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Learn by doing: Modelling the effect of training and job interruptions on tree cutting time for chainsaw operators in plantation forests, Tanzania

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Abstract

Timber harvesting in Tanzania uses semi-mechanized and labour – intensive logging systems. Manual or semi-mechanized logging operations by using hand tools are more favoured due to cheap labour availability. For example, tree cutting is done manually using two-man crosscut saws, axes or chainsaws. This study was conducted at Sokoine University of Agriculture Training Forest to assess the effect of training and job interruptions for chainsaw operators during tree cutting operations in softwood plantation forests in Tanzania. Tree cutting operations using experienced and inexperienced chainsaw operators were studied in three experiments; before training, after training and after the break. Time study and work sampling techniques were used for data collection. Descriptive statistics and modeling was performed for each crews' performance. Results show that generally, experienced crew spends lesser time in cutting as compared to inexperienced crews. However, start up chainsaw crew spent 32% higher time for preparation before tree felling. However, the crew showed significant improvement after training unlike the experienced one. The analysis of the delay times start up crew was had a significant proportion of the delay times during the first engagement which decreased substantially in the other two experiments. Generally, there was an improvement of the cutting time after training for all crew categories with decrease after the break. This observation signifies that job interruptions impact the productivity of the crews. Therefore, on job training on resumption of the operations may significantly improve crews' productivity, safety as well as ensuring product quality.

Key words: Tree cutting, training, chainsaws, time studies, Tanzania

INTRODUCTION

Timber harvesting in plantation forests started in early 1970's whereby designated government department did logging and forest roads management (Ahlback, 1986). Till early 1980's harvesting was mostly derived by volume with no apparent regard for efficiency and good working conditions of the crews. Beginning 1985 the country's macro-economic policies changed towards a market economy where wood industries were also privatized with the aim of bringing higher operations efficiency in production and lower costs (Ngaga et al., 1998). However, when private companies took over, they adopted some methods, equipment and logging techniques of the public regimes. This means they might have automatically retained the advantages and problems associated with that regime. Today, timber harvesting still uses semi-mechanized and labour- intensive logging systems. "Manual or semi-mechanised logging operations by using hand tools are more favored due to cheap labour availability" (Fue et al., 1999, Silayo, 2004). Tree cutting is done manually using two-man crosscut saw, axes or chainsaws both in natural and plantation forests

To date, logging crews in many plantation forests are recruited locally without apparent consideration of their knowledge and skills for these activities. The impact of engaging crews who have not received prior professional and technical skills have found to have some impacts on productivity in many parts of the world (Garland, 1989; Kirk et al., 1997). It is however known that logging productivity is affected by many factors that are interrelated, and one or more may be independent of the other (Silayo et al., 2007; Mauya et al. 2011). For example, all the environmental, social, political, labour (worker), economic factors as well as the applied system influence logging productivity. Improving technology (mechanization and planning) of harvesting in many parts of the world is expected to lower the risks associated by these factors. Unlike in developed countries where mechanization in timber harvesting is applied, traditional methods (basic technologies) are still being used in developing countries (Anton, 2000) including Tanzania, which in most cases give low productivity. Labour quality also plays a significant role in ensuring improved productivity in forestry.

However, although investors in forestry industry recognize the importance of engaging professional staff for optimizing operations, they have made use of policy vacuums and availability of cheap labour to engage less and ill-skilled personnel in harvesting operations. This is due to the fact that about 75% of the Tanzanian population lives in rural areas (Kallonga et al., 2003) where most of them survive with low income under poor social infrastructures (URT, 2005; Silayo et al., 2010). Since most forests border these populations, workers with little knowledge of forest work can often be engaged at low wage rates. This implies that timber harvesting crews are given in-service training and thus most learning takes place on site. Garland (1989) pointed out that in areas where no formal training is provided, workers learn through trial and error. Such learning may take a substantial number of labour-hours to produce 'N' units in a production run. The slower the rate of learning, the greater the cost to the employer, as optimal production levels are not being attained (Kirk et al., 1997). New machine operators may increase costs of equipment maintenance for example as they may misuse them while increasing environmental hazards as well as threatening their own safety.

Therefore, logging crews' performance needs to be studied over time as they perform operations and their learning curve determined to enable the logging firms better calculate wood flows and include it as an important variable during operations planning (Stirling, 1990). If optimum production levels of crews are known employers may use this knowledge to improve payment schemes, working and living conditions of the labourers. Currently a huge number of poorly paid employees produce substantial amounts which could be produced by a smaller number of qualified and trained workers. Qualified crews produce high quality products and the chances of adhering to safety regulations are higher. Therefore using skilled labour may reduce the rates of occupational accidents. Education of the employee also implies an increased investment in the work force; more capital becomes tied up in the workers which, in turn, influence productivity (Yelle, (1979; Ottaviani and Tabolt, 2014). Past experience indicates that individuals learn by experience and their performance gets better and better at the job by carrying out the tasks more and more (Wright, 1936; Alchian, 1963; Rapping, 1965). As for other industries, learn by doing is vital for increased productivity and reduced safety hazards during forest harvesting. This study was therefore carried out to analyse the time consumed by chainsaw operators during tree cutting operations based on the theories of 'learn by doing'.

MATERIALS AND METHODS

Description of the study area

This study was carried out at the Sokoine University of Agriculture Training Forest, (SUATF) Olmotonyi, in Arusha region, Tanzania (Figure 1). The forest lies between latitudes 3' 15º – 3' 18º South and longitudes 36' 41º – 36' 42º East. It is bordered by Meru forest plantations to the East and West while Arusha catchment forests borders to the North with Timbolo and Shiboro villages to the South. SUATF was formally part of Meru forest project under the Ministry of Natural Resources and Tourism until 1978 when it was transferred to the University of Dar es Salaam for the purpose of research, training and production.

