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PERFORMANCE OF A DOUBLE-GRIP HYPRO 775 MACHINE IN PROCESSING SMALL-SIZED PINE WOOD

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Abstract: *In forest operations, productivity studies represent one of the central topics because their output is frequently used to develop predictive models, to compare alternatives or just to set production rates and to make informed decisions needed to reach a balance between the work effort and payment. Ecuador has started to change its technology in forest operations by a transition towards the increment of mechanization to procure wood from forests planted for timber production purposes. Nevertheless, the change has brought no new research approaches to check the performance of the new machines. A particular case is that of tree processing operations at the landing by means of double-grip processor machines. This study aimed to evaluate the performance of these machines in processing timber from thinning operations and to estimate, by a check study, the sample size needed for a full-scale study. For this reason, a number of 57 processed trees were included in the study and a detailed time-and-motion analysis was implemented to check the variability and central tendency of the data, a fact that also enabled the operational description. Based on the study outcomes, basic statistics were computed to characterize the performance of the operations under the assumptions of a preliminary study, and the number of observations for a full-scale study were estimated. On average, close to 4 logs were recovered from a tree which resulted in an average work cycle time of 45 seconds that was characterized by a succession of very fast events such as gripping, feeding, and cutting. Elemental cuts, for instance, accounted for a number of 228 observed events and they averaged close to 1.5 seconds. The estimation of the sample size based on a confidence threshold of 95% and on an assumed precision of 5% revealed a rather low number of observations (127) needed at the work cycle level. However, factors such as the variability in some work elements, as well as the occurrence of other work tasks on a regular basis should be considered in the attempt to adopt the sample size and to conduct a full-scale study. Until conducting a full-scale study, the results given herein could serve as reference in the performance of tractor-mounted double-grip processors in*

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landing operations.

Key words: *Double-grip, tree processing, statistics, check study, performance, sample size.*

1. Introduction

Planted forests, which are typically established for timber production purposes, represent a common alternative to provide fiber for different kinds of industries. Ecuador is not one of the countries that places high emphasis on timber harvesting activities, since the main focus is on the conservation of resources; however, there are some actions in the country that promote a sustainable commercialization [13]. A typical problem for Ecuadorian forestry is that it is not grounded in detailed information and statistics that reflect the dynamics of the sector and its contribution to the economy. However, the production of wood is at least 70 years old, while the country holds numerous wood species distributed in various native and exotic forest crops. This is due to the geographical location of the country with areas that have up to twelve hours of light a day throughout the year [8]. In December 2000, through the Ministerial Agreement No. 131, the Regulations for Sustainable Forest Management and Wood Harvesting were issued, a document that was restructured in June 2004 through the new Ministerial Agreements No. 037, 038, 039, and 040 [13], as a result of the evident deterioration of natural resources, because of activities such as illegal logging and the increase in agricultural lands. According to the Ministry of the Environment Ecuador [14], the classification of land cover in Ecuador is the following: native forests, forest plantations, agricultural lands, shrub and herbaceous vegetation, bodies of water, anthropic zones, and other lands. This study was conducted in a typical forest plantation established by a company and which spreads on 13,727 ha, out of which the commercial plantation holds 9,421 ha. The forest was established using species from the *Eucalyptus* and *Pinus* genera. Unfortunately, there is no data about the extent of such forests in Ecuador; however, it is appreciated that they could extend on an area of 123,720 ha [14].

