factory production planning (ARO; BATALHA, 2013; MURARA; ROCHA; TRUGILHO, 2013; ROCHA, 2002; VITAL, 2013).

Therefore, the objective of this study is to assess the effect of layout changes on operational efficiency, productivity, and yield in two machining lines for planks, beams, rafters, boards, and battens of *Eucalyptus* sp.

MATERIAL AND METHODS

Study Location

The study was conducted at a *Eucalyptus* spp. wood machining center in the city of Campina Grande do Sul, Paraná. The wood is received with dimensions larger than those specified for commercial use. In the company, machining operations are carried out to adjust the dimensions, bringing the pieces to the standard thickness, width, and length required for the furniture and construction sectors.

Production Lines

The company has five production lines; two underwent restructuring and were evaluated in this study. These lines consist of horizontal band saws with 20 HP motors and simple circular cross-cut saws with 5 HP motors. The horizontal band saws are from the same manufacturer and have the same technical characteristics, varying only in the number of heads. They feature 700 mm diameter flywheels with blades 31.75 mm wide, 1.20 mm thick, and a kerf of 1.70 mm. The maximum cutting and feed speeds are 33.75 $m.\ s^{-1}$ and 24.50 $m.min^{-1}$. respectively. The cutting capacities range from 100 to 350 mm in width and a minimum thickness of 5 mm, with a minimum piece length of 500 mm. The cross-cut saws have 300 mm diameter blades and a cutting speed of 54.97 $m.s^{-1}$.

Evaluated Production Lines

Two production lines (1 and 2) were evaluated before and after the change in its layout. Both lines perform machining on wood that is already pre-sawn to specified dimensions at the time of purchase. On these lines, thickness, width, and length leveling are carried out, or the pieces are resized, generating smaller dimension parts.

Before the layout change, lines 1 and 2 followed the configuration shown in Figure 1a. Each stage required three operators, totaling nine workers per line, with the first operator feeding the machine, the second removing waste and assisting the third in positioning the piece for the next stage or assembling the bundle for removal from the line. In the new layout, a simple horizontal saw was added, and a roller table was placed between the machines, eliminating the need for two operators between stages and reducing the number of workers per line to seven (Figure 1b).

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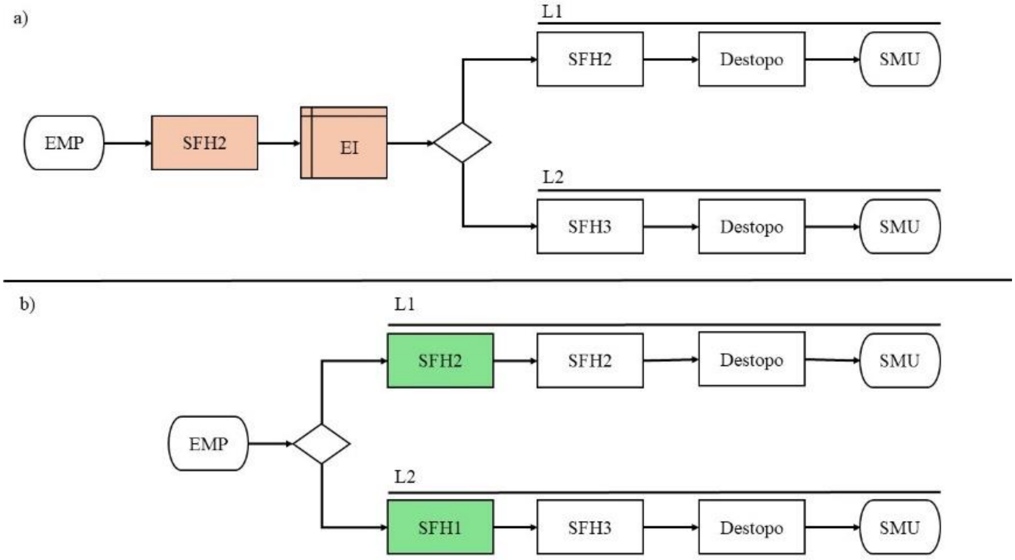

Figure 1. Production lines before and after the change in machine layout. Raw material input (EMP); double-head horizontal band saw (SFH2); intermediate stock (EI); production line one (L1); production line two (L2); triple-head horizontal band saw (SFH3); cross-cut saw (Destopo); machined wood output (SMU).
Figura 1. Linhas de produção antes e depois da alteração da disposição de máquinas. - EMP é a entrada de matéria prima; SFH2 é a serra fita horizontal dupla; EI é o estoque intermediário; L1 é a linha de produção um; L2 é a linha de produção dois; SFH3 é a serra fita horizontal tripla; Destopo é a destopadeira; SMU saída de madeira usinada.