The forest covers about 840 hectares of natural and plantation (SUA, 1991). Currently about 80% of the forest area is covered by plantation forests of softwood and hardwood species while the rest is a natural forest. The main tree species grown include Cupressus lusitanica, Pinus patula, Eucalyptus sp., Grevillea robusta and Acacia sp. SUATF is on the slopes of Mount Meru, at between 1740 to 2320 m above sea level (Shemwetta et al., 2002; Abeli et al., 2003). The seasonal climate includes a consistently dry period between June and October. Rainfall patterns vary considerably, but average annual precipitation is about 1200 mm. The mean annual temperatures range between 18°C in the morning to 23°C in the afternoon (SUA, 1991).

During this study, logging was carried out using common tools used in other forest plantations in Tanzania. Tree cutting was done using chainsaws and two man crosscut saws. Skidding was done manually, by semi-mechanised methods using farm tractors fitted with 2-4 drum skidding winched as well as by using oxen while hauling was performed using farm tractors fitted with trailers.

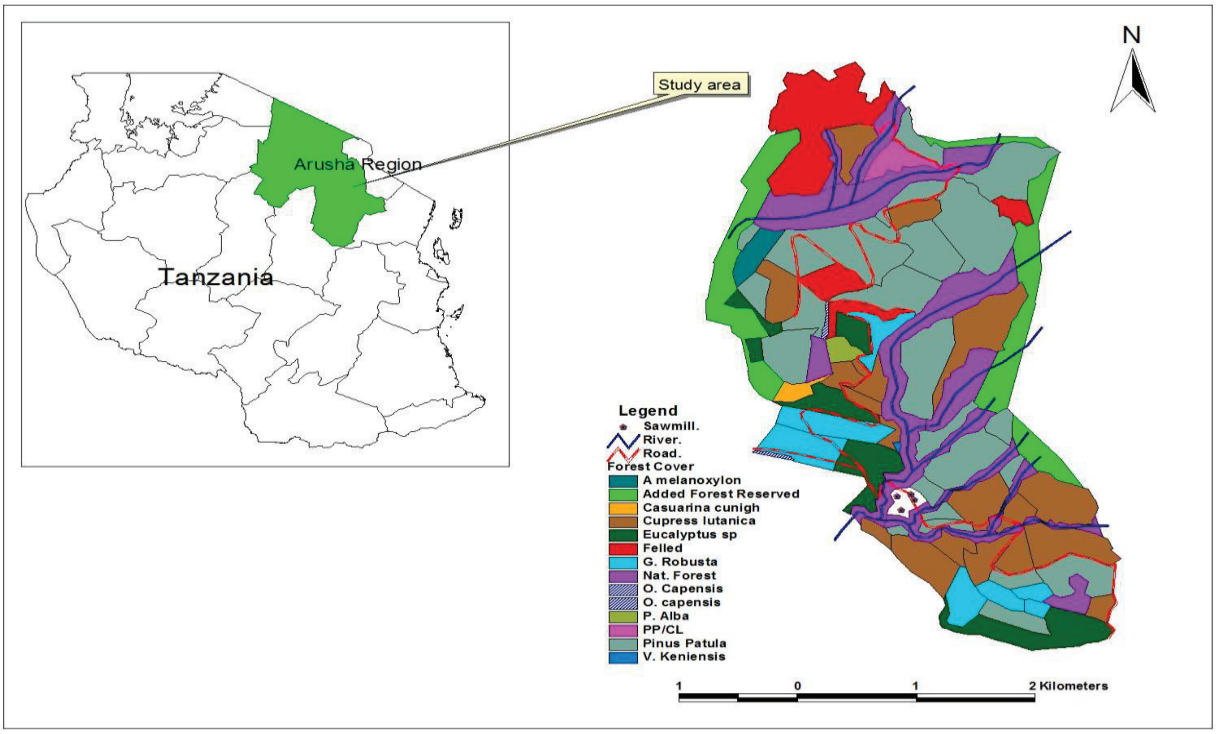

Figure 1: Location and map of the study area showing different forest cover types

Experimental design

The study was conducted on chainsaw tree cutting operations. The chainsaw operators were divided into two groups. The first consisted of newly recruited (start-up operator) which was engaged during the study and the second group consisted of experienced operator(crews with experience in tree cutting). Each operator was first studied in situ for up to three months, after which they were trained and studied again; and then left to rest for the same period before being studied again. This arrangement aimed at assessing the impact of production breaks on learning and forgetting behaviour of the crews. This was based on the fact that experience accumulates as more hours are spent with the new skill with the output increased by learning and decreased by forgetting (Argote, 1996; Morrison, 2005).

During breaks operators were assigned other activities by management to avoid possibilities of being involved in the same activities in the same forest or elsewhere to avoid uncontrolled variability. The break was scheduled for three months based on the experience that logging operations stop during rain seasons in many areas in the country. Rain seasons are assumed to be on a span of three to four months. Therefore, a conservative decision was made to be three months with expected that they would be enough to assess the job interruption that results from labour movements across sectors and especially between forest and agricultural sectors. Tree cutting was done using well maintained chainsaws, as they are the main tools used for timber harvesting in both natural and plantation forests in Tanzania.

Start-up crew

This category was made up of individual/operator without prior experience in tree cutting operations. The operator was a man aged 29 years old. He had occasionally been involved in different forest related activities including carrying out forest inventory, log skidding and log loading as a casual labourer for over four years.

Experienced crew

The operator in this category comprised individuals who had previously been involved in tree cutting operations using the same tools for at least one year. A motor-manual chainsaw operator who had worked for over 8 years in the same forest as an operator was involved. Prior to his current assignment he had been involved in different activities including work at the tree nursery, log skidding and loading. The crew (31 years old) revealed that he did not receive any formal training on either logging operations or chainsaw tree cutting operations. He learned the operation of the chainsaw from a retired operator while assisting him in tree cutting for about two months in thinning operations which are considered less intensive.

