PREDICTABILITY IN THE PRODUCTIVE PROCESS OF THINNING AND CLEARCUTTING MECHANIZED OPERATIONS IN *Pinus taeda L.*

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Resumo

Previsibilidade no processo produtivo de operações mecanizadas em desbaste e corte raso de Pinus taeda L. No setor florestal brasileiro, especialmente nas atividades realizadas em povoamentos florestais, algumas organizações não acompanham o ritmo do desenvolvimento e adoção de ferramentas e metodologias de gestão da qualidade, como observado em outros setores. Este trabalho objetivou avaliar o processo de colheita florestal de uma empresa quanto a sua previsibilidade com base nos pontos críticos identificados nas operações de desbaste seletivo e corte raso. Entrevistas e gráfico de Pareto foram utilizados para a identificação e a avaliação de pontos críticos, respectivamente, e para a avaliação do processo foi empregado o Controle Estatístico do Processo (CEP) por atributos e variáveis nas principais falhas. Nas entrevistas realizadas com os colaboradores foram apontados sete pontos críticos. Na avaliação com o gráfico de Pareto, observou-se que cerca de 80% dos problemas identificados na colheita da empresa são atribuídos aos danos às árvores remanescentes, sortimento (medidas de comprimento e diâmetro do produto) e altura de toco. Dentre as possíveis causas para as falhas identificadas estão problemas com treinamento dos funcionários, manutenção do maquinário e planejamento das operações. Na avaliação com o CEP, os gráficos de controle indicaram que o sortimento e a altura de toco, apesar de estarem dentro dos limites especificados pela empresa, foram considerados instáveis e não previsíveis.
Palavras-chave: Colheita florestal; Gráfico de Pareto; Controle estatístico do processo.

Abstract

Some organizations in the Brazilian forestry sector, especially in the activities carried out in forest stands, do not follow the development pace of other industries and the adoption rate of management and quality methodologies and tools. This study aimed to evaluate the predictability of timber harvesting process based on critical points identified in the selective thinning and clear cut operations. Interviews and Pareto chart were used, for the identification and evaluation of the critical points, respectively, and for the evaluation of the process, it was used the Statistical Process Control (SPC) by attributes and variables in the main failures. In the interviews conducted with workers, seven critical points were identified. The evaluation with Pareto chart showed that 80% of the failures identified during harvest are attributed to the damage to the remaining trees, sorting (measures of length and diameter of the product) and stump height. Among the possible causes of the critical points are problems with employees' training, regular maintenance of machinery and operations planning. In the evaluation with the CEP, the control charts indicated that the sorting and stump height, although within the limits specified by the company, was considered unstable and unpredictable.
Keywords: Forest harvest; Pareto Chart; Statistical Process Control.

INTRODUCTION

During the industrial revolution, the need to increase production to meet the demand of a fast-growing population resulted in industries focusing on a faster production. Consequently, consumers began worrying about the quality of the products (TRINDADE *et al.*, 2012).

Along with the increasingly demanding customers, the companies began to strive for excellence in the quality of their products. For this reason, they began to use preventive approaches and searching for tools to identify nonconformities at the established quality standards, allowing making faster decisions in order to prevent flaws on the production line, consequently in the products. However, in the Brazilian forestry sector, some organizations are not keeping pace with the development and the adoption of tools and methodologies for quality management (TRINDADE *et al*., 2012; SOARES *et al.*, 2016).

In Brazil, the first quality control system in the forestry sector was implemented in the early 1980s, being performed on periodical surveys by a special quality team or by senior managers of the company (TRINDADE *et al.*, 1986). This beginning, particularly on forestry and harvesting processes, is a result of a few research proving the viability of the adoption of quality management tools in these activities.

The concern of the forestry companies with the quality of their products can be favorable to the client's satisfaction. However, actions focused only on the quality of the final product contribute little to waste reduction and, consequently, production costs, as it can generate high quality costs when most of the financial resources should be allocated to prevention and monitoring (JACOVINE *et al*., 1999; LEITE *et al.*, 2005). For this reason, the improvement of quality of the productive processes regarding the reduction of waste and costs, besides customer satisfaction becomes increasingly important in competitive environments.

