Predicting Wood Conversion Efficiency in Illoabuchi Sawmill, Port Harcourt, Nigeria

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Abstract: Lumber which is a processed wood is usually available in hardwood and readily available in soft wood species. Nigeria was very rich in forest resources but now wood supply status has declined greatly as a result of over exploitation and inadequate conversion process of the wood resources in many sawmills. In order to reduce the volume of wood wastes in the conversion process, there is need for an intensive research which focuses on wood conversion efficiency. The study was conducted to develop wood conversion efficiency predicting equation for sawmills in Illoabuchi, Rivers State. Five sawmills were randomly selected and two species were evaluated for the study. The results shows that the kind of wood species used for the study have no direct significant impact on lumber recovery obtained during log conversion but log characteristics such as diameter at the middle and log taper significantly influence lumber volume recovery. The significant influence of log characteristics on lumber recovery confirms that the shape of the log influences the amount of lumber recovered, lumber recovery percentage decreases with an increase in log taper. Furthermore, from this study using statistical models, it is observed that power model alone could be used to accurately predict lumber volume recovery from log characteristics. The findings have shown that the knowledge of log characteristics influence on lumber recovery is important in waste reduction in sawmill which in turns have provided valuable information that could enhance efficiency in lumber recovery process.
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1. Introduction

Lumber is wood that has been processed into beams and planks. It is usually available in hardwood species but also readily available in softwood. According to Birikorang *et al*., (2007), the main sources of lumber in the domestic market are conventional sawmills and chain-saw millings. Kukogho *et al*., (2011) defined sawmill as a wood processing industry equipped with various wood processing machines. Among other industries, sawmill industry faces many economic barriers that act together to reduce its competitiveness. However, one of the area which the sawmill industry can improve its competitive position is the recovery of saleable products per unit of log volume purchased (Kilborn, 2002).

Nigeria was rich in forest resources but now the forest share of the real Gross Domestic Product (GDP) has declined steadily hence it requires urgent attention. Wood related-industries such as sawmills, plywood mills, paper mills etc contribute immensely to the economy in Nigeria (Adewumi, *et al*, 2004). The research of FORMECU (1992) stated that about 75,000 people are directly involved in industrial conversion of logs which is about a quarter of the labour force in the manufacturing industry in Nigeria.The wood supply status of Nigeria has deteriorated greatly as a result of ineffective control of forest resource exploitation. Coupled with this, is the inefficient conversion of wood resources in many sawmills (Okunomo *et al*., 2008).

The main aim of forest management is maximizing stand yield (wood volume). In sawmilling the volume of log input is not the same as the volume of recovery. Inaccurate information on the relationship between timber input and lumber output can lead to erroneous projections related to the volume of timber needed to fill future demand, impacts on forest inventories, and future prices for lumber, timber, and timberland. In order to reduce the volume of wood wastes in the log conversion process and sustain the sawmills and corresponding profit margin, there should be an intensive research focus on efficient conversion of log so as to stem down the percentage of waste in Nigeria sawmills. Lumber recovery factor (LRF) is a measure of the conversion efficiency of sawmills. Log conversion efficiency in the sawmilling industry is commonly expressed as the yield or recovery of sawn wood milled from a given log (Adams, 2007). LRF is calculated as the nominal board feet (BF) of lumber recovered per cubic foot volume of log input to a sawmill (Keegan *et al*., 2010). LRF has been used as measure of conversion efficiency in past research on sawmills efficiency (Steele and Wagner, 1990). Appiah (1983) indicated that lumber yield/recovery is the most single item affecting cost/revenue relationships of a mill and its profitability. Therefore it is imperative to understand the wood conversion efficiency in sawmill and be able to predict it.

2. Methodology

Study area

This study was conducted in the sawmills in Illoabuchi, Rivers State, Nigeria. It was chosen for the study due to its position as one of the major timber production areas in Rivers where wholesale and retail selling of sawn wood takes place. Illoabuchi sawmill was established in 1989 on about 1.5hectres of land comprising 180 plank retail shop and about 80 sawmills. Hence many people in this area take timber (wood) marketing as means of livelihood. It is located on latitude 4^0 78' 89" N and longitude $6^0 98'$ 75" E.

