PRODUCTIVITY AND COST ANALYSIS OF GRAPPLE SKIDDER AT SAO-HILL FOREST PLANTATIONS, TANZANIA

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ABSTRACT

Grapple skidder was introduced by Mufindi paper mill for timber harvesting operations at Sao-hill forest plantation .It aimed at improving skidding productivity and reducing operational costs. However, it was not well known to what extent the machine was efficient in terms of productivity and cost. Therefore this study was conducted to analyze the productivity and cost of grapple skidder at Sao hill forest plantation. Time and motion studies were used for data collection. Time elements of grapple skidder operations that were recorded included: travel empty time, grappling time, travel loaded time and unloading time. It was found that the grapple skidder productivity was reduced exponentially with increasing skidding distances. The productivity for skidding operations ranged from 42.2 m^3/h to 15.4 m^3/h when the skidding distances were 10m to 125m respectively. Analysis of cost data indicated that, average skidding cost for grapple skidder was 1 875 TZS/m^3(1.4 USD/m^3). The study concludes that, on the basis of cost effectiveness grapple skidder should prove satisfactory for skidding operations in Tanzania. These observation suggest that reducing skidding distances through proper planning of skid trails ahead of logging operations and maximization of pay load are more crucial for economic skidding operation using grapple skidder.

Keywords: Grapple skidder, timber harvesting operations, productivity and cost, time study technique.

INTRODUCTION

Skidding is a process of moving of whole trees or tree sections from one location to another. Skidding can be done by connecting a cable or chain or a grapple to one end of the tree or logs and dragging them with a Skidder or other suitable machine to a location where they can be loaded onto trucks for transport to the mill (Meghdad 2008). In Tanzania, timber extraction is done either by human power (manual), animal and/or machine power by using tractors, skidders and cable yarding systems such as ground lead systems and skyline system (Migunga 1996). However the need for increased production and reducing operational costs has made Mufindi paper mills to introduce grapple skidders. Grapple skidders grasp the load with a pair of curved, hydraulically operated arms (the grapple) that are suspended at the rear of the machine (KFCA 2000). According to Benno (2002) the main advantage of grapple skidder is that, it has higher productivity, mostly because the larger grapple and greater power of the machine ensures higher operating speed, faster cycle times, and the ability to handle larger loads.

Literature indicates that, the productivity of grapple skidders have been reported by many authors under varying harvesting conditions world wide. Jixing *et al.* (2004) on mechanized harvesting system consisting of feller-buncher and grapple skidder, reported grapple skidding productivity of 14.5m^3/h with a unit cost of 2.53 USD/m^3. Benno (2002) analyzed the productivity of grapple skidders in South Africa and obtained an average productivity of 45.5m^3/h. Holmes *et al.* (2002) studied the productivity of grapple skidder, they indicated that the productivity of the skidder was 22.39m^3/h and the unit cost was 1.99 USD/m^3. However the results of these studies are specific to regions, countries and location as they may vary from each other depending on skidding distance, timber or load size, stand density and terrain factors. Since these types of machines have never been studied in detail in Tanzania this study was therefore conducted to determine the productivity and costs of grapple skidders at Sao Hill Forest Plantation(SHFP). Specifically the study intended to: determine productivity and cost of grapple skidder, determine factors affecting productivity and cost of grapple skidder, generate models for estimating productivity and cost of grapple skidder. Such information generated from this paper would be useful in improving operational efficiency through better planning and control of future work, determining skidding operation costs and in comparing the efficiency associated with the grapple skidder versus farm tractors, cable skidders, animal skidding and cable yarding systems.

MATERIAL AND METHODS

Description of the study area

This study was conducted in Sao-Hill Forest Plantations during a clear felling operation by Mufindi Paper Mill Company Limited. SHFP is the largest plantation in Tanzania with 45 000 ha of planted forests out of total gazetted area of 135 000 ha (Sumari 2008). It is located between latitudes 8° 18′ - 8° 13′ S and longitudes 35° 06′ - 35° 20′ E in the southern highlands of Tanzania in Mufindi district, Iringa region. The plantations are on rolling terrain interacted with some low hills and wide flat-bottomed valleys at an altitude varying from 1 400 to 2 000m above sea level (Fue *et al.* 1999). The main tree species planted are *Pinuspatula, P. eliotii, P. caribea, P. cassia, Eucalyptus saligna, E. maidenii, E. grandis* and *Cupressus lusitanica.*

The climate of SHFP is characterized with rainy season from November through May and a dry season during the rest of the year. The area receives between 600 mm to 1 300 mm of rainfall annually (Mlowe 2007). Temperatures are fairly cool, reaching close to freezing point between June and August. The mean monthly minimum and maximum temperatures are 10 °C and 23°C respectively.