Compared to traditional, close-to-nature production forests, planted forests feature a spatial layout and a management type that enable an extended mechanization of the harvesting operations, as well as a substantially increased extraction intensity in the thinning phase, which is typically enabled by a systematic and geometrical operational approach of sequentially extracting a given number of planted rows [19]. This may be done by implementing several harvesting systems, starting with those fully mechanized and ending with those which use manual labor to a greater extent. When operating with small-sized wood such as that coming from the first thinning operations, it is reasonable to think that the efficiency increment of log processing operations can be substantially improved if this operation is moved to landing; at the landing, an increment of efficiency could be sustained by several conditions such as the availability of more space and the presence of flat terrains. At least for motor-manual operations, this is a preferable option [19], and currently tree bucking is done at landing in many European countries [15]. Mechanized processing, in particular, is used in the case of resinous species, both in the forest and at the landing, for which two main constructive types of machines were developed in time: single- and double-grip harvesters [19] and processors. When the full tree method is implemented to harvest wood, which means that trees are felled and extracted to the landing without any additional processing at the felling place [5], tree processing may be done at the landing by the use of either a motor-manual or a mechanized approach [19], and it aims mainly at converting the trees into logs. Mechanized processing at landing may be done using the same types of machines, with the difference that double-grip processors do not typically integrate the equipment needed for felling. Characteristic to the first type of processor is that a given tree is commonly gripped only once at the beginning of a processing work cycle and the processing is run until the tree is converted into logs and harvesting residues (slash) which are placed in different piles. This kind of processor may be integrated in various machines such as tower yarders [7]. The second option is typically using a crane to grip the trees and to feed them into a processor which is mounted on a machine such as a tractor or something similar, where the latter powers the processor. In this configuration, the movement degrees of the processor itself could be less compared to the first option. Nevertheless, the technology has its own benefits among which the crane, which is operated as an independent feature, could be better used for loading and piling tasks.

Double-grip processors have entered in the harvesting operations implemented in the planted forests of Ecuador, probably as an alternative to replace the highly-intensive less performant work, which is common to motor-manual operations [9]. In particular, this option is used in processing full trees extracted from thinning operations implemented in coniferous forests which are typically grown up to an age of 18-20 years, when the main harvest is implemented by clear cuts. In such cases, thinning operations are commonly done twice, at the age of 8 and 12 years, to remove part of the stock by selective thinning (personal communication from Aglomerados Cotopaxi). As this option of mechanized processing is relatively new in Ecuador, no production rates or ergonomic assessments were done to check the performance of such operations, while the extent of forests established for production purposes is becoming significant in Ecuador. In fact, to our knowledge, no timber harvesting production rates, models or statistics are available in Ecuador, maybe due to the fact that this profession is not considered to be among the most important in the country [13], a reason for which data availability is limited. In addition, international studies on the performance of double-grip processors could also be limited since we found a limited number of references on the operational performance of similar machines. A single paper was identified to study the operational performance of single- and double-grip harvesters in a comparative approach [10], but it referred to operations done in the forest and not at landing.

This study is a part of the Ecu4Rate project, which is aimed at developing production rates and ergonomic assessments for timber harvesting operations in Ecuador. This study was preliminary in nature and it was implemented to statistically describe the processing operations done by a double-grip processor with the general aim to estimate the sample size needed for a full-scale study. Therefore, the objectives of this study were to:

i) describe the typical work in processing operations,

ii) produce the initial estimates on time consumption, and

iii) estimate the sample size and find solutions for a full-scale study.

2. Materials and Methods

2.1. Study Location, Harvesting System, and Work Organization

The field phase of this study was carried out in the forests managed by Aglomerados Cotopaxi, which is established in Lasso, Ecuador. The company processes wood from species belonging to the *Pinus* and *Eucalyptus* genera which are regularly planted in and harvested from the company's forest. The forest under study is located at S0° 41.632' - W78° 34.907', 3189 m a.s.l., and it was planted in 2006 using Monterey pine (*Pinus radiata* D. Don); at the field study date the forest was operated by thinning and it was 9 years old. The average breast height diameter was 12 cm and the average height was 12 m. The applied silvicultural system consisted in selective thinning. Trees were felled motor-manually and then they were skidded to the landing by means of an agricultural tractor equipped with a winch. Here, the trees were bunched in piles along a road, then a HYPRO 775 double-grip processor was used to convert them into logs of ca. 2.4 m in length. The processing machine (Figure 1) was manufactured in Sweden and its main technical features are given in Table 1.