Training plan

Taylor (1903 as cited by Edwin, 1982) argued that "employees should not learn their skills haphazardly from more experienced workers, who may not be using the "one best way," but from management experts who are thoroughly familiar with the job". The training programme focused on hands-on skills based on the recommended tree cutting practices such as directional felling, proper limbing and bucking practices, appropriate ergonomic postures during tree cutting, proper use and maintenance of cutting tools and chainsaws. Accident prevention and safety precautions were also emphasized to reduce workplace accidents and risk hazards. The methods for safety and health training ranged from passive, information based techniques (e.g., lectures) to learner-centred performance-based techniques (e.g., hands on demonstrations), hypothesising that greater knowledge acquisition and more transfer of training to work setting will occur (thereby improving behaviours safety performance and reducing negative safety and health outcomes). This was due to the fact that there is ample evidence in the training literature that active approaches to learning are superior to less active approaches (Frese and Zapf, 1994). Training was performed in the field.

Training incorporated specific group requirements. Points to be emphasized depended on the group. Training venue (field) and timing were selected to offer the best options for the intended training and convenience to participants/crews. Swahili language was used for training the crews. After the training sessions, field work and work studies were then performed concurrently.

Data collection

Time studies on tree cutting operations were performed on clear felling operations. Snap-back (zero-reset) time study methods were used to collect data on productive and delay times. Selected independent variables that might affect tree cutting productivity and costs and workers' learning rates were measured and recorded concurrently during the time studies. The selected variables measured and recorded were; stump diameter, diameter at breast height (overback), in centimetres, tree height, in meters, number of logs bucked, log lengths, centimetres, number of trees cut per day, and terrain slope in percentages.

Data analysis

Descriptive statistical analysis, regression analysis and economic (costs) analyses were performed. Descriptive statistics and regression models were developed to establish relationships between dependent and independent variables using MINITAB 15 Computer Software. The dependent variables were time for; felling (TFell), limbing (TLimb), measuring (TMeas), bucking (TBuck) and the total cutting (TCut) time (excluding delays) all recorded in minutes. The independent variables were; stump diameter (over-bark), (SDia in cm), stump basal area (over-bark) (SBA in cm^2), diameter at breast height (over-bark) (Dbh in cm), total tree height (THgt in m), number of logs cut from an individual tree (NLogs), total log length (TLogL in m), log volume (over-bark) (LVol in m^3), total log volume (over-bark), (TLvol in m^3), total tree volume (over-bark) (TTvol in m^3), necessary delay (ND) and unnecessary delay (UND) all recorded in minutes.

Delay time analysis

Delay times are times that are not related to effective working time. The delays were categorized as being necessary (or technical) and unnecessary (being personnel and or operational). The analysis of the delay times was based on the total observation of the individual element that contributes to such a delay. For example, instead of measuring the time used for moving separate from brushing, all these were recorded and analyzed under 'preparation' time component. The preparation time which forms part of the necessary delay (Harstela, 1993) has been analyzed separate in this study as it constitutes a reasonable portion of the necessary delay time and was easy to be recorded in the field.

Descriptive time study statistics

Descriptive statistics were performed based on crew category (start up and experienced) and the experimental phase which included a study before training, after training and after the break. This section presents and discusses summary statistics for the dependent and independent variables.

RESULTS AND DISCUSSION

Tree felling time element

Table 1 summarizes statistics of the felling sub-operation for both chainsaw operator categories. Results indicate that the average preparation time per tree of an inexperienced chainsaw operator was 32% higher than for the experienced one. Preparation time was that proportion used by the crew in clearing around the tree, positioning and the overall decision of the direction of fall. The average felling time per tree was higher for the inexperienced crew by 2% as compared to experienced crew. This indicates a relatively faster cutting rate for inexperienced operator. When t-test was performed to check for similarities on the three independent variables (Dbh, SDia and SBA) across experiments it was found that they don't differ significantly as p-values were below the 0.05 threshold level. This is probably due to the fact that the crews worked in the same even aged stand.

Table 1: Summary statistics for the tree felling sub operation for the three experiments

Crew category	**Variable**	**Before training**				**After training**				**After break**			
Experienced crew		**Mean**	**Std**	**Min.**	**Max.**	**Mean**	**Std**	**Min.**	**Max.**	**Mean**	**Std**	**Min.**	**Max.**
	TFell	0.87*	0.51	0.08	2.7	0.87	0.64	0.08	4.0	0.68*	0.39	0.08	2.25
	ND	0.50	1.51	0.00	12	0.52	1.64	0.00	2.7	0.04*	1.27	0.00	12.6
	UND	0.13	0.62	0.00	4.07	0.21	0.03	0.00	3.33	0.28*	0.66	0.00	6.87
	Dbh	32.89	9.31	9.00	58	32.52	9.16	10.0	58	33.8	10.0	9.0	65
	SDia	35.1	9.64	14.00	64	34.5	9.5	14	64	36.1	10.4	14	70
	SBA	0.13	0.07	0.19	0.49	0.13	0.07	0.02	0.41	0.14	0.08	0.02	0.5
Start up crew	TFell	0.85*	0.56	0.08	4.10	0.54*	0.81	0.08	4.0	0.83	0.49	0.08	2.8
	ND	1.09*	3.99	0.00	58.1	0.62*	0.28	0.16	1.50	0.45	1.35	0.0	12.3
	UND	0.30	0.92	0.00	12.16	0.05	0.25	0.00	3.66	0.25*	0.58	0.0	4.1
	Dbh	33.24	8.89	9.00	56.0	33.56	8.09	15	54	32.4	9.2	9.0	58
	SDia	35.82	9.10	14.0	60	35.83	7.82	17	58	34.4	9.33	14	64
	SBA	0.13	0.06	0.02	0.36	0.134	0.06	0.03	0.34	0.13	0.07	0.02	0.41

Note: the data were tested at 95% confidence interval about the mean. std = standard deviation, Min. = minimum, Max. = maximum, TFell = Time spent to fell a tree, ND = Necessary delay, UND = Unnecessary delay, Dbh = Diameter of a tree measured at breast height, SBA = Stump basal area.