In this regard, one of the operations which contribute most to the increase of costs in timber production is forest harvesting, therefore, the adoption of quality management tools for this activity may contribute to the improvement on the quality of this process, reducing waste and impacts of the operation cost over the price of the timber. This work aimed to evaluate the harvesting process of *Pinus taeda* L regarding its quality prediction based on two critical points found at the company's thinning and clear cutting operations.

MATERIAL AND METHODS

The research was carried out in a forestry company located in the city of Campo Belo do Sul/SC, geographic coordinates 50°45' and 51°05' west longitude and 27°35' and 28°05' south latitude. This primary sector company conducts planting, forest management and sales of logs, particularly from *Pinus* spp, *Eucalyptus* spp, and *Araucaria angustifolia* (Bertol.) Kuntze.

According to Alvares *et al.* (2013), in the Serra Geral region, where the company is located, the altitudes ranges from 800 to 1200 meters, the climate is predominantly Cfb type according to Köppen classification, a humid subtropical mesothermal climate, with mild summers without defined dry seasons, and with occurrence of severe frosts. The average annual temperature ranges from 12 to 16 ºC, and annual rainfall is above 1,500 mm.

Currently, the company develops quality control studies oriented to forest harvesting activities. The present research subsidizes studies carried out by the employees, by identifying the critical points that still need control, aiming to reduce the costs with timber production, improving the relationship with customers. For this reason, the work was carried out in two stages: identification and evaluation of critical points and the assessment of the process.

The company conducted five mechanized and one semi-mechanized harvest. Four of the mechanized harvest were intended to thinning and one for clear cutting. The present study evaluated the critical points of the mechanized third thinning and the mechanized clear cutting. The thinning was composed by cutting (*Harvester)*, extracting (*Forwarder*) and loading (Mechanical Crawler Loader). Regarding clear cutting, the observed activities were logging (directional *Feller*), grand-based extraction (*Skidder*), processing (*Harvester*) and loading (Mechanical Crawler Loader).

In general, for *Pinus spp* stands, the company performs four to six thinnings, according to the need, using the system of short logs. The clear cutting was performed in stands above 25 years using the system of whole trees. The timber produced is used in different segments of forestry sector.

Identification and evaluation of critical points in the process

The identification of critical points or problems observed in the activities of thinning and clear cutting was performed, as a preliminary analysis, with 21 from 53 employees of the company from the harvest activity, covering machinery operators, harvesting leaders, and forest managers and coordinators, who highlighted the main problems faced in operations.

To evaluate these points, a Pareto chart was designed to identify the main failures based on the frequency that they were mentioned in the survey with employees according to the methodology applied by Coletti *et al.* (2010). Then, it was possible to establish an order to deal with the failures, facilitating the establishment of priorities and decision-making (FARIA; SOUZA, 2014).

Process evaluation

The characteristics of the quality in the production process were assessed based on the critical points selected by the frequencies shown at the interviews and the diagram, employing the Statistical Process Control (SPC) for variables and attributes. This tool uses statistics to provide information for more effective diagnosis to prevent and detect failures; consequently, it helps to increase productivity, avoiding waste of raw material (IGNÁCIO, 2010). The statistical control by variables was applied as a function of measurable characteristics of the critical points, using a continuous scale. Based on the data of each critical point, the analysis of the process stability was given by control charts (mean and dispersion), following the methodologies presented by Montgomery (2004).

The graphs consist of a midline - ML (centerline), which represents the average value of the quality variable, corresponding to the situation of the process under control, and a pair of control limits located above (upper control limit - UCL) and below (lower control limit - LCL) the midline, and the distance between them obtained by the average ± 3 standard deviations (HENNING et al., 2014). The calculation of the limits was performed according to the equations proposed by Montgomery (2004). The upper limit of specification - LSE, established by the company, was added to the control charts by average.

According to the methodology used by Soares et al. (2012), the mean values and standard deviation of each sample of the critical points evaluation were inserted in the graphs, respectively, to the control charts of average and dispersion to verifying the studied variables and the process stability. From these values, the existence of points outside the calculated limits were analyzed.

The statistical control by attributes was used for the critical points characterized by discrete variables, i.e., those that could be judged as conforming or nonconforming. A control p-Chart was used to evaluate the probability of nonconformities since the size of the collected samples varied within each established plot. Therefore, it was determined the probability of defects in each sample, represented in the chart by a midline. So, to produce the P-chart, the Midline (LM) and the Upper Control Limit (LSC) were calculated from equations presented by Montgomery (2004). The Lower Control Limit (LCL) was not considered, because the companyaims a no-defect production. In the statistical analysis of the critical points selected for the final stage of the work, the sampling error was determined, considering a permissible error of 10%.