Sampling technique

Reconnaissance survey was carried out in order to identify the commonly sawn timber within the study area. Simple random sampling was used to select five sawmills in the study area. Purposively sampling technique was used in data collection based on the frequency of the sawn species. Two species of timber was surveyed in the five different sawmills in illoabuchi, Rivers State, Nigeria. *Mitragyna ciliata* and *Entandrophragma angolense* were the species commonly sawn in the mill hence were used for the study. Ten logs was selected from each of the species, giving a total of twenty logs in each sawmill.

Measurement of variables

The following variables of interest was measured on sampled logs

1. Log length
2. Log diameter at top
3. Log diameter at middle
4. Log diameter at base

Data analysis

The data collected from log measurement was processed into suitable form for statistical analysis. Data processing includes log taper, log volume, volume of sawn timber and wood conversion efficiency.

Log volume

Before primary conversion, log diameter at the top, middle and bottom was measured and used to estimate log volume using the Newton's formula as presented by Husch et al. (1982).

$$V_{Log} = \frac{L}{6}\left(A_b + 4A_m + A_t\right) ------ Eqn.1$$

Where V_{Log} = Log volume (m^3)

L = Log length (m)

A_b, A_m, A_t,= cross sectional areas at the base, middle and top of the tree respectively (m^2)

Sawn timber volume

The volume of sawn timber (plank) was estimated for individual planks from each of the logs from equation 2:

$$V_{st} = \sum n\left(l.b.h\right) ------ Eqn.2$$

Where V_{st} = volume of sawn timber (m^3)

l = length of sawn timber (plank) (m)

b = breadth of sawn timber (plank) (m)

h = thickness of sawn timber (plank) (m)

n = number ofof sawn timber (plank) (m)

Log taper

Log taper was calculated as the difference between diameter at the base and diameter at the top divided by log length as adopted by Missanjo and Magodi, (2015).

$$L_t = \frac{d_b - d_t}{l} ------- Eqn.3$$

Where L_t = Log taper

d_b = log diameter at base

d_t = log diameter at top

l = log length

Log ellipticality

Log ellipticality describes how much a log's outline deviates from a circle. The formula used to measure ellipticality (*e*) indicated in equation 4 as prescribed by Steward, (1999):

$$e = \frac{\sqrt{\left(\frac{d_b}{2}\right)^2 - \left(\frac{d_t}{2}\right)^2}}{\left(\frac{d_b}{2}\right)^2} ------ Eqn.4$$

Where e = Log ellipticality

d_b = log diameter at base

d_t = log diameter at top

Lumber recovery

Wood conversion efficiency was estimated as a measure of lumber recovery. Lumber recovery is the ratio of volume of lumber recovered from each processed log to that of log volume expressed in percentage.

$$LR = \frac{V_{st}}{V_{\log}} X \frac{100}{1} ------ Eqn.5$$

Where LR = Lumber recovery

V_{st} = volume of sawn timber (m^3)

V_{Log} = Log volume (m^3)

Development of wood conversion efficiency predicting equations

Model description

Simple linear, multiple linear, semi logarithm, double logarithm, power, polynomial equations was used to develop wood conversion efficiency predicting equations. The equations was of the form:

Semi logarithm model

$$\ln C = b_0 + b_1 X_1 ----Eqn.6$$

Double log model

$$\ln C = b_0 + b_1 \ln X_1 + b_2 \ln X_2 + b_3 \ln X_3 --Eqn7$$

Power model

$$C = b_0 X^{b_1} ------Eqn.8$$

Combined variable model

$$C = b_0 + b_1 X_1^2 X_2 ------Eqn.9$$

Polynomial model

$$C = b_0 + b_1 X_1 + b_2 X_2^2 + b_3 X_3^3 ----Eqn10$$

Where C = Conversion efficiency

X = log variables such as Diameter, length, taper, ellipticality, volume

a,b = Regression parameters

Model evaluation

The model formulated was evaluated with a view of selecting the best estimator for wood conversion efficiency. The evaluation was based on the following criteria:

1. Coefficient of determination (R^2)

$$R^2 = 1 - \left(\frac{RSS}{TSS}\right) ------Eqn11$$

Where R2 = Coefficient of determination

RSS = Residual Sum of Square

TSS = Total Sum of Square

2. Standard Error of Estimate (SEE)

$$SEE = \sqrt{MSE} ------Eqn12$$

Where SEE = Standard Error of Estimate

MSE = Mean Square Error

3. Significance of the overall regression equation (F-ratio)
4. Significance of regression coefficient

A model with higher R^2, least SEE and significant overall regression as well as significant regression coefficient was selected as the suitable model for wood conversion efficiency.