Data Collection and Processing

Information on the nominal thickness, width, and length of the pieces wass collected before entering and after leaving the production line, and at the end, the daily volume of raw material and finished products was determined. The equation adapted from Rocha (2002) was used to determine operational efficiency and yield, and the equation adapted from Contador (2017) was used to determine productivity, as shown in Table 1:

Table 1. Equations for determining the variables of interest in the study.
Tabela 1. Equações de determinação das variáveis de interesse de estudo.

Variables	Equation	
Operational Efficiency ($m^3.op.h^{-1}$)	$Ef = \frac{VE}{(Op \times t)}$	(1)
Productivity ($m^3.op.h^{-1}$)	$P = \frac{VS}{(Op \times t)}$	(2)
Yield (%)	$R\% = \frac{VS}{VE}$	(3)

Legend: VE represents the volume of raw material used on the line during the shift; VS represents the volume of machined wood during the shift; Ef represents operational efficiency; P represents productivity; R represents the yield in the wood machining process; p-values less than 0.05 in the Shapiro-Wilk test indicate that the data are non-normally distributed; * indicates significance in the Kruskal-Wallis test; ** indicates high significance in the Kruskal-Wallis test.

Statistical Analysis

The Shapiro-Wilk and Kruskal-Wallis tests were conducted, followed by Dunn's test, to assess the performance of the lines and determine if there was a statistical difference between them. Finally, the ordinal Eta-squared test was used to analyze the effect of the layout on production.

RESULTS

The values of the variables for raw material volume, sawn wood, and operational efficiency were normally distributed, while productivity and yield did not exhibit this distribution. The Kruskal-Wallis test revealed significant differences between lines 1 before, 1 after, 2 before, and 2 after for the variables of raw material volume, machined wood, operational efficiency, and productivity, but no significant differences were found for yield (Table 2).

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Table 2. Shapiro-Wilk Normality Test and Kruskal-Wallis Test.
Tabela 2. Teste de normalidade de Shapiro-Wilk e teste de Kruskall-Wallis.

Variables	Shapiro-Wilk		Kruskall-Wallis	
	W Statistic	p-value	Chi-squared	p-value
VE	0.9809	0.2476	8.92280	0.03033*
VS	0.9914	0.8621	11.0050	0.0117*
Ef	0.9787	0.1806	23.5180	0.00003149**
P	0.9574	0.0073	28.9910	0.000000225**
R	0.9682	0.0360	7.3305	0.0620

Legend: VE represents the volume of raw material used on the line during the shift; VS represents the volume of machined wood during the shift; Ef represents operational efficiency; P represents productivity; R represents the yield in the wood machining process; p-values less than 0.05 in the Shapiro-Wilk test indicate that the data are non-normally distributed; * indicates significance in the Kruskal-Wallis test; ** indicates high significance in the Kruskal-Wallis test.

The minimum raw material consumption of line 1 differed by only 0.600 m³, with line 1 consuming 15.04 m³ before the layout change and 15.64 m³ afterward (Figure 2a). In line 2, the minimum values were 26.080 m³ before and 24.400 m³ after the change, a difference of 1.680 m³. The difference between the minimum values of the two lines was 11.040 m³, while the range of the average values was 1.850 m³ in line 1 and a reduction of 4.240 m³ in line 2 (Figure 2a). From the boxplot information (Figure 2a), it can be observed that lines 1 and 2 showed a smaller interquartile range after the layout change. The range for line 1 before the change was 13.020 m³, and after the change, it decreased to 5.790 m³. The value for line 2 before the layout change was 11.020 m³, and after the change, it was 4.640 m³. This demonstrates improved standardization in consumption following the change and reduced fluctuation in consumption during the shift.

The average machined wood volumes varied between 20.7020 m³ and 26.410 m³, with a variation of 5.7080 m³ between the lines. The minimum volume was found in line 1 before the change, while the maximum was in line 2 before the change, with a value of 37.850 m³ (Figure 2b). After the layout change, the range between the first quartiles in both lines decreased. Line 1 showed a reduction of 0.850 m³, while line 2 saw a reduction of 3.970 m³, indicating greater uniformity in the production process. The median increased after the layout change (Figure 2b), reaching 24.050 m³ and 26.840 m³ for lines 1 and 2, respectively. The difference between the medians of the lines was 6.560 m³. Regarding the volume of machined wood, a difference was observed between line 1 before and line 2 before and after the change, highlighting greater production per shift in these lines.