Methodology of data collection of the selected critical points

Considering the results of the prior analysis of the critical points mentioned, the following items were selected as performance indicators along with SPC: damaging to the remaining trees (thinning), assortment (clear cutting), and height of the stump (thinning and clear cutting). The first was evaluated as an attribute and the others as variables using the random sampling method.

To evaluate the damage caused by the thinning activity to the remaining trees, two areas were analyzed after the third thinning. The sampling was carried out in 14 plots with a surface area of 400m² each. The assortment critical point was attributed to the failures found in the logs' dimensions of *Pinus* spp., with knotand the diameter ranging from 18,0 to 24,9 cm, with 1,9 m of length. Figure 1, adapted from Souza et al. (2012), shows the data from length and diameter (large and small), collected daily and non-sequential, with a sample size of 10 out of 15 samples used in the evaluation.

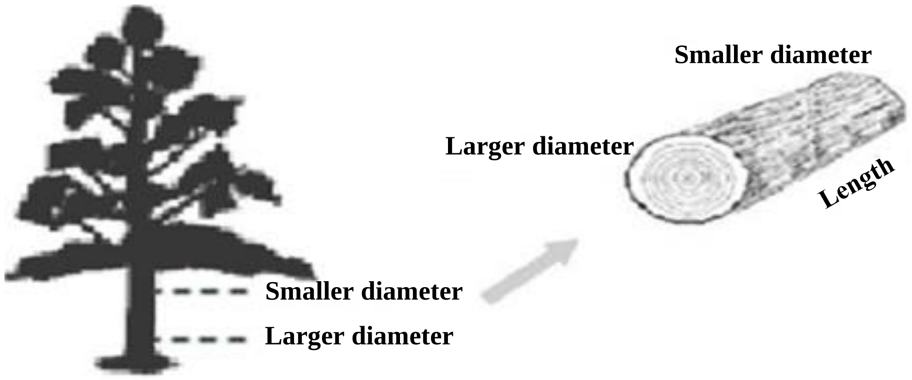


Figura 1. Esquema do processamento da tora.
Figure 1. Scheme of the processing of the log.

The data collection for the variable height of the stump was performed in two fronts of the harvest, at thinning (the third), and at clear cutting, one sample per hectare, totaling 30 samples with size equals 15. The maximum limit for the stump heights varies according to the harvester or feller head used by the team in each front.

RESULTS

Identification and assessment of the process critical points

The critical points most mentioned by the employees were damage to the remaining trees (31.82%), assortment, which covers the length of the log and the diametric classification (25%), and the stump height (20.45%). In addition, dirt in the load (13.64%), node in the 2nd log (4.55%), trees left in the field (2.27%), and safety (2.27%) were mentioned (Figure 1).

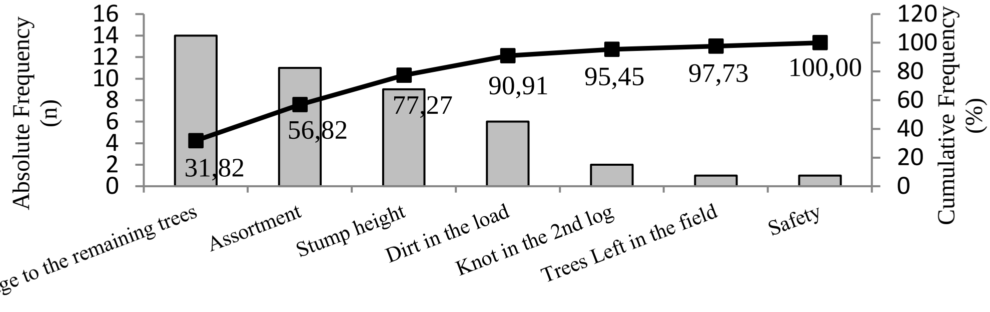


Figura 2. Gráfico de Pareto para os pontos críticos da colheita florestal na empresa avaliada.
Figure 2. Analysis of the critical points by the Pareto chart.