Fig. 1. *A snapshot of the HYPRO 775 processor in operations*

Table 1

Main technical features of the HYPRO 775 processor [12]

Feature	Measurement unit	Value	Observations
Weight, including hydraulic oil	kg	1400	-
Width (folded)	m	2	-
Feed speed	m/s	>3.5	
Tilt angle	°	65	
Slew	°	280	
Crane length	m	7	
Diameter range	cm	3-50	min-max
Maximum delimbing diameter	cm	40	

The operator of the processor was accustomed to the machine and type of operation carried out by experience gained in similar operations done for the same company. The processor was powered by a Massey Ferguson 4291 tractor featuring an engine output of 77 kW. Both the processor and the tractor were relatively newly purchased machines. The crane used to load the trees was the product of HYPRO. The degrees of movement freedom of the processor are indicated in Table 1 by the tilt and slew angles.

2.2. Field Data Collection

The operations were surveyed by a field researcher for four full operational days between 9th and 12th of May 2018. The full data collection protocol consisted of mounting four types of data loggers one of which was an external GPS receiver that was set to collect location data at a sampling rate of one second, and the rest of the data loggers were equipped with sensors to measure the sound pressure level, the vibration level, and the heart rate of the operator (sample rate of one second). In addition, an external miniaturized camera was used to document the operations observed on each day. The camera was mounted at a convenient distance with the field of view oriented towards the machine in a way that enabled a full view of the tractor, the processor, the crane movements, and the operator (Figure 2), and the data was collected daily as successive media files having a duration of 20 minutes each. In those cases in which the machine moved between different piles of trees, the field researcher moved the camera accordingly and placed it into a new location. Due to the very fast work sequence on each tree, it was impossible to measure in detail the production output; as such, some features of production were interpreted or extracted in the office phase of the study. Following the field survey, a total number of 71 media files (ca. 24 hours of operation) were collected and stored into a personal computer. Of these, 13 corresponded to the first day, 27 to the second day, 22 to the third day, and 9 to the last day. Video footage was used as primary data for this study.

2.3. Data Processing

This study followed the recommendations of implementing pilot (check) studies which are commonly referred to as those studies aiming to get relevant data about a population under investigation, including here those populations which make the scope of productivity studies in forest operations [4]. Pilot (check) studies are implemented to produce the statistical data needed in the estimation of the sample size for full-scale studies, as well as to provide insight on the way that work is organized [1, 2, 4, 5]. Often, the implementation of verification studies is based on the experience of researchers, even though in the general work science some minimum number of observations is provided for such attempts [11]. Based on the data collected by pilot studies, one can estimate the number of observations required to ensure the statistical accuracy, by using the formulae provided by statistical textbooks; this kind of formulae typically rely on statistical indicators such as the estimated variance and average values of a population [1, 2]. A common formula to estimate the sample size at work cycle level is that used by Murphy [16], and it is based on four variables: Student's t statistic for a given confidence threshold and the assumed precision, as well as the variance and the mean value for a given work cycle time, which are estimated from data collected by pilot studies. This formula was used for the estimation of sample size following the development of relevant statistical indicators.

Another interesting feature of a check study is that the data provided by it may be used to give an overview of the performance of a system taken into analysis, assuming that there would be enough data collected for such an attempt. In this study, video data was used to document the work organization, to produce the data needed to describe it and to estimate the sample size for a full-scale study.

The first three files, covering one hour of observation, were selected from the video data and a detailed elemental analysis was done by replaying them in slow motion, at half of their original speed. A Microsoft Excel database was developed to account for several process and time variables and it served to the introduction of the beginning and ending time of each work element observed in the video footage in the real sequence of occurrence. In the database, the delimitation of work elements and the measurement of time consumption was done to the nearest second. The attributes included in the database were the calendar date, the number of the video file, the number of the tree, the tree diameter at the end (which was visually estimated proportionally to the size of the processor's rollers), the number of logs recovered from each tree, the time of beginning and ending of a given work element (event), the time consumption of each element (by difference), an event code, and comments where necessary. The video analysis and the development of the final database were completed in one day by one skilled researcher; the total number of row entries in the initial database was 734, accounting for a number of 60 trees and 221 processed logs. However, due to some events such as placing the camera or having incomplete tree processing work cycles in a given video file, the initial data was cured by removing these events. This approach resulted in a subset of detailed data covering 719 row entries, accounting for 57 trees and 216 processed logs.

Following an in-depth analysis, some events were reclassified in the final database which was developed at the work cycle level; this final database covered the number of trees and logs as stated above, as well as all the events documented for 3315 seconds. Table 2 gives a short description of the observed events.

