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OPTIMAL ROAD SPACING FOR MANUAL SKIDDING SULKIES

W. S. Abeli

Sokoine University of Agriculture, Department of Forest Engineering, P.0 Box 3012, Chuo Kikuu, Morogoro, Tanzania

&

G.M . Magomu

Makerere University, Department of Forestry, P.0 Box 7062, Kampala, Uganda

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ABELI, W.S. & MAGOMU, G.M. 1993. Optimal road spacing for manual skidding sulkies. An optimal road spacing is the one which minimizes the overall sum of skidding costs, road construction and road maintenance costs. As road spacing increases, skidding cost increases while road construction and maintenance cost decreases. Each skidding means has its own optimal skidding distance and road spacing. This study analyses skidding productions and optimal road spacing for hand sulkies skidding logs in one of the forest plantations in Tanzania. Results from this study indicate that when undertaking thinning operations especially in flat to gentle sloping terrains, sulky skidding could be considered as a better alternative to tractor and manual skidding methods. Besides being simple and cheap, the system causes minimum stand and soil damages, creates employment opportunities for the rural people and does not demand foreign capital.The average skidding distance in this study was measured to be 71 *m* while average skidding production was estimated to be 1.21 m^3/man-hour. An optimal road spacing which minimizes the overall total costs in this forest was found to be 137 *m.*

Key words: skidding means - skidding sulkies - skidding distance - skidding production - skidding cost - stock density - road construction cost - road maintenance cost - optimal road spacing

ABELI,W.S. & MAGOMU, G.M. 1993. Penjarakkan jalan yang optima untuk pengheretan manual "sulkies". Penjarakkan jalan yang optima akan meminimakan jumlah keseluruhan kos pengheretan, pembinaan jalan dan kos pembaikpulihan jalan. Apabila penjarakkan jalan bertambah, kos pengheretan bertambah manakala kos pembinaan jalan dan pembaikpulihan jalan menurun. Setiap pengheretan mempunyai jarak pengheretan dan penjarakkan jalan yang optima. Kajian ini di buat bagi menganalisa produksi pengheretan dan penjarakkan jalan yang optima bagi pengheretan kayu balak "hand sulkies" di salah satu ladang hutan di Tanzania. Hasil kajian menunjukkan bahawa pengheretan sulky boleh dipertimbangkan sebagai alternatif yang lebih baik berbanding penggunaan traktor atau pengheretan secara manual, di kawasan-kawasan tanah rata atau landai yang diperlakukan operasi penjarangan. Sistem ini bukan sahaja ringkas dan murah, ia berupaya meminimakan kerosakan pada dirian dan tanah, menunjukkan peluang pekerjaan bagi masyarakat luar bandar serta tidak memerlukan bantuan kapital dari negara luar. Purata jarak pengheretan yang di ukur dalam kajian ini ialah 71 *m* dengan anggaran purata pengeluaran pengheretan sebanyak 1.21 m^3/jam-orang. Penjarakkan optima yang berupaya meminimakan jumlah kos secara keseluruhan dalam hutan ini ialah 137 *m.*

Introduction

Skidding is the transportation of logs or trees in the forest by dragging partially or wholly on the ground (FAO 1974). It is either done manually or by the use of tractor machines which vary in size and capacity. Unlike in the developed countries, in developing countries the type of the skidding means is more or less pre-determined by what is available rather than the most suitable and economical means (Dykstra 1981).

Both tractor machines and manually operated skidding sulkies have been used for skidding logs in forest plantations in Tanzania (Ole-Meiludie 1984). While tractors have been used both in thinnings and in clearfelling operations, manual sulkies have been used mostly in thinnings and in places where the total volume of timber required per day is not very high. Although sulky productivity is lower than tractor skidding, sulky skidding, however, creates more employment opportunities to the rural people and causes minimum stand and soil damages. Skidding production figures have been found to vary from 0.6 to 2.0 m^3 h^{-1} depending on the terrain conditions and the skidding distances (Skaar 1973, Ole-Meiludie & Omnes 1979, Mboya 1985).

In any forest, forest roads are expensive undertaking and take a significant portion of the productive forest land. The closer the road spacing, the higher the road construction cost and the more forest land taken up by roads (Dykstra 1983, Abeli 1985). On the other hand, the wider the road spacing, the less the road costs and the smaller the area of wasted forest land although it tends to increase the skidding costs. This means therefore, when planning to construct branch roads, there has to be an optimal road spacing which minimizes the total of road and skidding costs plus land waste.

According to Dykstra (1981), an optimal road spacing is the one which minimizes the overall transportation costs that is, the sum of skidding costs, road construction cost, road maintenance and hauling costs. So far a number of formulas to determine the optimal road spacings have been developed (Von Segebaden 1964, FAO 1974, Dykstra 1981). All these formulas show that road construction cost, skidding cost, volume of timber harvested and road maintenance cost are the most important factors which need to be considered when determining the optimal road spacing.