*Means which showed to differ significantly across the experiments

These results indicate as well that inexperienced operator had about 50% delay times on both delay categories as compared to experienced one. Observations showed that higher proportions of the necessary delays of the inexperienced operator were contributed by saw chain maintenance, re-fuelling, saw jamming and spontaneous rests. While unnecessary delays were mainly from excessive resting, responding to mobile phone and talking with by-passers, actions which were seldom done by the experienced operators.

Results obtained after training indicate that experienced operator observed a slight improvement on the time used in the preparation which was lowered by 5% as compared to 65% of inexperienced operator. Meanwhile, there was significant difference on the preparation time between the two operators when preparation time was compared separately for each experiment, before training (t test, df = 556, p = 0.001) and after training (t test, df, 498, p = 0.002). While there was insignificant reduction on delay times for the experienced, inexperienced operator observed an average of 44% and 71% reduction improvement on necessary and unnecessary delays respectively. Felling time was lowered by 2.1% and 43% by the experienced and inexperienced operators respectively signifying a faster felling rate of inexperienced operator.

On resuming the operations different trends were observed on both crews. For example, the preparation time for the experienced operator decreased by 9.2% while felling time rose for about 12% with insignificant difference on other time elements (i.e. necessary and unnecessary delays). Results for the start up operator indicate an overall increase on time elements which implies that the crew had forgotten some of the basic operation conducts. For instance, preparation time increased by 5% with about 14% felling time increase while necessary and unnecessary delays increased by 30% and 70% respectively when compared to the situation before the break. By comparing the two crews, it was found that start up operator spent more time per tree as compared to the experienced operator after resuming operation. This indicates that the start up crew was starting to learn the production process thus may mistakes due to try and error learning.

Delimbing time element
Delimbing time study statistics are presented in Table 2. Observations show that this activity consumed on average low time per tree as compared with felling. This is probably due to the fact that Pinus patula tree species are characterized by fewer branches and relatively shorter canopy height. Several studies (Aluma, 1976; Migunga, 1982) have reported a different observation from a clear felling operation of Pinus radiata, while Dykstra and Howard (1980) report relatively higher time consumption for similar activities on harvesting mixed hardwood forests of north-eastern United States.

Table 2: Summary statistics for the log delimbing sub operation for the for the three experiments

Crew category	**Variable**	**Before training**				**After training**				**After break**			
		Mean	Std	Min.	Max.	Mean	Std	Min.	Max.	Mean	Std	Min.	Max.
Experienced crew	TLimb	0.46	0.61	0.0	3.0	0.37	0.53	0.0	2.4	0.45	0.64	0.0	3.0
	ND	0.25	0.77	0.0	7.2	0.21	0.67	0.0	5.77	0.22	0.68	0.0	7.0
	UND	0.14	0.32	0.0	2.0	0.16	0.36	0.0	2.0	0.14	0.34	0.0	3.0
	THgt	19.7	3.65	7.0	28	19.6	3.54	6.5	28	20.3	4.14	8.0	34
Start up crew	TLimb	0.55	0.71	0.0	6.3	0.38*	0.57	0.0	3.0	0.47	0.63	0.0	3.37
	ND	0.68	3.3	0.0	38.8	0.24*	0.9	0.0	7.0	0.25*	0.8	0.0	7.2
	UND	0.19	0.6	0.0	5.55	0.08*	0.3	0.0	3.0	0.33*	0.3	0.0	3.0
	THgt	20.1	3.8	7.0	30.0	20.4	3.1	10	28	19.8	3.5	7.0	28

Note: the data were tested at 95% confidence interval about the mean. std = standard deviation, Min. = minimum, Max. = maximum, TLimb = Time spent to delimb a tree, ND = Necessary delay, UND = Unnecessary delay, THgt = Tree height.
*Means which showed to differ significantly across the experiments

Since the number of observations varied between experiments, the correlation analysis was performed by considering the first 246 observations for each experiment. Results indicate that there was a positive relationship with p-values being < 0.05, ranging between 0.001 to 0.013 between the delimbing time and the tree heights when Pearson correlation analysis was performed with ‘r’ ranging from 0.22 to 0.29 across the experiments. Furthermore, the results show that there was no significant difference (t-test, $p>0.05$) of the independent variables in all the experiments. On the other hand, there were significant differences between limbing times of the two operators when studied before training (t-test, df = 488, p = 0.022) while there were no significant difference after training and after break (t-test, df = 488, p = 0.205) and (t-test, df = 488, p = 0.440) respectively. However, the start up crew was observed to have a significant proportion of the delay times during the first engagement which decreased substantially in the other two experiments. This could be attributed to the learning experienced by the crew as the cutting proceeded.

Log measuring time element

Normally crews were supposed to cut logs of 4.2 meters long although adjustments were allowed depending on the stem shape and or specific requirements from the sawmills which here reflected the market requirements. Measuring stems was performed by the crews by using a measuring stick for a chainsaw operator while crosscut saw crews used the saw blade. Results indicate a substantial time decrease in measuring for all crews across the experiments (Table 3).

In general chainsaw operators find measuring a tedious operation as they have to carry with them a calibrated stick which could easily be misplaced. As a result they were observed making visual estimates. Unfortunately visual estimates which largely depend on logger's ability to judge after several trial measurements resulted into high variation of the log lengths which ranged from 4 to 5.1 m long. This variation may explain unnecessary wastage of the merchantable parts on the tree. It is also observed that measuring time was highly variable, depending on the logger's judgment and the number of trial and error measurements made.