Process assessment

Damage to the remaining trees

In 14 plots sampled, totaling 206 trees, 29 of them were somehow affected by machinery or by trees felled during the operation, i.e., an average of 2.07 damaged trees per plot. The p-chart shows the damage proportion caused to the remaining trees (Figure 2). For this variable, the sampling error was 37%.

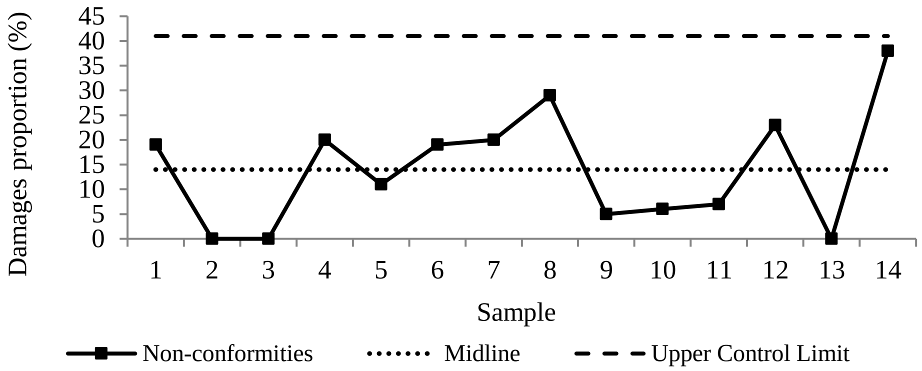


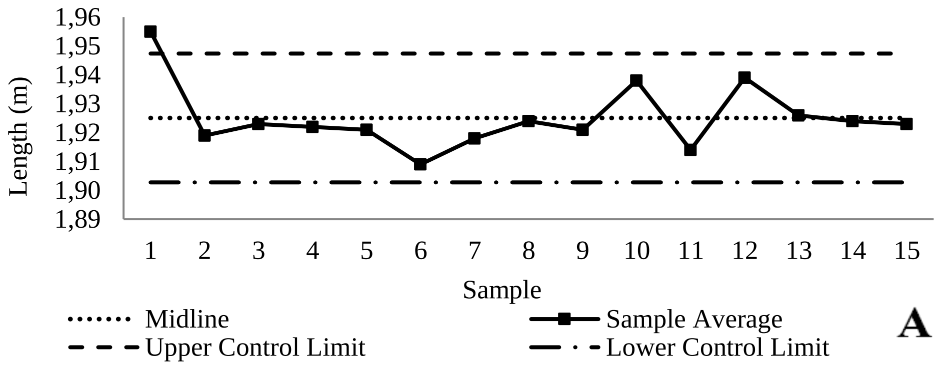
Figura 3. Gráfico-p de controle de danos causados às árvores remanescentes após o 3° desbaste.
Figure 3. P-chart of damage control caused on the remaining trees after the 3rd thinning.

Assortment

The values of the assortment variables were obtained from 15 samples of size 10.

Length

With a sampling error of 0.64%, the average length found was 1.93 m. The control graphs by average and dispersion of the assortment can be observed in Figure 4.



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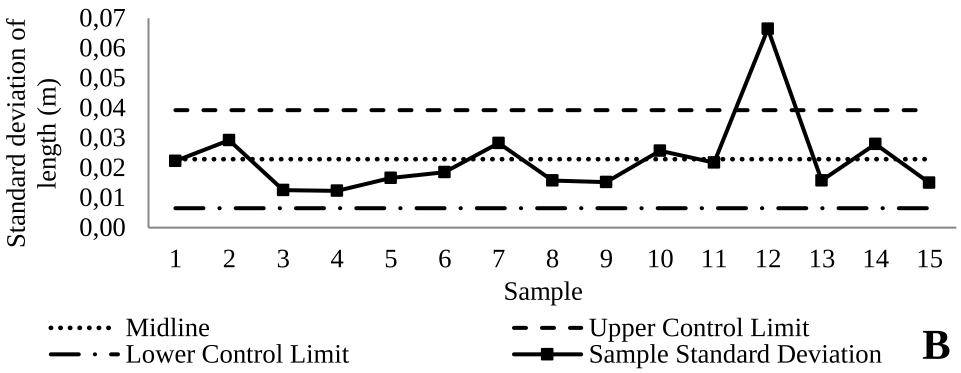


Figura 4. Gráficos de controle por média (A) e por dispersão (B) para comprimento da tora de *Pinus* spp. no sortimento avaliado.
Figure 4. Control charts of the mean (A) and standard deviation (B) for log length of Pinus spp. in evaluated assortment.