Table 2

Events identified in the office phase of the study

Time category	Abbreviation	Comments
Workplace time (s)	*WT*	Sum of all the analyzed time, including delays and excluding undocumented time (i.e., moving and placing camera).
Productive time (s)	*PT*	Sum of all the time in which productive tasks were carried out.
Delays (s)	*DT*	Sum of all the time in which the system was in a state of interruption by personal or technical delays.
Personal delays (s)	*tpd*	Delays caused by personal reasons: talking to a colleague or just not performing work.
Technical delays (s)	*ttd*	Delays caused by the process mechanics (i.e., blade of the saw blocked, or immobilized under or over the processed tree).
Work cycle time (s)	*WCT*	Sum of all the time categories that could be related to the processing of a given tree, computed on a tree-processing basis.
Loading time (s)	*tl*	Time spent to load a tree into the processor. Computed on a tree-processing basis.
Gripping time (s)	*tg*	Time spent to grip a tree by the processor. Computed on a tree-processing basis.
Feeding time (s)	*tf*	Time spent to feed (including delimbing by forward-backward movement) a tree into the knives by the rollers of the processor. Computed on a log-processing basis, then summarized by addition at the work cycle (processed tree) level.
Cutting time (s)	*tc*	Time spent to detach the logs from a tree by sawing. Computed on a log-processing basis, then summarized by addition at the work cycle (processed tree) level.
Releasing time (s)	*tr*	Time spent to release processing slash/tops from the processor.
Other productive tasks (s)	*OPT*	Sum of all the time categories that were productive but not particularly related to a given work cycle. They occurred at different time intervals.
Piling tops (s)	*tpt*	Time spent to pile the tops and processing slash, which occurred for each couple of work cycles.
Piling logs (s)	*tpl*	Time spent to pile the processed logs, which occurred four times during the study.
Arrange tree bunches (s)	*tat*	Time spent to arrange the tree bunches, which occurred once during the study.
Move between piles (s)	*tmp*	Time spent to move between tree bunches, which occurred once during the study.

Sometimes the work cycles may be organized in a hierarchical arrangement [4], which means that some higher-level work cycles may include lower level ones, a behavior that is referred to as imbrication [5]. Following the analysis, it was observed that a higher work cycle level could be that of moving between piles, processing, pilling tops, and piling logs (Table 2). However, movements and piling occurred less frequently and the study was oriented towards the elements of an effective processing work cycle (loading, gripping, feeding, cutting, and releasing) for which all the observed events and their associated time consumption were organized in a final database.

2.4. Data Analysis

Data analysis consisted of simple steps to calculate the main descriptive statistics needed to reach the study objectives. Process variables were the diameter at the tree end (*D*), the number of logs recovered from a tree (*NL*), the number of cuts done on each tree (*NC*), and the number of feedings done for each tree (*NF*). For these variables, the basic descriptive statistics were computed and data was reported in box plot graphs showing the main statistical descriptors. Time consumption on events was documented in more detail by computing the specific shares in a work cycle and in the workplace time. Then, descriptive statistics were computed similarly to process variables. A normality check was run on time consumption mainly to see if the work cycle time (*WCT*) was normally distributed. For this reason, the Shapiro-Wilk test was implemented over all the time consumption variables excluding the delays. Based on these calculations, the performance of operations was estimated in terms of net and gross efficiency (i.e., time with and without delays spent to recover a log). For the last objective of this study, the sample-size formula discussed in Murphy [16] was used to estimate the number of observations for a full-scale study under the assumption of a confidence threshold of 95% and three levels of precision, namely 1, 5, and 10%. While the formula was intended for analysis at the work cycle level, it also enables the estimation of the sample size at elemental level. As such, this approach was used to estimate the sample size at work cycle level, at elemental level, and by considering other tasks showing a highly repetitive occurrence in work. While the typically assumed error is of 5% [2], the approach of computing the sample size for errors of 1 and 10% was taken to check how this parameter would offset the number of observations needed in a full-scale study and how this could be reflected in the available resources. The statistical steps described above were implemented in Microsoft Excel which was fitted with the Real Statistics freely available add-in [21].