Table 3: Summary statistics for the log measuring time element for the three experiments

Crew category	Variable	Before training				After training				After break			
		Mean	**Std**	**Min.**	**Max.**	**Mean**	**Std**	**Min.**	**Max.**	**Mean**	**Std**	**Min.**	**Max.**
Experienced crew	TMeas	1.14	0.8	0.0	5.7	1.0*	0.7	0.0	5.33	0.91	0.6	0.0	5.35
	NLogs	3	1.3	1.0	6.0	2.77	1.9	0.0	6.0	2.8	1.25	0.0	6.0
	TLogL	12.56	5.6	4.2	29.0	12.1	5.6	0.0	36	12.1	5.57	0.0	29.5
Start up crew	TMeas	1.34	1.1	0.0	7.0	1.26	0.8	0.0	3.66	1.1*	0.81	0.0	5.7
	NLogs	4.8	1.7	0.0	6	4.8	1.6	0.0	6.0	3.2	1.5	1.0	6.0
	TLogL	12.8	5.7	0.0	29	12	5.1	4.2	27.8	12.5	5.5	4.2	27.8

Note: the data were tested at 95% confidence interval about the mean. std = standard deviation, Min. = minimum, Max. = maximum, TMeas = Time spent to measure a tree for backing, NLogs = Number of Logs, TLogL = Total log length.

*Means which showed to differ significantly across the experiments

Average measuring time for the start up crew was 8% longer as compared to the experienced one. However, the average measuring time per tree, number of logs and the total log length between experienced and inexperienced crews differed significantly in all experiments (t-test, df = 488, p = 0.001). There was a positive correlation between the measuring time and the tree lengths for all experiments where 'r' value ranged from 0.27 to 0.73 with the start up crew reading the least (r = 0.27, df = 290, p = 0.001) during the first study. This indicates that the measuring time is dependent on the tree length. The longer the tree, the longer the measuring time expected.

Bucking time element

Bucking time is given as the total time required by the crew to crosscut the stem at all desirable bucking points. The underlining hypothesis is that bucking time is a response of the stem size (both the diameter and the length). The summary statistics for the bucking time of the chainsaw operators is given in Table 4. Results indicate that bucking time occupied a significant portion of the total time required in tree cutting operation for both crews and at all experiments. Bucking time for the start up crew was longer by 18% and the average volume (m^3) per tree was slightly greater by 1.1% than for the experienced crew. The differences observed could be due to reasons that start up crew had frequent saw jamming at the beginning. Although there was no significant difference between bucking time for the experienced crew across the experiments, the start up crew observed a 15% improvement after training and about 7% depreciation after the break.

Table 4: Summary statistics for the bucking time element of the three experiments

Crew category	Element	Before training				After training				After break			
		Mean	**Std**	**Min.**	**Max.**	**Mean**	**Std**	**Min.**	**Max.**	**Mean**	**Std**	**Min.**	**Max.**
Experienced crew	TBuck	3.48	2.8	0.17	20.0	3.2	2.2	0.0	11.0	3.1	2.4	0.0	15.5
	TLVol	0.81	0.6	0.03	3.22	0.77	0.5	0.0	3.22	0.86	0.62	0.0	3.5
Start up crew	TBuck	3.93	3.5	0.0	22.7	2.91*	2.3	0.0	10.0	3.30	2.59	0.0	20.0
	TLVol	0.86	0.6	0.0	2.85	0.82	0.5	0.0	2.46	0.78	0.57	0.04	3.22

Note: the data were tested at 95% confidence interval about the mean. std = standard deviation, Min. = minimum, Max. = maximum, TBuck = Time spent to buck a tree, TLVol = Total log volumes
*Means which showed to differ significantly across the experiments

Productive tree cutting times

Table 5 presents summary statistics of the productive cutting times (excluding delays) for each working element and experiments as a percentage of total productive cutting time. Results show that bucking occupied a considerable proportion of the productive time followed by measuring element for both crew category and in all experiments.

Table 5: Breakdown of the average productive cutting times

Crew category	Element	Before training		After training		After break	
		min/tree	**%**	**min/tree**	**%**	**min/tree**	**%**
Experienced crew	Preparation	0.60	11	0.59	11	0.34	8
	Felling	0.87	16	0.88	17	0.67	15
	Limbing	0.47	8	0.37	7	0.45	10
	Measuring	1.15	21	1.11	21	0.98	22
	Bucking	2.43	44	2.38	44	2.10	45
Total Productive time		**5.52**	**100**	**5.33**	**100**	**4.54**	**100**
Start up crew	Preparation	1.15	18	0.55	11	0.60	12
	Felling	0.86	14	0.64	13	0.84	15
	Limbing	0.55	9	0.38	9	0.47	9
	Measuring	1.34	21	1.26	26	1.10	21
	Bucking	2.39	38	1.96	41	2.35	43
Total Productive time		**6.29**	**100**	**4.79**	**100**	**5.37**	**100**

The overall assessment of the productive and non productive times shows that productive time occupied a significant proportion of the total workplace time in all experiments (Table 6). Furthermore, crews showed an improvement in all time elements after training. However, the improvement for the experienced unlike for the start up crew did not differ significantly (t-test, df = 496, p = 0.057) and (t test, df = 578, p = 0.001) for the experienced and the start up crews respectively.

Table 6: Breakdown of the average productive and non productive cutting times

Crew category	Element	Before training		After training		After break	
		Min/tree	**%**	**Min/tree**	**%**	**Min/tree**	**%**
Experienced crew	Productive time	5.52	71	5.33	72	4.54	71
	Necessary delays	1.48	19	1.20	17	1.09	17
	Unnecessary delays	0.76	10	0.75	11	0.75	12
	Total cutting time	**7.76**	**100**	**7.28**	**100**	**6.38**	**100**
Start up crew	Productive time	6.29	62	4.79	76	5.37	72
	Necessary delays	2.95	29	1.19	18	1.36	18
	Unnecessary delays	0.88	9	0.36	6	0.68	10
	Total cutting time	**10.11**	**100**	**6.34**	**100**	**7.41**	**100**

Delays

A summary of the average delay times in each category as a percentage of average total delay time is presented in Table 7.