Larger diameter

The average diameter found in the assortment was 27.57 cm, with a sampling error of 5.77%; the control graphs by average and dispersion are presented in Figure 5.

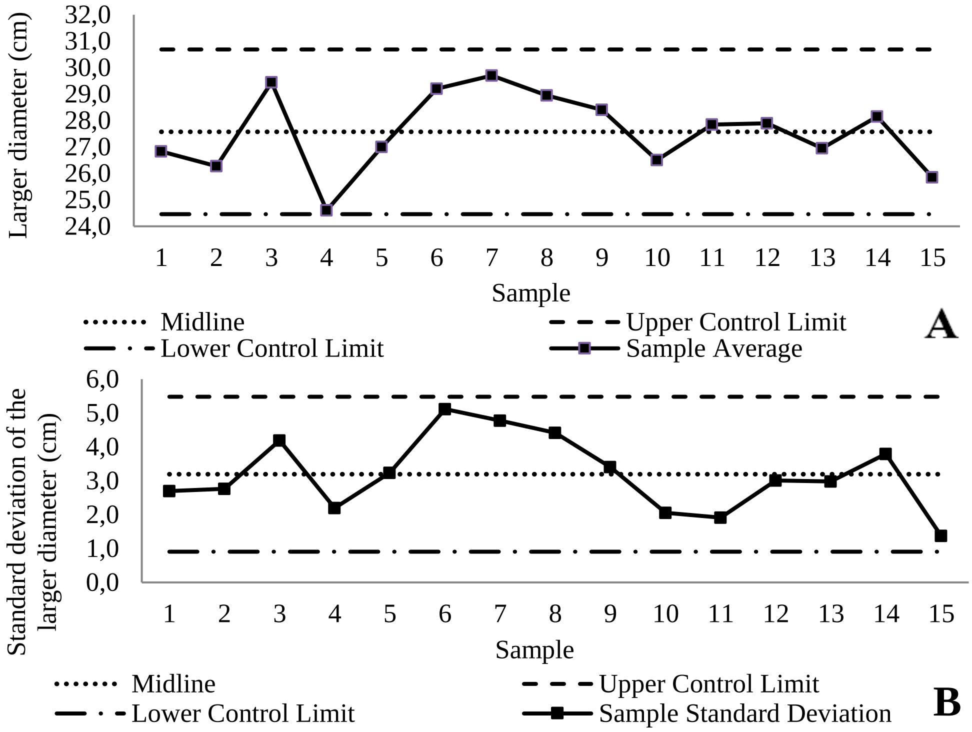


Figura 5. Gráficos de controle por média (A) e por dispersão (B) para diâmetro maior da tora de *Pinus* spp. no sortimento avaliado.
Figure 5. Control graphs of the mean (A) and standard deviation (B) for larger log diameter of *Pinus* spp. in assortment.

Smaller diameter

With a sampling error of 5.2%, the average diameter found was 24.75 cm and a width of 19.00 cm. The control graphs by average and dispersion of the variable for assortment are observed in Figure 6.