3. Results and Discussion

3.1. Descriptive Statistics and Performance

Figure 2 shows the main descriptive statistics of the process. While those related to the diameter should be interpreted with caution due to the way this variable was estimated, the rest show a relative homogeneous distribution which averaged 4 logs, cuts, and feeds per processed tree.

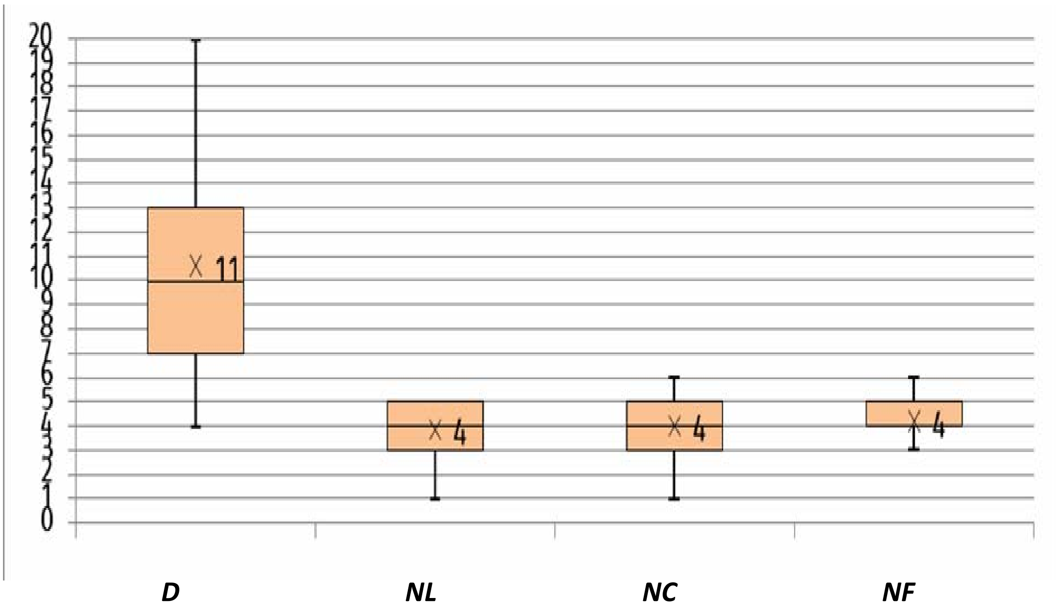

Fig. 2. *Main descriptive statistics of process variables*

In general, the number of logs was related to the number of cuts and feeds (including delimbing), by linear significant functions (results not included here). In what regards the utilization rate of the machine, these preliminary results indicate a number close to 90% (productive time, Table 3).

Total time and time share on events Table 3

Time Category	Abbreviation	# of events in study	Sum	Share (%)
Workplace time (s)	*WT*	-	3315	100.00
Productive time (s)	*PT*	-	2974	89.71
Delays (s)	*DT*	-	341	10.29
Personal delays (s)	*tpd*	-	49	14.37*
Technical delays (s)	*ttd*	-	292	85.63*
Work cycle time (s)	*WCT*	57	2553	100.00
Loading time (s)	*tl*	-	873	34.20**
Gripping time (s)	*tg*	-	196	7.68**
Feeding time (s)	*tf*	-	958	37.52**
Cutting time (s)	*tc*	-	351	13.75**
Releasing time (s)	*tr*	-	175	6.85**
Other productive tasks (s)	*OPT*		421	100.00
Piling tops (s)	*tpt*	22	238	56.53***
Piling logs (s)	*tpl*	4	111	26.37***
Arrange tree bunches (s)	*tat*	1	25	5.94***
Move between piles (s)	*tmp*	1	47	11.16***

Note: *Share in workplace time, **Share in work cycle time, ***Share in other productive tasks

In the delay time category, technical delays were dominant (86%) and they were related to the process mechanics because all the cases consisted of saw blocking in, under or over the processed tree which, in addition to the time consumed in these events, required regripping time that was also included in this category. A work cycle was defined around loading, gripping, and feeding a log, along with the time needed to remove the processing slash from the processor. Feeding and loading time were dominant in a work cycle, with shares of 37 and 34%, respectively.