Table 7: The average delay times

Crew category	Delay time Element	Before training		After training		After break	
		Min/tree	%	Min/tree	%	Min/tree	%
Experienced crew	Preparation	0.6	18	0.59	19	0.44	16
	Necessary delays	2.08	60	1.8	57	1.66	58
	Unnecessary	0.76	22	0.75	24	0.73	26
	Total	**3.44**	**100**	**3.14**	**100**	**2.82**	**100**
Start up crew	Preparation time	1.15	19	0.56	21	0.61	19
	Necessary delays	4.10	67	1.75	65	1.97	60
	Unnecessary	0.88	14	0.36	14	0.68	21
	Total	**6.12**	**100**	**4.11**	**100**	**3.26**	**100**

Results show that delay times were higher for all crews across the experiments as compared with the unnecessary ones. The shorter unnecessary delay time may be due to the effect of the presence of the researcher which might have provided a kind of informal supervision. Probably to avoid the impact of the researcher in the field automatic methods like cameras can be proposed for conducting time studies. According to McDonald (1999); González (2005) there have been attempts to implement an automated time study system for the skidder that was successful in order to minimize the risk and potential safety hazards as well as to reduce the cost of collection of data in the field. There was no significant different of these delays in all experiments unless for the start up chainsaw operator who observed a significant decrease in delay time after the training.

Most of the necessary delays (although not separately accounted for) were contributed by saw pinching, saw sharpening and refuelling. Although chainsaw could normally be filed twice a day, i.e. before the start of the operation and probably at the middle of the operation, the exercise seemed to take relatively longer time as the crew made use of this time to check on his phone and or make some calls to friends during this exercise. This habit repeats even during minor saw maintenance. Dykstra and Howard (1980) reported that the frequency and duration of refueling delays is often more an indication of the feller's habits rather than the need for fuel.

Saw pinching especially for the start up crews was common. On the other hand crews spent substantial amount of time in preparation for cutting which included walking to the tree, brushing around, deciding of the felling direction and making an escape route. Of these elements, walking to the tree was the most time consuming element which varied with the condition of the site on both the undergrowths and the general terrain slope. For example, studies from elsewhere have shown that there is a direct relation between walking time and both, the distance and the slope. In general, there are two types of slopes that effect time consumption of walking: uphill and downhill. Normally, walking downhill takes less time and adversely walking uphill takes longer time. In the study by Long et al. (2002), time consumption of walking was mostly affected by inter-tree distances.

Regression models

Regression models were developed for each cutting sub element which included tree felling, delimbing, and measuring the felled tree for backing and backing. The regression models for these elements are presented below;

Felling sub operation models

Felling of a standing tree involves cutting a cross-sectional area of wood rather than a linear distance. Therefore, felling time is assumed to be proportional to the tree cross sectional area of which was being sawn. Consequently, tree size determines the cross-sectional area to be crosscut. Based on these facts the following hypothesis was developed for this operation for each of the cutting method and the experiment. The regression hypothesis for felling operation was as follows;

Ho: Felling time (T_{Fell}) = f(SDia, Dbh, $SDia^2$, SBA)

Felling operation models for the experienced operators

Before training

$$TFell = -0.305 + \underset{(0.002284)}{0.0358} SDia$$, $R^2 = 0.42$, n =339 (1)

After Training

$$TFell = 0.0378 + \underset{(0.002611)}{0.0364} SDia$$, $R^2 = 0.54$, n = 250 (2)

After the break

$$TFell = -0.102 + \underset{(0.001657)}{0.0216} SDia$$, $R^2 = 0.33$, n = 341 (3)

Felling operation models for the inexperienced operators

Before training

$$TFell = -0.189 + \underset{(0.003126)}{0.0294} SDia$$, $R^2 = 0.23$, n = 341 (4)

After Training

$$TFell = -0.0249 + \underset{(0.001484)}{0.0248} SDia$$, $R^2 = 0.48$, n = 136 (5)

After the break

$$TFell = -0.308 + \underset{(0.002027)}{0.0333} SDia$$, $R^2 = 0.39$, n = 419 (6)

Tree stump diameter (SDia) was found to significantly influence felling time in most of the experiments as compared to other independent variables tested. A study by Kluender and Stokes (1996) and Mousavi (2009) showed similar results. Behjou et al. (2009) observed a higher correlation between Dbh and felling time when the distance between the harvested trees is included in the model. However, despite being used by many researchers, Dbh did not appear to be a significant variable and therefore was not included in the model based on the fact that it is highly correlated with the stump diameter (SDia) as has also been observed by (Migunga, 1982; Brokaw and Jill, 2000).

Although it is believed that cutting tools have a great interaction with the surface being cut (i.e. the cross-sectional area which is here referred to as the squared stump diameter, ($SDia^2$), the $SDia^2$ was also not included in the model as it could not show any significant improvement and increases dangers of multicolinearity.

It was observed that the selected independent variables tested showed relatively a good relationship. In few experiments the SDia despite being used as a potential predictor did not appear to have significant influence. This is an indicator that cutting time was also influenced by other unobserved factors in the respective experiments. These factors may include operator's skills, health, self motivation and environmental conditions which could not be measured directly in the field. Generally both crews showed a significant improvement after training with a relative fall of the dependent-independent variables relationship after the break.