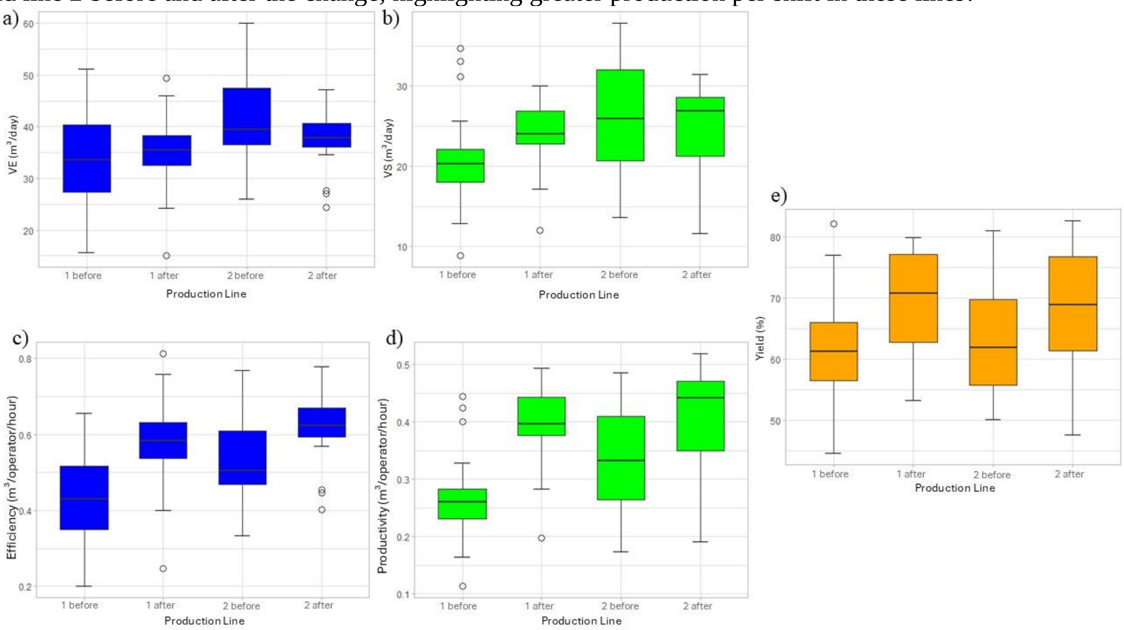

Figure 2. Results of lines one and two before and after the layout change: a) Volume of raw material consumed per shift; b) Volume of machined wood per shift; c) Operational efficiency per operator hour; d) Productivity per operator hour; e) Machined wood yield. "1 before" refers to the production line before

the layout change; "1 after" refers to the production line after the layout change; "2 before" refers to the production line before the layout change; "2 after" refers to the production line after the layout change.

Figura 2. Resultados das linhas um e dois antes e depois da alteração do layout - a) Volume de matéria-prima consumida por turno; b) Volume de madeira usinada por turno; c) Eficiência operacional operador hora; d) Produtividade operador hora; e) Rendimento da madeira usinada; 1 antes é a linha de produção antes da mudança de layout; 1 depois é a linha de produção depois da mudança de layout; 2 antes é a linha de produção antes da mudança de layout; 2 depois é a linha de produção depois da mudança de layout.

Operational efficiency, also known as the individual contribution of each operator to productivity, presented the lowest average value of 0.4301 $m^3.op.h^{-1}$ for line 1 before the change, with the highest result for line 2 at 0.6151 $m^3.op.h^{-1}$, showing a difference of 0.185 $m^3.op.h^{-1}$ between the lines, as presented in Figure 2c. Analyzing the data in the boxplot (Figure 2c), it was observed that the interquartile ranges displayed higher medians, while their interquartile ranges were reduced. In line 1 before the change, the lowest median was 0.4306 $m^3.op.h^{-1}$, whereas in line 2, the highest median was recorded at 0.6230 $m^3.op.h^{-1}$.

The average productivity values ranged from 0.2654 $m^3.op.h^{-1}$ to 0.4139 $m^3.op.h^{-1}$, with the lowest productivity performance was obtained by line 1 before the layout change, followed by line 2 before the change, line 1 after, and line 2 after (Figure 2d). The median and the range of the first and third quartiles increased when comparing the results, and there was a reduction in the interquartile range of 0.0715 $m^3.op.h^{-1}$ for line 1 and 0.0647 $m^3.op.h^{-1}$ for line 2 (Figure 2d).

As shown in the chart (Figure 2e), the interquartile range for yield increased after the layout change, indicating a potential loss in the quality of the sawn wood supplied by third parties and/or the absence of production planning and input purchasing at the sawmill. However, both the median and average values increased compared to the previous factory layout.