At this point, a comparison to similar machines was difficult to make. However, feeding (delimbing) time is commonly among the greatest contributors to the mechanized tree processing operations. It accounted for almost 38% in this study, and its share in given operations could be affected by the characteristics of the trees; if no largely developed branches are to be removed, then it could be reduced substantially and it was also observed in this study that some cases required only feeding to cut, while other cases required feeding to delimb and cut. For comparison, Borz et al. (2014) observed processing operations done at landing by a single-grip processor. They found a share of delimbing time which accounted for approximately 10% of the wood processing time in the case of spruce trees. The study of Nakagawa et al. (2010) outputted a figure of 11% for tree processing at landing using single-grip processors.

Cutting time accounted for approximately 14% (351 seconds) and it corresponded to a number of 228 sawing events (results not shown herein); as such, a cutting event took, on average, close to 1.5 seconds. It is worth mentioning that cross-cutting events were measured from the exit to the return of the sawing blade to its initial position, therefore cutting included blade returning from the cut. At an elemental level, most of the events were very fast, such as the gripping (*tg*), feeding (*tf*), cutting (*tc*), and releasing (*tr*) time, a fact that was reflected also at the work cycle level, in the time cumulated on elements for each processed tree (Figure 3). As such, a work cycle time averaged close to 45 seconds, but it varied between 20 and close to 80 seconds (outliers not included in Figure 4). The main contributors to that were the loading and feeding time which averaged 15 and 17 seconds, respectively. Cutting time per tree averaged 6 seconds while the gripping and releasing averaged much less time (3 seconds). By the approach of the study, the measurement was done to the nearest second. However, a wider variation in some elements was observed, even if just informally, such as the cutting, gripping, and releasing time; therefore, the real variation of these categories was somehow affected by the study approach. Mechanized cutting, on the other hand, is known to output an excellent performance which is typically characterized by a small amount of time needed to perform the cuts. For instance, Apăfăian et al. (2017) found that cuts done by a single-grip harvester to fell and buck the trees require a small amount of time, which is in the range of 2-3 seconds. In their study, tree delimbing accounted for more than 40% of the cycle time. A recent study by Prinz et al. (2020) has shown that effective cutting may take as little time as milliseconds, depending on the diameter at which the cuts are performed. For diameters of approximately 10 cm, the effective duration of cross-cutting reached up to 50 milliseconds, and it increased by a cubic law depending on the diameter. In their study, diameters of up to 70 cm required an effective cutting time shorter than 300 milliseconds. Some of such crosscutting mechanical behaviors could be true also for this study, if the effective cutting had been measured instead of all the actions needed to cut, including guiding bar retreating after cutting. Nevertheless, the shortest time measurement unit used in productivity studies is typically the second [2], [11], therefore the effect of the potential cutting variation on the work cycle time consumption variation was assumed to be minor.