Delimbing sub operation models

Delimbing is considered to be a surface work procedure (Migunga, 1982). The limbing time was therefore the effective time required to cut off branches and stubs and removing the tree top. Limbing time therefore is expected to be dependent on the number of branches and their cross-sectional areas, the surface conditions of the tree stem and the horizontal distance to be covered by the cutter during delimbing. It is assumed that the total cross-sectional areas of branch stubs increases with tree size and the number of branches increase with crown length (Migunga, 1982). Since the crown length did not form part of the data collected based on the fact that the studied species are characterized by a small crown of fewer branches, the hypothesis was formulated based on the tree size and length as follows;

Ho: Limbing time (TLimb) = f(Total tree height, Diameter at breast height)

Limbing and topping models for the experienced operator

Before training

$$TLimb = -0.364 + \underset{(0.0088)}{0.0421}\, Height \text{ , } R^2 = 0.064 \quad (7)$$

After training

$$TLimb = -0.243 + \underset{(0.00945)}{0.0311}\, Height \text{ , } R^2 = 0.042 \quad (8)$$

After the break

$$TLimb = -0.306 + \underset{(0.0081)}{0.0371}\, Height \text{ , } R^2 = 0.059 \quad (9)$$

Limbing and topping models for the inexperienced operator

Before training

$$TLimb = -0.343 + \underset{(0.0106)}{0.0445}\, Height \text{ , } R^2 = 0.058 \quad (10)$$

After training

$$TLimb = -0.467 + \underset{(0.0102)}{0.0415}\, Height \text{ , } R^2 = 0.050 \quad (11)$$

After the break

$$TLimb = -0.363 + \underset{(0.00852)}{0.0422}\, Height \text{ , } R^2 = 0.056 \quad (12)$$

The R^2 value was relatively very low on both crews in all experiments. The species that were felled are characterized by fewer branches which were somewhat on a shorter crown length along the merchantable stem. Generally, the crown comprised the narrower tree to where the small-end diameters which was set at 15cm could not be obtained. As a result crews especially chainsaw operators tend to avoid delimbing unless it is necessary on the targeted logs. As a result crown length was not a statistically significant predictor of delimbing time. Therefore tree height was found to be the most important factor influencing delimbing time. A study by Samset et al. (1969); Matthes et al. (1975); Dykstra and Howard (1980) and Migunga (1982) found out that limbing operation on average requires more time per tree than any other cutting sub-operation when either chainsaw or crosscut saw is used in cutting.

Log measuring sub operation models

Measuring the stem for bucking was done by the cutting crews themselves by subjective decision making. In most cases this operation was done concurrently with bucking operation because a crew measures and bucks before measuring and bucking the next log. Measuring involved taking physical measurements with a scaled tool like a tape, graduated stick or the saw blade as its length is known. Since log length varied depending on production requirements and the log quality, judgment of the log quality formed also a measuring component.

Therefore, measuring operation tends to be highly variable. For example unlike the two-man crosscut saw operators, the experienced chainsaw operator did not use and measuring instrument but rather visual judging. This trend was also observed as the start up crew get used to the operations. Thus it was often trial and error process. However, it is assumed that measuring time would be most closely related to linear stem measurements. Therefore develop an estimating model the following hypothesis was formulated;

Ho: Measuring time (TMeas) = f(Height, NLogs, TLogL)

Measuring operation models for the experienced operator

Before training

$$TMeas = -0.365 + \underset{(0.01224)}{0.0231}\, Height + \underset{(0.03515)}{0.366}\, NLogs \text{ , } R^2 = 0.41 \quad (13)$$

After training

$$TMeas = -0.339 + \underset{(0.01173)}{0.0288}\, Height + \underset{(0.03479)}{0.319}\, NLogs \text{ , } R^2 = 0.45 \quad (14)$$

After the break

$$TMeas = -0.124 + \underset{(0.02837)}{0.00004}\, Height + \underset{(0.00338)}{0.282}\, NLogs \text{ , } R^2 = 0.32 \quad (15)$$

Measuring operation models for the inexperienced operator

Before training

$$TMeas = -0.279 + \underset{(0.0188)}{0.0384} Height + \underset{(0.0537)}{0.285} NLogs, \quad R^2 = 0.21 \tag{16}$$

After training

$$TMeas = -0.594 + \underset{(0.0158)}{0.0374} Height + \underset{(0.03879)}{0.381} NLogs, \quad R^2 = 0.47 \tag{17}$$

After the break

$$TMeas = -0.313 + \underset{(0.01181)}{0.0162} Height + \underset{(0.03446)}{0.397} NLogs, \quad R^2 = 0.41 \tag{18}$$

Tree height (Height) and the number of logs (NLogs) appeared in the equations despite their low or non significance levels. Most crews tend to estimate the log length and sometimes making a number of trials. As a result time in the components becomes so difficult to accurately be separated from the rest of the activities. This approach is thought to have affected time estimate model for this activity. A study by Mousavi (2009) found out that separating the time consumption of measuring logs from other sub activities is difficult and mostly it may sound reasonable to be totalled to other activities like measuring at the landing. Further observed that time consumption of measuring was not related to any variable(s), however, it may be influenced by the trees' height and ground condition (topography and under growth tree cover); though this could not be proved in that study nor in this one.

The NLogs and TLogL were strongly collinear but only NLogs entered into the model due to its relative higher significance level. On the other hand the degree of co-linearity between the tree height and the number of logs, both as independent variables varied from low to high and between crews and experiments. For example, a general analysis for 'r' values showed that correlations varied between 0.386 and 0.642 across the experiments.

There were also coincidences of finding trees with multiple stems ranging between two and three branches mostly as high as 10m from the ground. In this case, what has been described as a shorter tree results into many logs and therefore measuring time here varies unpredictably with the total tree height.

Bucking sub operation models

According to Migunga (1982) effective bucking time per tree is the sum of the bucking times required for all the logs into which the tree stem is divided, and includes any time necessary to move broken or cull sections. Productive time is here considered to be proportional to cross-sectional area cut which was measured as the basal area at any the bucking point. In this study therefore, bucking time was recorded as the total time spent in cross cutting the stem. The number of logs obtained and their total volume were assumed to influence the time used.