Statistical analysis

Descriptive and inferential statistics was used in this study. Regression analysis option was used to develop suitable predicting equations on wood conversion efficiency. Product moment correlation analysis was used to evaluate association between measured log characteristics and lumber recovery factor. T- test analysis was used to compare the differences of lumber recovery from the two species studied.

3. Results

General measured log characteristics

A total of hundred (100) logs were measured at illoabuchi sawmill which were used in estimating the conversion efficiency. There was a wide range of measured log characteristics among the studied species. Each sample log was sawn into 9^1 x 1^1 x 12ft planks. Table 1 reveals the result of descriptive statistics of diameter at the top, middle, base, log volume, stump timber volume, log taper, and lumber recovery. The conversion efficiency was measured using lumber recovery which ranged between 17.09% and 58.89% for *Mitragyna ciliata* and 25.08% and 51.74% for *Entandrophragma angolense.*

Table 1. Descriptive statistics of measured log variables

Variables	Species	Mean	Maximum	Minimum
DT	*Mitragynaciliata*	0.391332	0.6691	0.2909
	Entandrophragmaangolense	0.371203	0.6788	0.2909
DB	*Mitragynaciliata*	0.453512	0.7467	0.3103
	Entandrophragmaangolense	0.421235	0.7370	0.3016
LV	*Mitragynaciliata*	0.518863	1.4020	0.2579
	Entandrophragmaangolense	0.477593	1.4020	0.2579
STV	*Mitragynaciliata*	0.180728	0.3823	0.1062
	Entandrophragmaangolense	0.173280	0.3823	0.1274
DM	*Mitragynaciliata*	0.410766	0.6982	0.2909
	Entandrophragmaangolense	0.394522	0.7273	0.2909
LT	*Mitragynaciliata*	0.420901	0.6958	0.2861
	Entandrophragmaangolense	0.390301	0.6805	0.2774
LE	*Mitragynaciliata*	2.1684	3.3789	0.7993
	entandrophragmaangolense	2.2342	3.4365	0.9750
LR	*Mitragynaciliata*	37.297	58.8852	17.0878
	Entandrophragmaangolense	39.135	51.7394	25.0838

DT = Diameter at the top, DM = Diameter at the middle, DB = Diameter at the base, LV = Log Volume, STV = Stump timber volume, LT = Log taper, LE = Log ellipticality, LR = Lumber recovery.

Species influence on lumber recovery

T-test was used to compare the lumber recovery of the two studied species in the sawmill. The result shows that there are no significant differences in lumber recovery of *Mitragyna ciliata* and *Entandrophragma angolense* in the sawmill ($p = 0.209$). The lumber recovery of the species is shown in Figure 1.

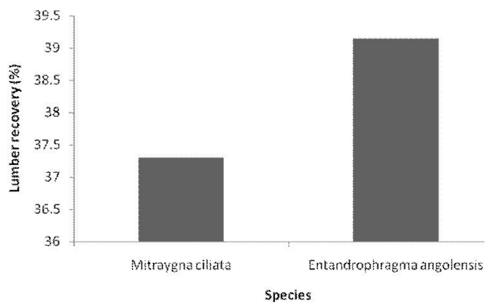

Figure 1. Mean lumber recovery of studied species

Relationship between lumber recovery and log characteristics

Correlation analysis was used to test the degree of association between lumber recovery and log characteristics. It was observed from the result presented in table 2 that there is negative correlation between lumber recovery and log characteristics. Among the measured and estimated log characteristics, diameter at the middle showed the highest association with lumber recovery (-0.778). The shape of the log also influences the amount of lumber recovery. The result shows that log taper had higher correlation than log ellipticality (Table 2).