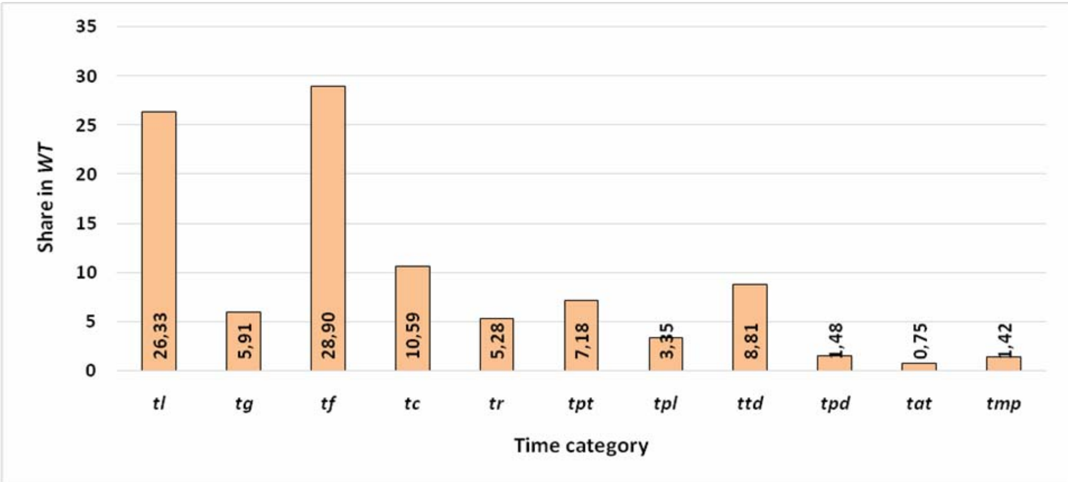

Fig. 3. *Share of events in the workplace time*

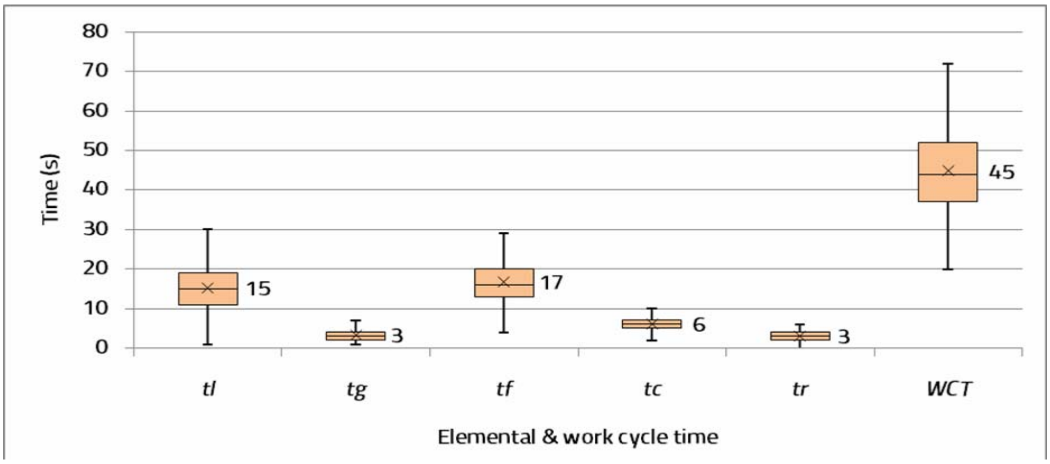

Fig. 4. *Descriptive statistics of the elemental and work cycle time consumption*

Other productive tasks such as piling tops, logs, arranging log bunches, and moving between bunches of logs accounted for 421 seconds, which was 14% of the productive time. Figure 3 shows a detailed analysis of the share of the recorded events in the workplace time. While the shares of work elements were kept proportional, other categories of productive time such as those mentioned above may occur on a regular basis and they could count for a scaled-up study. Piling tops (processing residues), for instance, accounted for ca. 7% and it occurred on a regular basis. Worthy of mentioning are also the categories of piling logs, trees, and moving between tree bunches, which are supposed to occur on a regular basis. Normality assumptions were valid for the work cycle time (*WCT*), the cutting time (*tc*), and the log piling time (*tpl*). The main descriptive statistics of the most repetitive work elements which were included in a typical work cycle are given in Figure 4.

Estimates on the productivity and efficiency are difficult to make given the fact that a precise measurement of the processed trees and logs size was impossible; nevertheless, some figures could be given based on the number of processed logs, which could be a suitable production accounting unit based on the assumption of a small variation in their size. As such, a total number of 219 logs were processed resulting in a gross efficiency of ca. 15 seconds (0.004 h) per log. Given the small proportion of delays, the results on net efficiency (ca. 14 seconds per log) did not change dramatically. However, these are only preliminary results. Therefore, the production rate was estimated at approximately 238 logs per hour or approximately 69 trees processed per hour. Another behavior is that in mechanized processing the productivity increases as a function of the tree size up to a point where machines struggle because they reach their capability limits and the productivity starts to decline [22]. Such behaviors were observed in this study in relation to the size, shape, and richness of a tree’s limb. For instance, larger and curved trees showing a difficult pruning condition required more processing work to feed and delimb them.