Data collection

Three categories of data were collected. Category one focused on work place time (WPT); WPT is the total time spent in performing a task from the beginning to the end. It is made up of productive or effective time (work element contributing directly to production) and delay times (interruptions in the working cycle). Delays were further subdivided into necessary delay (inevitable interruption due to the nature of the work) and unnecessary delays (those which could theoretically be eliminated by improved supervision and training). The second category involved the measurements of independent variables upon which work-element times were thought to depend, which included slope of skidding route in (%), skidding distance (m), number of trees per turn (logs), volume per turn (m^3) and merchantable length (m). The last data category was on labour and machinery costs collected from the field and from various secondary sources.

Experimental design

According to Hassler *et al.* (2000), logging productivity in timber harvesting in the field can be estimated using different time and motion study techniques. In this study work studies were conducted using continuous time study technique. Stopwatches graduated in minutes and centiminutes were used for detailed time study. The work cycle elements of the skidding operation were distinguished based on studies by Gibson and Rodenberg (1975); Lanford and Stokes (1996); Klepac and Rummer (2000).

Travel empty: begins when the skidder leaves the landing with the empty grapple and ends when the skidder arrives at the felled stems to be skidded.

Positioning: the time begins when the grapple swings towards the bunch of logs and ends when the skidder starts grappling the load.

Grappling: begins when the skidder starts to gather a load and ends when the grapple is fully loaded.

Travel loaded: begins when the skidder starts to travel back to the landing with a grapple full of felled stems and ends when the skidder reaches the landing.

Release/unloading: begins when the skidder opens the grapple and drops the felled stems on the landing and ends when the skidder is ready for another load.

Delays: all delays associated with the work elements were recorded and their cause noted. They were either necessary or unnecessary delays as described earlier.

Data Analysis

Both descriptive statistics and regression analysis of the data were performed by using Microsoft Excel spreadsheets and Minitab 15. Besides determining the means standard deviation, the range and standard errors of the mean, some regression equations were developed to find out which independent variable have significant influence on productivity of work elements. Correlation coefficient (R^2) was used to determine the amount of influence that an independent variable has on the dependent variable.

Regression equations were developed for the following work elements: Travel empty, grappling, travel loaded and unloading. For each of the skidding element, regression hypothesis was formulated to test if the dependent variables were influenced by the selected independent variables. The independent variables analyzed included: Skidding distances, volume per load, number of logs per load and slope of the terrain. Using the formulated regression hypothesis, multiple linear regression equations were derived and used to indicate the relationship between dependent and independent variables. For convenience of presentation, the following abbreviations or symbols have been used to indicate the dependent and independent variables used in the regression equations:

Skd = skidding distance, (m), Nlgs = number of logs per turn, Vol = volume of logs per turn, (m^3), TE = travel empty time, (min), Gl = grappling time, (min), TL = travel loaded time, (min), TU = Unloading time, (min), TT = total skidding time, (min), P = production rates, (m^3/h), S_c= unit skidding cost, (T Shs/ m^3).

Travel Empty

This time element involved traversing the linear distance from the landing to the stump ready for collection of the logs for skidding to the landing. Travel empty was proportional to surface linear distance and slope of the terrain being traversed. For this reason the following hypothesis was formulated.

$$H_o : TE = f(Skd, Slope)$$

Grappling

Grappling time element involved backing into position to trees felled by the feller buncher, gathering them into loads and ends when the grapple is fully ready for traveling while loaded. Grappling time therefore depends on the number of logs loaded and volume of logs. The following hypothesis was formulated.

$$H_O : Gl = f\{N\lg s, Vol\}$$

Travel loaded

This includes the effective time required by the skidder with grappled logs to move from the stump or loading site to a road side landing. According to Wang *et al.* (2004) skidding time depends on a number of factors including slope, terrain conditions (surface roughness, number of obstacles), soil type, skidding distances traversed, weight of logs (which depends on number of logs and volume) and speed of the skidder. The following hypothesis was formulated

$$H_0 : T_L = f\{N\lg s, Dis, Slope, Vol\}$$

Unloading time/Release time

Unloading or releasing time included the time required for the grapple skidder to open the grapple and drop logs on the landing. Unloading time was therefore expected to depend on the number of logs per turn and volume being unloaded. Therefore, the following hypothesis was formulated.