Table 2. Correlation matrix between log characteristics and lumber recovery

	DT	DM	DB	LV	STV	LT	LE	LR	SPP
DT	1								
DM	0.957**	1							
DB	0.908**	0.930**	1						
LV	0.965**	0.988**	0.946**	1					
STV	0.921**	0.921**	0.853**	0.920**	1				
LT	0.893**	0.920**	0.999**	0.937**	0.840**	1			
LE	-0.767**	-0.664**	-0.521**	-0.644**	-0.657**	-0.497**	1		
LR	-0.689**	-0.775**	-0.753**	-0.744**	-0.490**	-0.752**	0.437**	1	
SPP	-0.109**	-0.086	-0.158	-0.081	-0.064	-0.161	0.047	0.130	1

** Significant at 0.01 level

DT = Diameter at the top, DM = Diameter at the middle, DB = Diameter at the base, LV = Log Volume, STV = Stump timber volume, LT = Log taper, LE = Log ellipticality, LR = Lumber recovery

Conversion efficiency prediction models

The conversion efficiency models were based on measured and estimatedlog variables. A number of different models were examined for predicting each of the parameters. All models had significant parameters and predicted conversion efficiency considerably well. Coefficient of determination (R^2), Standard Error of the Estimate and F- was computed for each developed model. These estimated statistics were used as a guide in selecting the best model. Residual plots of predicted conversion efficiency and residuals were plotted for the selected model. Generally, using diameter at middle as the independent variable consistently gave the best model. Table 3 shows the selected function for each model tested.

Table 3. Selected conversion efficiency prediction models

Model	Function	Regression Parameters	R^2	SEE
Simple linear	$C=B_0+B_1DM$	$B_0=61.483$ $B_1=-57.865$	0.601	4.503
Semi Log	$InC=B_0+B_1LT+B_2DM$	$B_0=4.317$ $B_1=-0.896$ $B_2=-0.816$	0.652	0.118
Power	B_0DM^{B1}	$B_0 =18.859$ $B_1 = -0.742$	0.647	4.239
Combined variable	$C=B_0+B_1DB^2LT$	$B_0=44.283$ $B_1=-66.572$	0.526	4.911
Polynomials	$C=B_0+B_1DM+B_2DM^2+B_3DM^3$	$B_0=112.022$ $B_1=-344.449$ $B_2=494.861$ $B_3=-256.398$	0.646	4.290
Double Log	$InC=B_0+B_1InDM$	$B_0=2.936$ $B_1= -0.737$	0.643	0.118

Conversion efficiency prediction model validation

In order to determine the predictive ability of the selected models, t- test was used to test for significant difference between the observed conversion efficiency values with predicted values. It was observed that the double and semi logarithm models were significant hence not good for prediction (table 4). Simple, combined variable, polynomial and power models were not significant. However, the power model was selected as the best conversion efficiency prediction model having the highest R^2 and least SEE among the predictive models.

Table 4. validation of selected models

MODEL	MOV	MPV	P value	Remark
Simple	38.1489	38.1494	0.4996	NS
Double logarithm	37.4535	22.9198	0.0001	S
Semi logarithm	37.4535	97.0183	0.0001	S
Combined variables	38.1489	38.1485	0.4996	NS
Polynomial	38.1489	38.1494	0.4998	NS
Power	38.1489	38.1280	0.4911	NS

MOV = Mean observed value, MPV = Mean predicted value, NS = Non significant, S = Significant

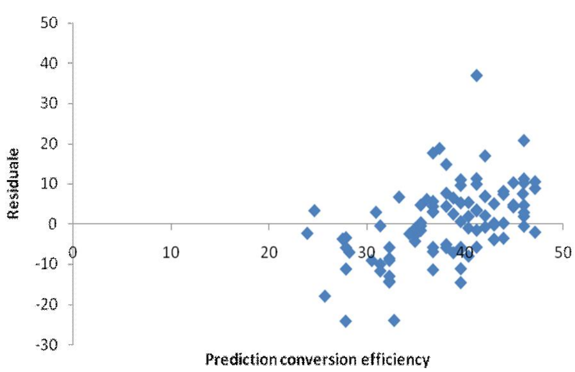

Fig 2. Residual plot of selected power model

4. Discussions

Log conversion efficiency in the sawmilling industry is commonly expressed as the yield or recovery of sawn wood milled from a given log (Adams, 2007).The efficiency of any sawmill could be measured by the quantity of finished product recovered from a log compared to those resulting into residue. Past research work on sawmill conversion efficiency has used lumber recovery as a measure. Lumber recoveries of the studied species were estimated. The average lumber recovered for *Mitragyna ciliata* and *Entandrophragma angolense* were 37.3% and 39.14% respectively. The lumber recovery values gotten for the studied species are similar with findings of other research on lumber recovery. Missanjo and Magodi (2015) found out that the average lumber recovered for their studied species ranged from 36.74% to 39.68%. Rappold et *al*. (2007) reported that the lumber recovery for circular sawmills is (40.0 ± 10%). The reasons for the low recovery might be as a result of the kerf, age of machines and the experience of the operators. Rappold *et al*. (2007) and Smith and Joe (2006) stated that age of the machine, skill and experience of the machine operator can significantly contribute to the lumber recovery from the log. According to Olufemi *et al*., (2012), log conversion efficiency can be further improved in these mills by ensuring that logs are converted on time to reduce the harmful effect caused by bio-deteriorating agents. Sawmill equipment should be adequately maintained and the level of accuracy of sawyers would also improve the efficiency of wood conversion.