3.3. Sample Size

Sample size estimation for full-scale studies is important in the attempt of balancing the accuracy and the use of study resources. This is particularly important for analytical approaches such as the one used in this study, which may be resource intensive. The results shown in Table 4 for a confidence level of 95% (Student’s t = 3.842) and three levels of precision indicate a high heterogeneity.

Table 4

Results of the sample size estimation

Time Category	**Abbreviation**	**Sample size based on assumed errors**		
		E=1	**E=5**	**E=10**
Work cycle time	*WCT*	3,163	**127**	32
Loading time	*tl*	11,021	**441**	110
Gripping time	*tg*	18,802	**752**	188
Feeding time	*tf*	6,589	**264**	66
Cutting time	*tc*	4,588	**184**	46
Releasing time	*tr*	21,939	**878**	219
Piling tops	*tpt*	24,614	***985***	246
Piling logs	*tpl*	5,401	***216***	54

For an assumed precision of 5%, and judging at the work cycle level, the number of observations required was reasonable (127). Nevertheless, loading, gripping, and particularly releasing time have shown a greater variability of data and they have failed the normality test. Therefore, such data behaviors could be taken into analysis when setting the number of observations. In addition, other events such as piling tops were characterized by a high variance, resulting in a number close to 1000 observations needed if such elements are to be accounted, for instance, as separate work cycles. Other events such as moving between tree bunches provided insufficient data for an estimation of sample size assuming that they were independent work cycles. However, the distance could also vary largely, depending on the availability and spatial distribution of wood bunches at the roadside. Therefore, the effort of sampling could be substantial. For instance, one could spend a lot of time to get enough data for events such as piling tops, logs, and movements between the log bunches to be able to correctly define and sample a higher-level work cycle to serve for sample size estimation under this assumption. In this study, which covered one hour of field observation, log piling occurred four times, which means that it was repeated for each 14 processing work cycles, while piling tops occurred 23 times, meaning that it appeared for each 2.5 processing work cycles. Keeping the proportions, for 10 hours of study one will probably find 40 log piling events and 230 top pilling events which will probably provide some new insight on the sample size. However, by keeping the same proportions for the resources spent in data analysis, then one would have to spend 10 days on this task to resize the sample. This is because data analysis by video interpretation in an office depends largely on the analyzed process, its complexity, and the complexity of the study design [6, 17], while the process analyzed in this study was quite complex. In addition, some of the observed events may depend to a greater extent on the amount of processed wood, while some could be related also to the work habit of the operator.

The scenario of using 1% precision resulted in numbers which are out of reach in practical applications of time study, at least by the methods described herein. For instance, for the same confidence level, a precision of 1% resulted in more than 3000 observations needed at the work cycle level. These would require approximately 40 hours of filed observation and an unreasonable number of 40 days of continuous office analysis. A lower level of precision (i.e., 10%) led naturally to significantly lower effort needed for collecting data in a full-scale study. Similar to the above-mentioned, the highest amount of data was that needed under the assumption of having the top piling events as independent work cycles, a fact that led to a number close to 250 observations. Therefore, for a precision of 10%, the results of this study could be valid at work cycle level.

4. Conclusions

Considering the conditions surveyed in this study, approaching a full-scale study at elemental level could be quite demanding for the office analysis of the data and probably impossible to implement in the field using traditional pen-and-paper approaches. The available options to tackle this situation may consist of dropping the elemental time study and just recording the work cycle time, as defined in this study, a case that even though would facilitate the collection of cycle time data, it would not enable a process analysis at elemental level, neither would it enable an accurate exclusion of potential mechanical delays by assuming the same, pen-and-paper approach. However, if the approach will be based on video recording, then this option could run much faster in the office phase and it could need more substantial data analysis to control the variability of data coming from other, less frequent events. Another option would be that of merging the gripping, feeding, cutting, and releasing events in a single work element called processing, while the rest of the events such as the loading, piling, and moving could be treated independently as the other work elements of a higher-level work cycle. This, however, could shift the focus from the processed tree to the processed bunch(es) of trees. To conclude, more data needs to be analyzed to be able to reach the best approach. Most probably, new analyses need to be run on a much higher number of events, such as piling tops to be able to cover the variability of these kinds of events.

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