$$H_O : TU = f\{N\lg s, Vol\}$$

Total skidding time

Total productive skidding times comprised the sum of the effective time and necessary delays of individual skidding element. It is therefore influenced directly or indirectly by those factors which influence individual time element.

$$H_o : TT = f\{N\lg s, Skd, Slope, Vol\}$$

The regression equations based on time study data were used to calculate the average production rates for the skidding operations as follows:

$$P = \frac{(Tvol)(F)(60)}{T} \quad (1)$$

Where:

P = production rate for a given machine, (m^3/h),

Tvol = total volume of all logs/trees for a given logging operation, (m^3),

60 = number of minutes per a workplace hour,

F = proportion measuring productive minutes per workplace hour,

T = total productive time (minutes) per trip from the respective regression equation.

Log volume was computed using Huber's formula as shown in equation.

$$Lvol = \frac{\pi md^2 L}{4} \quad (2)$$

Where:

Lvol = log volume (m^3);

md = log mid-diameter (m);

L = log length (m).

$$F = \frac{100 - D}{100} \qquad (3)$$

Where: F = a fraction measuring the proportion of productive time.

D = delay time expressed as percentage of workplace time, %.

The hourly costs, together with production rates were then used to calculate unit production cost as shown below

$$\text{Unit costs}\left(\text{Tshs}/\text{m}^3\right) = \frac{\text{Hourly costs}\left(\text{Tshs}/\text{h}\right)}{\text{Production rate}\left(\text{m}^3/\text{h}\right)} \qquad (4)$$

Results and Discussion

Log skidding work cycle

Time elements in a skidding work cycle included travel empty, grappling, travel loaded, and release or unloading. Total skidding time varied from 2.97 to 24.42 minutes with an average of 4.8 minutes per turn. However time varied among the work elements in a skidding cycle (Figure 1), of all the skidding elements, most of the total skidding time (1.51) was used in travel loaded elements. Travel loaded was influenced by the skidding distances, number of logs per turn and average volume per turn which averaged 2.09 m^3/turn. Furthermore, the number of obstacles on the route and the delays that were caused by poorly grappled logs, led into consumption of more time on the travel loaded element.