To verify the differences between the studied variables, Dunn's test was applied (Table 3), which showed that raw material consumption for lines 1 and 2 before the layout change differed, with line 2 consuming 39.400 m³ per shift. The volume of sawn wood showed a significant difference between line 1 before and line 2 before and after the change. When analyzing both lines, it is possible to verify the superiority of line 2 compared to line 1 in terms of the absolute volume machined during the workday (Table 3).

Regarding operational efficiency, the significant improvement in line 1 when comparing before and after the layout change is evident (Table 3). For this line, the first quartile, median, and third quartile values differed by 0.1867 $m^3.op.h^{-1}$, 0.153 $m^3.op.h^{-1}$, and 0.1152 $m^3.op.h^{-1}$, respectively. The same occurred when comparing line 1 before and line 2 after, where Dunn's test showed a difference in operational efficiency between the two lines.

Table 3. Dunn's Test applied to the studied Variables.
Tabela 3. Teste de Dunn para aplicado as variáveis de estudo.

Variable	Class 1	Class 2	n1	n2	Statistic	Adjusted p-value
VE	1 before	1 after	21	21	0.595	1
	1 before	2 before	21	21	2.78	0.0323*
	1 before	2 after	21	21	1.59	0.665
	1 after	2 before	21	21	2.19	0.172
	1 after	2 after	21	21	0.999	1
	2 before	2 after	21	21	-1.19	1
VS	1 before	1 after	21	21	2.13	0.198
	1 before	2 before	21	21	2.9	0.0226*
	1 before	2 after	21	21	2.83	0.0281*
	1 after	2 before	21	21	0.765	1
	1 after	2 after	21	21	0.696	1
	2 before	2 after	21	21	-0.0696	1

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Variable	Class 1	Class 2	n1	n2	Statistic	Adjusted p-value
Ef	1 before	1 after	21	21	3.54	0.00238**
	1 before	2 before	21	21	2.1	0.214
	1 before	2 after	21	21	4.57	0.0000297**
	1 after	2 before	21	21	-1.44	0.895
	1 after	2 after	21	21	1.02	1
	2 before	2 after	21	21	2.47	0.0817
P	1 before	1 after	21	21	4.14	0.000211**
	1 before	2 before	21	21	2.31	0.126
	1 before	2 after	21	21	4.95	0.00000438**
	1 after	2 before	21	21	-1.83	0.405
	1 after	2 after	21	21	0.816	1
	2 before	2 after	21	21	2.64	0.0491*
R	1 before	1 after	21	21	2.33	0.12
	1 before	2 before	21	21	0.405	1
	1 before	2 after	21	21	1.78	0.447
	1 after	2 before	21	21	-1.92	0.327
	1 after	2 after	21	21	-0.544	1
	2 before	2 after	21	21	1.38	1

Legend: VE represents the volume of raw material used on the line during the shift; VS represents the volume of machined wood during the shift; Ef represents operational efficiency; P represents productivity; R represents the yield in the wood machining process; "1 before" refers to the production line before the layout change; "1 after" refers to the production line after the layout change; "2 before" refers to the production line before the layout change; "2 after" refers to the production line after the layout change; * indicates significance in Dunn's test; ** indicates high significance in Dunn's test.

The productivity results differed significantly according to Dunn's test (Table 3), both between lines 1 before and after the layout change, between line 2 before and after, and between line 1 before and line 2 after. This disparity is evident when comparing the averages, medians, and interquartile ranges, which showed an increase and reduction between intervals, indicating greater uniformity in the production process.

Despite the increases of 9.54%, 6.85%, 3.97%, and 6.97% in the average and median of lines 1 and 2, Dunn's test (Table 3) showed that the layout change had no effect on yield. Since it is a reprocessing of the wood, better operational planning and a study focused on this variable would be useful to understand the effects of different measures on yield.

To analyze the effects of the machine layout change on the variables, the ordinal Eta-squared test was applied (TOMCZAK; TOMCZAK, 2014), assessing the effect of the layout change on the dependent variables (Table 4). The test indicated that the change in machine layout had a moderate effect on the raw material volume and the volume of machined wood. However, for operational efficiency and productivity, the layout change had a higher effect on these variables. For yield, the observed effect was lower (Table 4).

Table 4. Ordinal Eta-squared Test for Effect Evaluation.
Tabela 4. Teste de Eta-quadrado ordinal para avaliação de efeitos.