In the regression analysis, the volume was viewed as an alternative variable to the total cross sectional area cut and serves to explain some of the time required to move between bucking points because the volume accounts for the log length as well. Because a tree stem tapers and the fact that size (diameter) along the stem does not significantly differ in short intervals lets say of 10cm along the stem (Brokaw and Jill, 2000), then the stump diameter and diameter at breast height were used to give an indication of the bucking points in the respective tree stem. With this assumption then, the following regression hypothesis was formulated;
Bucking time (TBuck) = f(SDia, $SDia^2$, Dbh, DBh^2, THt, NLogs, TLogL, Lvol)

Bucking operation models for the experienced operators

Before training

$$TBuck = -0711 + \underset{(0.01285)}{0.0339} SDia + \underset{(0.08595)}{0.351} NLogs + \underset{(0.2856)}{1.15} TLvol, \quad R^2 = 0.62 \tag{19}$$

After training

$$TBuck = -1.21 + \underset{(0.02115)}{0.0522} SDia + \underset{(0.08433)}{0.478} NLogs + \underset{(0.334)}{0.583} TLvol, \quad R^2 = 0.66 \tag{20}$$

After the break

$$TBuck = -1.15 + \underset{(0.01165)}{0.0403} SDia + \underset{(0.06745)}{0.543} NLogs + \underset{(0.2315)}{0.407} TLvol, \quad R^2 = 0.60 \tag{21}$$

Bucking operation models for the inexperienced operators

Before training

$$TBuck = 0.635 - \underset{(0.01473)}{0.0244}\,SDia + \underset{(0.09164)}{0.245}\,NLogs + \underset{(0.2898)}{2.21}\,TLvol,\ R^2 = 0.59 \quad (22)$$

After training

$$TBuck = 0.441 - \underset{(0.01335)}{0.0273}\,SDia + \underset{(0.08433)}{0.228}\,NLogs + \underset{(0.334)}{2.24}\,TLvol,\ R^2 = 0.67 \quad (23)$$

After the break

$$TBuck = -0.311 + \underset{(0.01118)}{0.0175}\,SDia + \underset{(0.06579)}{0.394}\,NLogs + \underset{(0.2142)}{1.22}\,TLvol,\ R^2 = 0.62 \quad (24)$$

Of the independent variables selected to estimate bucking time, the diameter at breast height was not statistically significant probably due to its strong co-linearity with the stump diameter, SDia. R^2 values are relatively higher. However, prediction strength for increased after training and decreased substantially as the crews resumed operations after the break.

Total cutting time model

The total cutting time comprises the sum of the productive times of the individual cutting elements, thus excludes the delays. Considering cutting processes for a single tree, which was mathematically be defined as;

$$T_{Cutt} = T_{Fell} + T_{Limb} + T_{meas} + T_{Buck} \quad (25)$$

Where T_{Cutt} = total effective time consumption for cutting, min/tree, T_{Fell} = total effective time consumption for felling, min/tree; T_{Limb} = total effective time consumption for limbing, min/tree; T_{Meas} = total effective time consumption for measuring, min/stem; T_{Buck} = total effective time consumption for bucking, min/tree; Therefore, the factors that influence cutting elements may directly or indirectly influence total cutting time. For this study the following hypothesis was formulated;

Ho: Total cutting time (excluding delays) = f(SDia, Dbh, Dbh^2, Height, NLogs, LVol, TLVol)

Total cutting time models for the experienced operators

Before training

$$TCutt = -2.86 + \underset{(0.01437)}{0.143}\,Dbh + \underset{(0.1050)}{1.06}\,NLogs,\ R^2 = 0.644,\ n = 339 \quad (26)$$

After training

$$TCutt = -2.72 + \underset{(0.01455)}{0.146}\,Dbh + \underset{(0.1117)}{0.971}\,NLogs,\ R^2 = 0.67,\ n = 250 \quad (27)$$

After the break

$$TCutt = -2.26 + \underset{(0.01138)}{0.111}\,Dbh + \underset{(0.09098)}{0.984}\,NLogs,\ R^2 = 0.617,\ n = 341 \quad (28)$$

Total cutting time models for the inexperienced operators

Before training

$$TCutt = -1.78 + \underset{(0.02015)}{0.0930}\,Dbh + \underset{(0.1343)}{1.29}\,NLogs,\ R^2 = 0.476,\ n = 290 \quad (29)$$

After training

$$TCutt = -2.40 + \underset{(0.01531)}{0.0955}\,Dbh + \underset{(0.0855)}{1.19}\,NLogs,\ R^2 = 0.60,\ n = 309 \quad (30)$$

After the break

$$TCutt = -2.62 + \underset{(0.01277)}{0.135}\, Dbh + \underset{(0.09699)}{1.09}\, NLogs \text{ , } R^2 = 0.62,\ n = 419 \qquad (31)$$

Of the variables selected for modelling the total tree cutting time, tree height, total log length and total tree volume did not have a significant influence on the total cutting time. The stump diameter, diameter at breast height, basal area, number of logs and the total log volume showed to have some predictive capability to the dependent variable. However, the regression equations were limited to Dbh and NLogs because of their significant influence to the total cutting time as compared to the rest of independent variables mentioned above. Results show that the R^2 values for both crew categories ranged between 0.47 and 0.67 with the least being for the start up operator on his first engagement in tree cutting operations. Generally, the findings for the start up crew during the first experiment and the findings on the first and after break experiments indicate the presence of some influential factors to the cutting time which were either not observed or were difficult to record during this study. These may include factors like labour skills, environmental and institutional factors among others. For example studies by FAO (1976; 1997) and Mitra and Sood (1979) found out that total cutting time can be influenced by the skills and ability of labour as well as the cutting methods respectively.

CONCLUSION AND RECOMMENDATIONS

The study shows that the performance of experienced and inexperienced crews varied across the three experiments. Start up crew spent relatively more time in performing some activities during the first time of engagement due to some technical mistakes. However, the crew showed significant improvement after training unlike the experienced one. The analysis of the delay times for the start up crew showed that he had a significant proportion of the delay times during the first engagement which decreased substantially in the other two experiments. Generally, there was an improvement of the cutting time after training for all crew categories with decrease after the break. This observation signifies that job interruptions impact the productivity of the crews. Therefore, on job training before and on resumption of operations may significantly improve crew's productivity, safety as well as ensuring product quality.

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