At present most of the plantation forests in Tanzania are at mature stage and at different harvesting stages. Given the fact that the existing forest roads were constructed during the establishment and tending phases, there is need now to plan and construct proper and adequate logging roads (Abeli 1985). Again since each skidding means has an optimal road spacing which gives the lowest combined road and skidding costs, the need to determine optimal road spacing for each skidding means is imperative. This study analyses skidding productions and determines optimal road spacing for hand sulkies used in skidding logs in one of the forest plantations in Tanzania.

Methodology

The study area

The study was carried out at the Sokoine University of Agriculture (SUA) Training Forest near Arusha in 1988. The forest (840 *ha*) lies on the slopes of Mt. Meru at an altitude of between 1,700 and 2,230 *m* above sea level. The main tree species grown here are *Cuppresus lusitanica, Pinus patula* and *Eucalyptus*. Both thinning and clearfelling operations have been going on in this forest using both manual and semi-mechanized logging methods.

Data collection

Data was collected on three stands of *C. lusitanica* being thinned. Logs from these stands (11, 17 and 19 years old) were skidded to the roadside decks by means of locally made and manually operated two-man skidding sulkies. Each sulky with two wheels fitted with rubber tires weighed 25 *kg* and had a pulling handle of about 1.8 *m* long. Logs were chocked and slotted to the slots located on the inverted "U" shaped frame. The width of this frame was 90 *cm* and because of its shape, it formed a ground clearance of about 65 *cm.* When skidding, usually one end of the log drags on the ground while the other end is suspended (Figure 1).

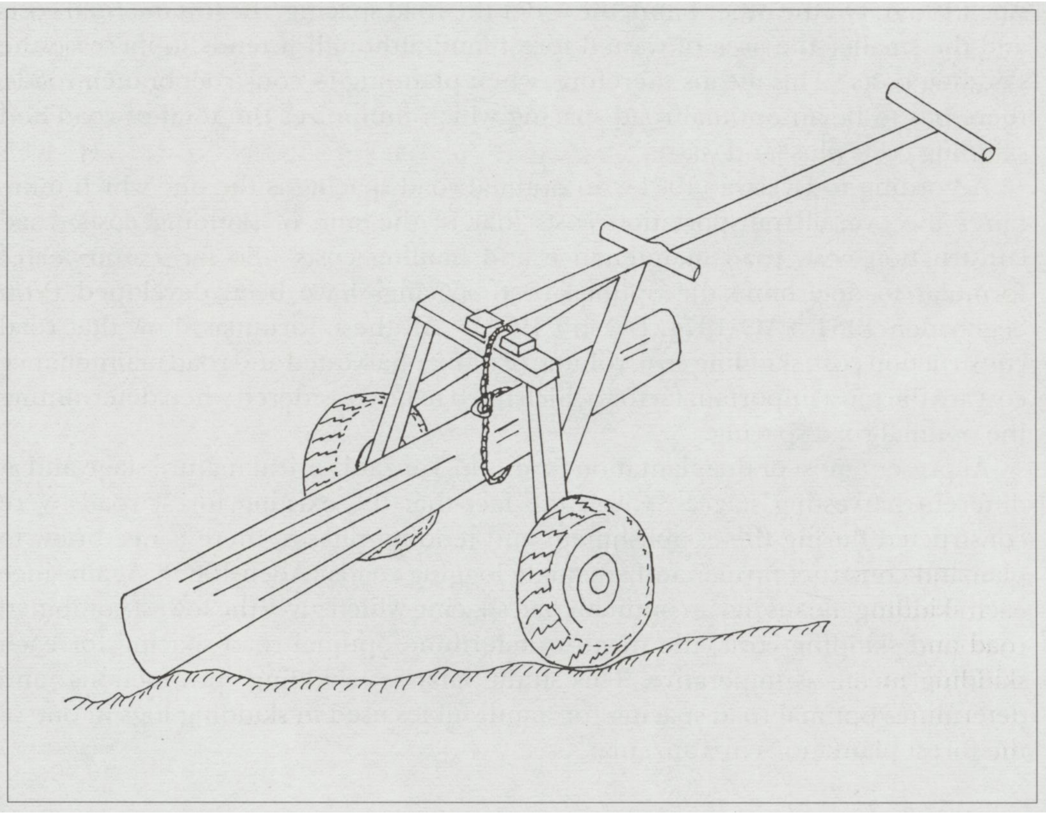

Figure 1. A sketch of a hand sulky with a log ready to be skidded

The total time spent in the forest skidding logs was recorded as work place time (WPT). Work place time was divided into productive time and delay time. The latter was further segregated into Necessary and Unnecessary delay times.