Variable	n	H^2-Ordinal	C-inf	C-Sup	**Effect**
VE	84	0.074	-0.0095	0.28	Moderate
VS	84	0.1	-0.0018	0.32	Moderate
Ef	84	0.256	0.15	0.46	High
P	84	0.325	0.16	0.53	High
R	84	0.0541	-0.02	0.25	Low

Legend: VE represents the volume of raw material used on the line during the shift; VS represents the volume of machined wood during the shift; Ef represents operational efficiency; P represents productivity; R represents the yield in the wood machining process; H^2-ordinal represents the ordinal Eta-squared from the effect test; n represents the number of samples; C-Inf represents the lower coefficient; C-Sup represents the upper coefficient; Effect refers to the impact of the machine layout change on the variables, according to the ordinal Eta-squared test.

DISCUSSION

Regarding the volume of machined wood, line 1 experienced an increase of 3.3480 $m^3.day^{-1}$, reaching an average value of 24.05 $m^3.day^{-1}$, while line 2 showed a decrease of 1.3 $m^3.day^{-1}$, with an average value of 25.11 $m^3.day^{-1}$. The average operational efficiency was 0.5835 $m^3.op.h^{-1}$ for line 1 and 0.6151 $m^3.op.h^{-1}$ for line 2. The average daily efficiency was 5.057 $m^3.op.day^{-1}$ and 5.3309 $m^3.op.day^{-1}$, higher than the values found by Salvador *et al.* (2020) for the sawing of *Eucalyptus spp.*, which reported an average efficiency of 2.43 $m^3.op.day^{-1}$.

As observed by Nyemba and Mbohwa (2017), there was an improvement in productivity due to the reorganization of machines, demonstrating the effectiveness of this change in improving productivity (Figure 2d). The results differed significantly according to Dunn's test (Table 3), both between lines 1 before and after, line 2 before and after, and between line 1 before and line 2 after. This disparity is evident when comparing the average, medians, and interquartile ranges, which showed a reduction, indicating greater uniformity on the production process.

There was a productivity gain resulting from the layout change, with line 1 reaching an average value of 0.3964 $m^3.op.h^{-1}$ and line 2 reaching 0.4139 $m^3.op.h^{-1}$, demonstrating an increase of 0.131 $m^3.op.h^{-1}$ and 0.0753 $m^3.op.h^{-1}$, respectively.

In a study conducted by Muhdi (2022), comparing two band saw models, productivity values of 0.810 and 0.830 $m^3.h^{-1}$ were achieved, with two operators performing the cutting activities, one at the entry and one at the exit. In a study by Câmpu and Derczeni (2023), productivity of 2.450 $m^3.h^{-1}$ was achieved with two operators using a horizontal band saw with a mobile head.

The average yields for line 1 before and after ranged from 62.30% to 69.15% (Figure 2e), higher than those reported by Anjos and Fonte (2017), who found an average yield of 41.07% to 48.55% for *Eucalyptus grandis*, 36.71% to 49.32% for *E. dunnii*, and 43.87% to 53.55% for *E. saligna*. It is important to note that the cited study deals with yields from sawn wood, whereas the results presented here refer to machining, which may explain the observed differences, given the focus on improving wood quality for the end consumer.

The results indicated that both lines maintained equivalent raw material consumption before and after the layout change, although line 2 initially showed higher consumption than line 1. The volume of machined wood did not vary after the change, but the daily production of line 2 was consistently higher than that of line 1 before the change. There were differences in operational efficiency between the lines before and after the change, indicating an improvement in this variable in both cases. Productivity varied between the lines, reflecting an increase in the volume of machined wood per operator per hour in all comparisons. However, yield was not affected by the layout change, due to the prior condition of the sawn wood, suggesting the need for a more detailed study on the choice of inputs before machining.

Other aspects observed with the change included the reduction of interquartile ranges across all lines in relation to raw material volume, machined volume, operational efficiency, and productivity. Additionally, there was an increase in median values and a reduction in interquartile ranges, suggesting greater production uniformity and a gain in production performance.

CONCLUSIONS

- The change in machine layout resulted in a significant increase in productivity and operational efficiency, as well as an improvement in yield and productivity per operator. The impact was moderate concerning the volume of raw material processed and the amount of machined wood, while the effect on wood yield was smaller but still relevant for process optimization.
- The change in machine layout improved operational efficiency in both lines, although Line 2 did not show a statistically significant difference.
- Productivity saw a substantial increase after the change, indicating higher production with less labor and working time.
- It is important to emphasize the need for a time study related to machine availability and effective working time for a better understanding of the behavior of both variables.
- The interquartile ranges decreased for the variables of raw material volume, sawn wood volume, operational efficiency, and productivity, indicating greater standardization in the production process.

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