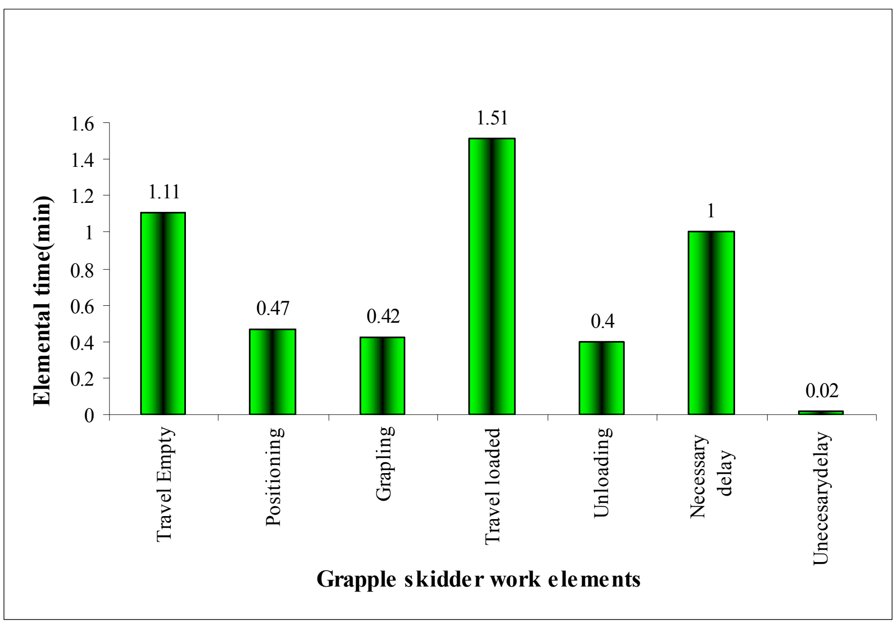

Figure 1: Grapple skidder work elements

Skidding production rates

The result shows that grapple skidder production rates averaged 27.57 m^3/h, ranging from 15.4 m^3/h at a distance of 124 m to 42.2 m^3/h at a distance of 10 m. The observed productivity was higher than the 25 m^3/h minimum production level set by the authority. Mufindi Paper Mills Company The results further indicate that skidding production rates decrease as the skidding distance increases (Figure 2). This observation is in line with other studies (Javadpour 2006 and Nikoy 2007), who reported that if other variables such as slope, number of logs per turn and volume per turn remain constant, the further a machine has to travel from the logs to the landing, the lower is the productivity and the higher are the unit production costs. From the results it can be deduced that, higher productivity of grapple skidder could be attributed by number of factors observed in the field. One could be the fact that the skidding operations were well organized in such a way that when the grapple skidder left for the landings, the timber jack cable skidder collects logs at points between the landings and the felling sites, ready for the grapple skidder to load. Timely maintenance services for the machines basing on the machine working hours reduced skidders breakdown during skidding operations, short skidding distances which averaged 55 m reduced the total cycle time.

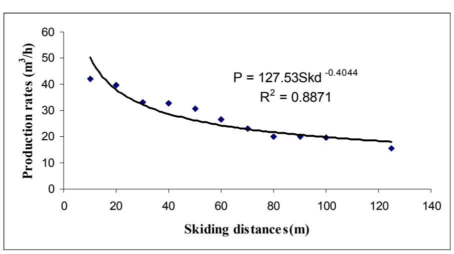

Figure 2: Production rates as a function of skidding distances

The skidding costs

The results show that the estimated fixed cost per scheduled machine hour was 7 577 TZS/h (5.7 USD/h) while the operating cost per productive machine hour was estimated to be 43 804 TZS/h. (32.8USD/h) Unit skidding costs were derived from fixed cost and variable cost which amount to 1 870 TZS/m^3 (1.4 USD). The results further agree with other research findings that an increase in average skidding distance (Figure 3), will increase the skidding unit cost (Nikoy 2007).

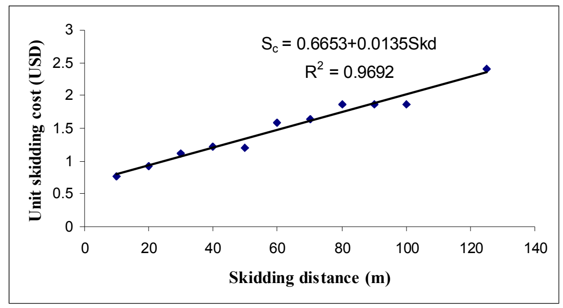

Figure 3. Unit skidding cost as a function of skidding distance

Factors affecting productivity for each work element

Regression equations were developed for each work element relating dependent variable (productive time) to independent variables that would theoretically be expected to influence the specific work element.

Travel Empty

The results indicate that travel distance is the best predictor of travel empty times as indicated by the high R^2. Furthermore, there were significant differences in travel time among skidding distances. No significant difference was found among slopes. This is attributed by the fact that the slope ranged from 0-4 % which is generally described as flat terrain which had no much resisting force on the skidding machines.

$$TE = 0.4969 + \underset{(0.000565)}{0.0089}\ Skd \qquad (5)$$

$R^2 = 0.70$, n = 124

Grappling

None of the variables selected for analysis were statistically significant predictor of grappling time. The result suggests that grappling time was influenced by the ease with which the grappling device was loosened and pulled out to grapple the bundle of logs. Therefore, the equation can not be used with confidence to predict grappling time. The average grappling time could instead be used to predict the grappling time.

$$Gl = 0.4655 + \underset{(0.00293257)}{0.00293257}\ N\lg os - \underset{(0.02)}{0.0307}\ Vol \qquad (6)$$

$R^2 = 0.026$, n = 124

Travel loaded

The results have shown that travel loaded time was best described by skidding distances, number of logs per turn, and volume per turn as indicated by high value of R^2. The results further agrees with the findings by Migunga (1996); Naghdi (2005); Javadpour (2006); Nikoy (2007) which have shown that distance was the most important factor affecting travel loaded time and skidding production rates. Volume per turn or pay load was a statistically significant factor as it affected the amount of weight carried by the skidder, this determines the resisting forces influencing the total tractive efforts required to move the load and the skidder and thus the time required to skid a turn of logs. The slope did not appear as a significant factor contrary to expectation based on field observation, Slope encountered in the field ranged between 0-4%.The terrains could be classified as easy terrain so that the changes in terrain were not significant.

$$T_l = 2.1988 + \underset{(0.002477)}{0.01125}N\lg s + \underset{(0.00056)}{0.0013}Skd - \underset{(0.029516)}{0.4693}Vol$$