Detailed work and time studies were undertaken in order to be able to determine the skidding productions and costs. Each skidding round trip journey formed a work cycle and each work cycle was made up of the following work elements: loading, skidding, unloading, piling and return empty.

In addition to time studies, independent variables considered to influence skidding production and optimal road spacing were also measured. These included the skidding distance, the number of logs or log volume per trip, terrain slope, ground roughness and stand volume density.

Skidding costs and road maintenance costs were obtained from SUA Training forest files or estimated by using (1977) cost estimation procedures. For road construction costs, construction costs estimated by Abeli (1985) for a secondary access road were used with some modifications.

Data analysis

Statistical computations on work element times and those independent variables associated with skidding operation and optimal road spacing were undertaken and tested (by use of t-test) to see if they had any influence on the skidding production and optimal road spacing. In addition, multiple linear regression equations were developed to determine those independent variables which were significantly correlated to the dependent variable(s). Using these regression equations, it was possible to estimate skidding productions under various working conditions. Costs presented in this study are 1988 production costs when 1 US dollar ($) was equivalent to about 125 Tanzanian shillings (shs).

Equation (1) developed by Mathews (1942) and later modified by Dykstra (1981) was used in computing the optimal road spacing. The equation assumes that the road will not be used for more than one year and all the logs will be skidded directly to the roadside decks.

$$S = \sqrt{\frac{10{,}000k\,(C_R + C_M)}{C_S V_A}} \quad \text{.............................} \quad (1)$$

Where

S = Optimal road spacing, *m*
k = 4 for two way skidding and 2 for one way skidding
C_R = Cost of constructing 1 *m* length of road, shs m^{-1}
C_M = Cost of maintaining 1 *m* length of road, shs m^{-1}
C_S = Cost of skidding 1 m^3 of logs 1 *m* distance, shs $m^{-3}m^{-1}$
V_A = Stand volume density, $m^3\ ha^{-1}$

Results and discussion

Skidding production

Table 1 summarizes statistics for productive skidding work elements while Table 2 shows summary statistics for some independent variables measured in the field.

Table 1. Summary statistics for productive work elements

Statistic	Loading (*min*)	Skidding (*min*)	Unloading (*min*)	Piling time (*min*)	Return empty (*min*)	Total productive (*min*)
Mean	1.8	2.07	0.89	0.85	2.02	7.63
Standard deviation	0.67	0.97	0.57	0.47	0.94	-
Minimum value	0.53	0.39	0.21	0.19	0.35	-
Maximum value	3.50	3.33	3.18	2.22	5.02	-
% of Productive time	23.7	27.1	11.7	11.0	26.5	100

Table 2. Summary statistics for some independent variables measured during log skidding

Statistic	Ground slope (%)	Ground roughness	No. of logs per trip	Volume per trip (m^3)	Skidding distance (*m*)	Return empty dist. (*m*)
Mean	- 4.40	3.0	1.50	0.15	71.0	66.0
Standard deviation	0.78	0.0	0.54	0.07	24.15	37.69
Minimum value	- 3.6	3.0	1.0	0.07	18.0	20.0
Maximum value	- 12.0	3.0	3.0	0.63	177.0	176.0

Productive working time took about 81% of the total work place time. Delay time which accounted for 19 % of the WPT was slightly higher than what was found by Ole-Meiludie (1984) and Mboya (1985) due to worker's low working experience and more ground obstacles encountered in the stands studied. Skidding loaded and return empty work elements took about 54 % of the productive working time in almost equal proportions. As the terrain slope increased, the less efficient the sulky became since it took more time to pull the empty sulky uphill and more time to skid logs downhill because of frequent brakings required to control downhill speed.

Although the skidding slopes ranged from 3.5 to 12 %, the slope measurements taken during the study were not equally distributed in each grade to justify statistical analysis. Most of the slope data collected ranged between 4 and 6 % and because of this, it was difficult to determine statistically the optimal skidding slope for the hand sulky. Despite the few data on the higher grades, the trend, however, showed that as the grades exceeded 6 %, skidding empty time (when pulling the empty sulky uphill) increased quite considerably. This means therefore in order to determine the optimal skidding slope for hand sulkies more studies need to be carried out to establish in addition the upper limits beyond which the system turns out to be strenuous and less efficient.