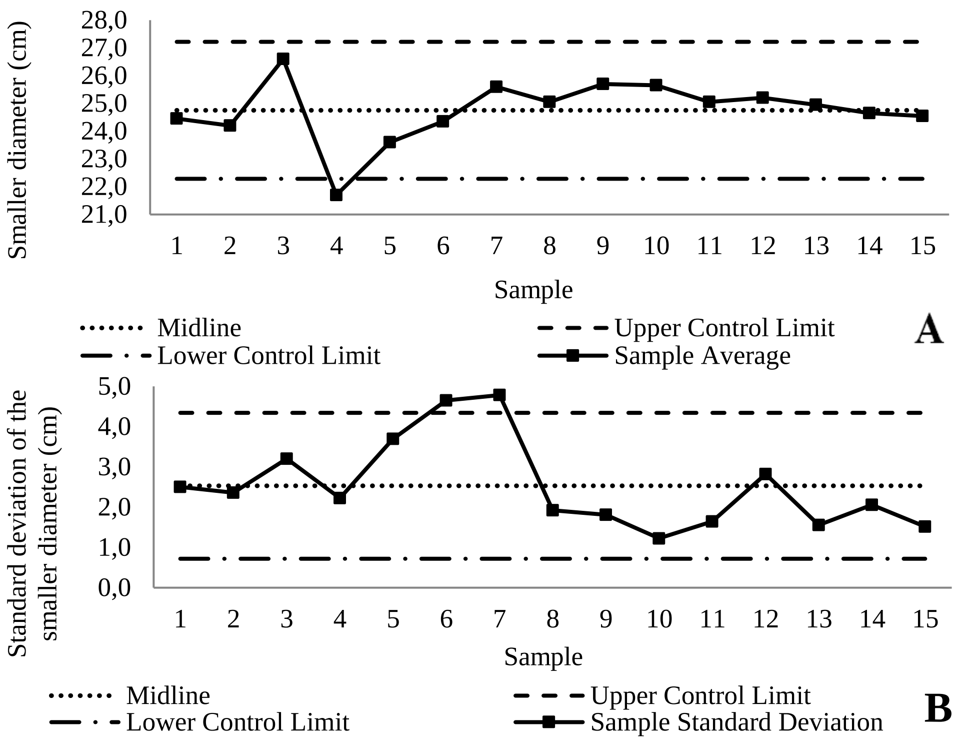


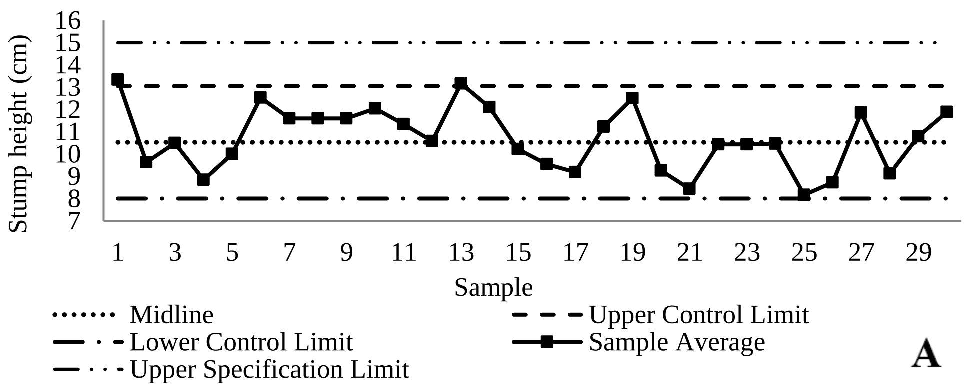
Figura 6. Gráficos de controle por média (A) e por dispersão (B) para diâmetro menor da tora de *Pinus* spp. no sortimento avaliado.
Figure 6. Control charts for the mean (A) and standard deviation (B) for smaller log diameter of *Pinus* spp. in the evaluated assortment.

Stump height

The values of stump height variables were obtained from 30 samples of size 15.

Thinning

To carry out the thinning, it was considered the maximum height of 15 cm specified by the company. The average height found was 10.53 cm (sampling error of 10.42%). The control graphs by average and dispersion for the variable are observed in Figure 7.



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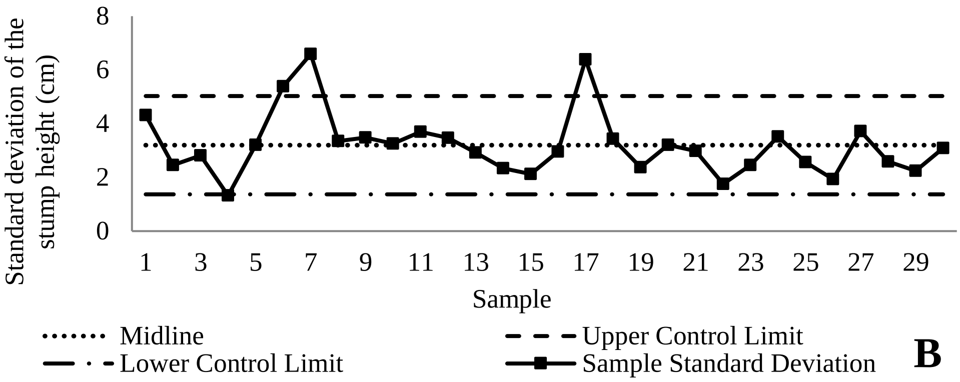

Figura 7. Gráficos de controle por média (A) e por dispersão (B) para altura de toco na frente de desbaste.
Figure 7. Control charts of the mean (A) and standard deviation (B) for the stump height in the thinning team.