The t-test result shows that there are no significant differences between the lumber recovered from *Mitragyna ciliata* and *Entandrophragma angolense*. This indicates that the studied species did not have influence on the amount of lumber recovered. This result is in agreement to the finding of by Hanks (1975) who observed that species differs in the lumber recovery produced which is due to the shapes of the species.

In this study effort was directed towards obtaining conversion efficiency prediction models. Before the models were developed, correlation analysis was carried out to give an insight of the association between lumber recovery and measured log variables. It was observed from the results that log characteristics are associated with the amount of lumber recovered. Log diameters, log taper and log ellipticality had negative correlation with lumber recover. Diameter at the middle had the highest correlation with lumber recovery (-0.775). It was observed from the correlation matrix that lumber recovery decreased with increasing log taper. The results of Missanjo and Magodi (2015) which stated that there were significant ($P<0.001$) differences between log taper on lumber recovery percentage with small taper having higher recovery percentage than medium and large tapers is in agreement with the findings of this study. This implies that the higher the log taper the lower the lumber recovery which is due to the fact that tapering increases the problem faced when sawing to get a rectangular lumber from a log. The more tapered the log, the shorter the rectangular solids that can be removed from the outside of this log (kilborn, 2002). The present results are consistent with the results in literature (Egbewole *et al*., 2011, Missanjo and Magodi, 2015 and Ese-Etame, 2006).

Realizing that log diameter and log taper are the most commonly used variables to predict lumber recovery (Egbewole *et al*., 2011, Missanjo and Magodi, 2015), six model forms namely linear, semi logarithm, double logarithm, polynomial, power, and combined variables functions were used in regression analysis. All the models show strong fit to the lumber recovery data which means that in all the model forms, R^2 values were high indicating that at least 50% of the total variation in the lumber recovery could be explained by log characteristics contained within the models. Complicated models, involving more variables that are correlated, were not considered in this study since inclusion of additional variables that are correlated do not necessarily improve the fit of the model significantly, but can create problem with multi-collinearity and can hence reduce the applicability of the developed model (Samalca, 2007; Zianis *et al*., 2005). Using diameter at the middle as independent variable consistently gave a better fit. Transforming the data in the form of logarithm model gave a better data fit. It was observed that combining diameter at the middle and log taper as independent variable improved the result. Although the double logarithm model had the highest R^2 and least SEE, it was not good for prediction and the residual plot shows that the double logarithm model overestimated the conversion efficiency of the studied species. Power model was selected as the best model for predicting conversion efficiency.

5. Conclusions

This study on conversion efficiency prediction using *Mitragyna ciliata* and *Entandrophragma angolense* has shown that the kind of wood species used for the study have no direct significant impact on lumber recovery obtained during log conversion. More so, it is observed that diameter at the middle and log taper significantly influence lumber volume recovery. The significant influence of log characteristics on lumber recovery confirms that the shape of the log influences the amount of lumber recovered, lumber recovery percentage decreases with an increase in log taper. However, the findings have shown that the knowledge of log characteristics influence on lumber recovery is important in waste reduction in sawmill which in turns have provided valuable information that could enhance efficiency in lumber recovery process. Furthermore, from this study using statistical models, it is observed that power model alone could be used to accurately predict lumber volume recovery from log characteristics and this will help in management decisions that influences conversion efficiency. Saw millers and consumers can use the developed model to predict the expected lumber recovery.

6. Recommendation

This research has demonstrated the effectiveness of log characteristics in predicting conversion efficiency. In order to maximize conversion efficiency in sawmills, forest manger must ensure that trees are well managed in other to get the best form to reduce waste in sawing. Log conversion efficiency can be further improved in sawmills by ensuring that logs are converted on time to reduce the harmful effect caused by bio-deteriorating agents

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