, $R^2 = 0.912$, n= 154 (7)

Unloading time/Release time

None of the selected variables was statistically significant determinant of unloading time, the low values of adjusted coefficient of multiple determinations for grapple skidder operation could be attributed to the fact that unloading time depends on factors that were not studied. The factors that were included in the study were highly variable and were not controlled during the study thus the low values. Such factors could include: operator experience, skill and training, travel speed of the grapple skidder, age of the grapple skidder, method of payment of the operator and the ease with which the grapple was released from the logs and pulled out from turn of logs.

$$TU = 0.4003 - \underset{(0.000781)}{0.0008}N\lg s + \underset{(0.005331)}{0.003156}Vol,\ R^2 = 0.01048,\ n = 124 \qquad (8)$$

Total skidding time

The regression equation indicates that of the variable selected for testing, number of logs per turn, distance to the landing and volume per load statistically influence the total skidding time. But slope did not significantly influence the total skidding time, this is because the terrain was favorable for the grapple skidder as the average slope is 4 % which is almost flat terrain. The results further indicated high coefficient of multiple determination (R^2) suggesting that, the large proportion of these variables had an influence on skidding time.

The results agree with other studies reported by Klunder *et al.* (1997) and Naghdi (2005), where it was noted that productive time of grapple skidder was sensitive to skidding distances, stem size, number of stems in the load, volume of stems per turn and harvest intensity. Furthermore, the high R^2 is an indication of improvement on the total skidding time that resulted from well planned landing operations.

$$TT = 2.761 + \underset{(0.0094)}{0.0367}N\lg s + \underset{(0.00121)}{0.0026}Skd + \underset{(0.0465)}{0.16263}Vol \quad R^2 = 0.72, n = 75, \qquad (9)$$

Skidding Productivity modeling

Using the total skidding productive time equation no, production rate model was derived by using the factors that were significant in the equation.

$$P = \frac{V \times F \times 60}{2.761 + 0.036NLGS + 0.0026Skd + 0.16263Vol} \qquad (10)$$

F was calculated to be 0.8 since the necessary delays covered 20% of the total workplace time. The production rate equation (9) was used to calculate production rates for various skidding distances (Table 1).

Table 1. Estimated production rates for grapple skidder

Distance (m)	Production Rates (m^3/h)
10	42.21
20	39.75
30	33.18
40	32.73
50	30.85
60	26.61
70	22.99
80	19.87
90	19.86
100	19.78
125	15.41
Average	27.57

Skidding cost model

In general the unit cost of skidding operations can be calculated as follows

$$S_c = H / P \qquad (11)$$

Where:

S_c= unit skidding cost

H= total skidding cost, in TZS/workplace hour

P= production rates in m^3/workplace hour.

For the situation considered in this analysis, individual unit –cost equation were derived by substituting into equation the appropriate value for H and the relevant equation for P.

$$S_c = \frac{51384(2.761 + 0.036N\lg s + 0.0025Skd + 0.16263Vol)}{V \times F \times 60} \qquad (12)$$

With these equations the average unit skidding cost was estimated. This has been presented in (Figure.3) by substituting average values for the range of distances encountered during the study. The unit costs increased linearly with increasing skidding distances. This trend suggest that, an increase in skidding distances results into the increase in total cycle time which ultimately lowers the average skidding productivity and increases the operating costs per hour, finally resulting into higher average unit cost (equation 12).

CONCLUSION AND RECOMMENDATIONS

Based on the results and subsequent discussion, it can be concluded that, the estimated grapple skidder production rates ranged from 42.2 m^3/h to 15.4 m^3/h for an average skidding distance of 10 m to 124 m respectively. The cost data has further shown that the estimated fixed costs per scheduled machine hour were 7 577 TZS/h (5.7 USD/h) while the operating costs per productive machine hour were estimated to be 43 804 TZS/h (32.8USD/h). Regression analysis results indicated that productivity and costs of grapple skidder was best estimated and influenced by number of logs per turn, volume per turn and skidding distances. However the regression models, productivity, and cost models presented here should be used only in a situation where the independent variables are within the range of the study data from which the numerical models were developed.

The study recommended that, in order to improve the productivity of skidding operations through reduction of both necessary and unnecessary delay, skid trails should be planned ahead of logging operations and the machine operators must be adequately trained prior to skidding operations. This will reduce the total skidding time which inturn will improve productivity and reduce total hourly costs.

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