Clearcutting

In this activity, the maximum height specified by the company for the team was 22 cm, with a sampling error of 9.94%. The average height found was 10.86 cm, and the amplitude was 22 cm, with values ranging from 3 cm to 25 cm. The control graphs by average and dispersion of the variable are observed in Figure 8.

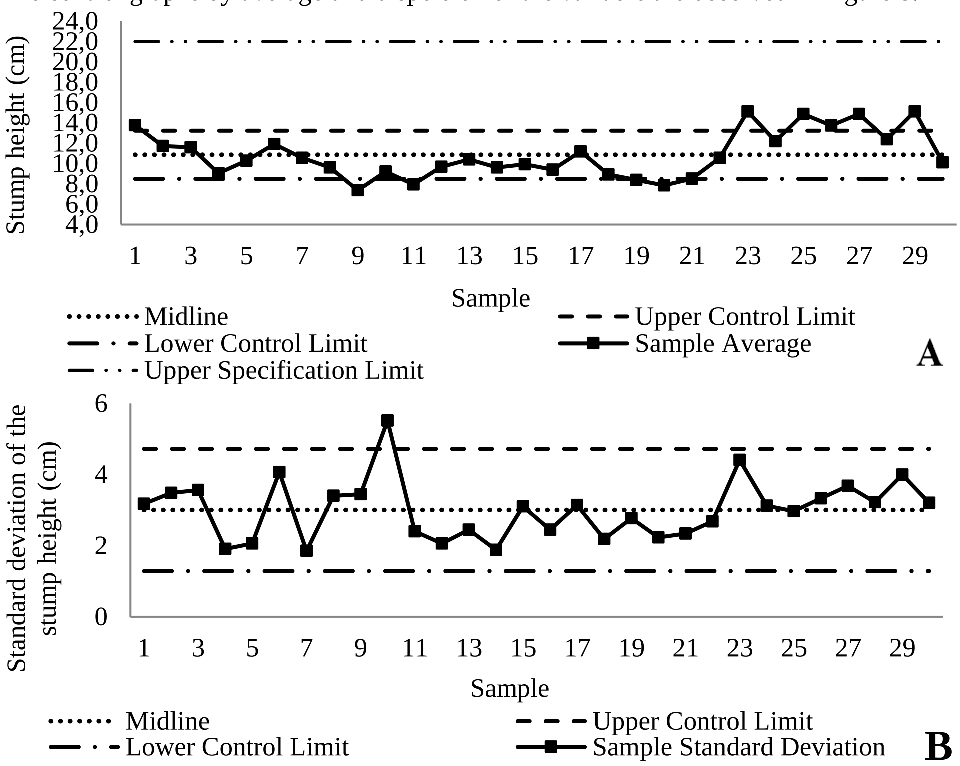

Figura 8. Gráficos de controle por média (A) e por dispersão (B) para altura de toco na frente de corte raso.
Figure 8. Control charts of the mean (A) and standard deviation (B) for the stump height in the clearcut team.

DISCUSSION

Identification and evaluation of the process critical points

According to Vieira (1999), most of the losses found in companies are explained by a few reasons. This way, it was possible to highlight that 80% of the critical points identified at harvest activities (Figure 2) were assigned to three main problems: damage to the remaining trees, assortment, and stump height. Separately, 31.82% of the identified problems can be solved by just decisions about the damage caused in the remaining trees. On the other hand, trees left in the field and security had lower occurrence at the interviews and their solutions means only 2.27% of the company's problems. All the points raised contribute to the reduction in the quality of the production process of the company, causing timber loss.

Process evaluation

Damage to the remaining trees

The p-Graph showed that in spite of the damage caused by the machinery, either moving within the field or during felling trees, none of the samples exceeded the upper limit of 41%, in addition, according to Montgomery (2004) and Oakland (2003), since the points are located between the statistical limits and present no tendencies, the process can be considered under control and predictable. Despite this, the limit is considered high, and due to the wide variation presented, the sampling error was greater than the minimum stipulated. This fact demonstrates the need to elaborate control charts more carefully, especially regarding the number of samples. In addition, these results act as a warning to the company, which must operate in a corrective way, reducing the variation and, consequently, the limit of damage to the remaining trees, wasting less of raw material.