Regression analysis showed that only about 50 % of the variations in skidding cycle time could be attributed to changes in skidding distances (both empty and loaded), volume or number of logs per trip, ground roughness and terrain slopes. This indicates that there are other independent variables not included in the equation which contributed also to the variations in total skidding cycle time. Equation (2) shows the relationship between total cycle time and some independent variables measured in the field.

$$\text{Totime} = 0.5401 - 0.0410\text{Slope} + 0.2841\text{Nlogs} - 0.1120\text{Rough}$$
$$0.8713\text{Logvol} + 0.0758\text{Skload} + 0.0205\text{Rtempt} \quad \ldots (2)$$

R^2 = 0.49, n = 145

where

Totime = total productive cycle time, *min*
Slope = downhill terrain slope, per cent
Nlogs = number of logs per trip
Rough = ground roughness
Logvol = load volume per trip, m^3/trip
Skload = skidding distance (loaded), *m*
Rtempt = return empty distance, *m*
R^2 = coefficient of determination
n = number of observations

When tested at five per cent probability level, only those regression coefficients associated with skidding distances (empty and loaded), slope and load per trip were significantly different from zero. This meant these were the most important independent variables which influenced skidding production. The shorter the skidding distance, the higher the skidding production and vice versa. For instance when the skidding distance was 18 *m*, skidding production was 1.65 m^3/man-hour while productivity dropped to 0.66 m^3/man-hour when the skidding distance increased to 107 *m*. With an average skidding distance of 71 *m*, the average skidding production was estimated to be 1.21 m^3/man-hour. These findings are very close to the findings of Ole-Meiludie (1984) and Mboya (1985) where productivity varied from 0.61 m^3/man-hour to 1.96 m^3/man-hour when the skidding distances were 85 *m* and 20 *m* respectively.

Skidding and road cost

Sulky skidding cost was estimated by the SUA Training Forest management to be shs 92.00 m^{-3} as compared to shs 241.50 m^{-3} by farm tractors. Assuming that the average sulky skidding distance was 71 *m* (as found in this study), the unit skidding cost was shs 1.30 m^{-3} m^{-1}. File Records also showed that the average road maintenance cost for this forest was shs 2.03 m^{-1} (Silloh 1988).

Based on Abeli (1985), road construction costs data and after adjusting for inflation and subtracting road surfacing costs, construction of branch roads in this forest was estimated to cost shs 490 m^{-1}. Assumption was that unlike secondary access roads, branch roads would not require gravel (as a surfacing material) due to less traffic and short duration under use.

Optimal road spacing

Since the terrain was not flat but rather gently sloping, log skidding was done in one direction only, *i.e*. down slope. Stands being thinned were estimated to have an average stock density of about 400 $m^3\ ha^{-1}$. Using equation (1) and cost figures given above, the optimal road spacing was estimated to be:

$$S = \sqrt{\frac{20{,}000\ (490 + 2.03)}{1.30\ (400)}}$$

$$S = 137\ m$$

From the above computation, the optimal road spacing when skidding with hand sulkies was 137 *m*. Since logs were skidded downhill only (one way skidding), the average skidding distance was supposed to be 68 *m* which is slightly lower than the actual average skidding distance measured in the field (71 *m*). The small difference (3 *m*) experienced in this study could largely be due to the skidding "weave quotient". When skidding from the stump site to the roadside deck, the sulky had to weave around obstacles rather than making a straight line path. This resulted in the actual skidding distance being slightly longer than the expected average skidding distance.

When the optimal road spacing obtained in this study is compared with the recommended optimal road spacing for farm tractors, the number of branch roads required for sulky skidding appears to be more than double for the same area. Sessions and Welker (1987), for example, recommend that the optimal road spacing for agricultural farm tractors should be 300 - 400 *m* when skidding downhill. This implies that before making a decision on which skidding means to adopt, in addition to slope and the skidding cost the road density and all the costs associated with road construction have to be considered.

Conclusions

The study shows that sulky skidding system is sensitive to slope, log size and skidding distance. The system works best on flat to gentle sloping terrains while as the terrain steepness increases, productivity decreases due to stress and more time is required to pull the empty sulky uphill. Depending on the terrain slope, skidding can either be one way or two ways. In flat areas, sulkies can be used to skid logs in both directions (two way skidding) while in gentle to steep terrains, sulkies are used to skid logs downhill only as was the case in this study.

Where log sizes are less than 0.20 m^3 per piece, *i.e.* fence posts, chiplogs and firewoods, sulky skidding could be considered as a realistic and better alternative to tractor skidding or manual forwarding and dragging. As observed in this study, besides low investment the system creates employment opportunities for the rural population, demands no foreign currency and above all, causes minimum soil and tree damages.

For gentle sloping terrains where logs are to be skidded in one direction only, a road spacing of about 137 *m* with an average skidding distance of about 68 *m* appears to be an optimal road spacing for hand sulkies. This is the spacing which minimizes the overall sum of skidding and road costs. A road spacing different from the one recommended in this study would definitely increase the overall total costs.

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