Assortment

The data were collected in log heaps set after processing the trees for security reasons. Therefore, due to the non-real time tracking of the machine's work, it was not possible to attribute the cause for each point outside the control limits. However, according to the interviews, the possible causes for problems in assortments are machinery calibration, staff training and planning the operations.

Length

The graphs revealed that the process has lengths above that determined by the company (1.90 m) to produce the desired product in this assortment, which in this case, was equal to the lower control limit. By evaluating the process by the average, it was observed that it starts out of control, with values above the upper limit, stabilizing in sequence. Despite that, the process is classified as unstable. Rezende *et al*. (2000) concluded the same in the evaluation of the length of logs from a company that uses timber as an energy source, where some points were operating within the standards, and others don't.

The assessment by data dispersion revealed that only sample 12 was out the control limits, showing lengths from 1.89 to 2.12 m, an inadequate log dimension to the product specified by the company. So, actions must be taken to improve the production process to make it predictable, meeting the limits specified by the company.

Larger diameter

The graphics showed that the averages of the process remained within the control limits, including sample 4, which did not reach the lower limit. The analysis of dispersion showed that the process to classify the largest diameter in the assortment is predictable, with greater variation in samples 6 and 15. Although the process is in statistical control, the analysis of the graphs shows that the observed diameters are above the limits determined by the diametric class of the assortment (18.0 and 24.9 cm) This can be explained by lowering the log, from the classes knot free, due to the presence of knots, causing losses.

Smaller diameter

The process remained stable until sample 4 when the average of the process goes below the lower limit. From the sample 5, the process stabilizes with the averages located within the statistical limits. The analysis of the dispersion graph indicates a wide variation in the sample standard deviation with points above the upper limit in samples 6 and 7. So, along with the graph of averages, the method shows itself as unstable/not predictable and presents most of the analyzed diameters within the specified limits for the class.

Stump height

Thinning

The process started out of control, with a sample above the upper control limit, but within the limit specified by the company. The same thing happened with sample 13. The dispersion analysis shows that the process is out of control, in samples 6, 7, and 17 (above the upper limit), and point 4 (below the lower limit).

In the joint evaluation of the graphs, it is possible to state that the stump height process of the thinning team, despite within the company's specifications, is considered unstable by SPC. The possible causes can be a result of residues, plowing of some stumps due to the traffic of machines and inexperienced operators, observed in the area during the collection. However, due to a higher sampling error (10.42%), one suggests attention both in the preparation of control charts, as well as for the variable itself, which highly depends on soil conditions, topography and operators' experience. It is noteworthy that stumps above the limit stipulated represent a loss of wood, usually from the log of greater commercial value.

Clearcutting

The process presented points that pass both control limits, so it is considered unstable. Nevertheless, the observed averages are below the company’s specification limit. Excluding for sample 10, the variation in height, in general, remained between the control limits.

However, in spite of meeting the company's specifications, the heights observed by the SPC are considered unstable/unpredictable. Similarly, in work presented by Rezende *et al*. (2000), the process with operates non-random causes, i.e., can be avoided, because during the process were found samples within the desired patterns showing that others could also fit in standardization.

CONCLUSIONS

- Despite developing systems focused on quality control of the forest harvesting sector, the company has a low-quality harvest, with critical points out of the control standards in its production, i.e., unpredictable.
- The control of damage caused in the remaining trees during thinning is considered a stable and predictable process; however, it is vital to carry out improvements to reduce the costs of the timber loss. To this end, the company can invest in training and improving the planning of operations specifically regarding the disposal of log yards and extraction distance.
- Regarding assortment, the process is considered, in general, unstable and unpredictable, showing special causes of variation. To solve that, the company can also invest in employee training, regularize the maintenance of machinery and improve the organization of heaps in the field.
- Regarding stump height, the process was carried out within the limits of the company; however, it was considered unstable and unpredictable by the SPC. In conclusion, the regular maintenance of the tools and the investment in training and machinery can help the company to reduce the waste of raw material.

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