PINE

Paper No. 00-5015
An ASAE Meeting Presentation

PRODUCTIVITY AND COST COMPARISON OF TWO DIFFERENT-SIZED SKIDDERS

by

John Klepac and Bob Rummer
General Engineer / Project Leader

USDA Forest Service
Southern Research Station
Auburn, Alabama, USA

Written for Presentation at the
2000 ASAE Annual International Meeting
Sponsored by ASAE

Midwest Express Center
Milwaukee, Wisconsin, USA
July 9-12, 2000

Summary:

Productivity and cost of two skidders, Timberjack models 460 and 660, were evaluated while operating in a loblolly pine plantation performing a clearcut harvest in the Southeastern US. Productivity without delimbing was 46.7tonnes per PMH for the model 460 and 51.7 tonnes per PMH for the model 660. Cost per tonne was $1.70 for the model 460 and $1.90 for the model 660. The model 460 utilized 67 percent of its grapple area, compared to only 56 percent for the model 660.

Keywords:

Harvesting, skidders, production, costs

Productivity and Cost Comparison, of Two Different-Sized Skidders

John F. Klepac
Bob Rummer

INTRODUCTION

The grapple skidder is the most common machine used on mechanized forest operations throughout the southern US. As the vital link between the woods and the landing, skidding accounts for between 25-30 percent of the total stump-to-truck cost per tonne for a typical chipping operation. Over the past three decades, technological advances have enabled equipment manufacturers to continually improve skidder design, enhancing both performance and ergonomics. A recent trend in skidder design has been the development of larger capacity grapple skidders. Most manufacturers currently offer a grapple skidder in the 160 to 172-kW range. Higher powered engines coupled with large capacity grapples enable modem skidders to haul as much as 0.1 -m^3 of wood.

Larger capacity skidders offer several potential benefits for forest operations. Bigger loads may increase the productivity of the skidder, allowing a harvesting system to balance with fewer machines. A system with fewer machines realizes savings in reduced maintenance, reduced labor, reduced moving costs, and reduced interference delays. An important application of larger skidders has been in southern shovel logging where system production rates may approach 500 tonnes per day. Whole-tree chipping systems are another high-production application where larger machines are critical.

Tufts et al. (1988) compared productivity among 12 different grapple skidders ranging from 57 to 138-kW. Total cycle time equations were developed that incorporated horsepower, load factors, and skid distance. The observed travel loaded speeds on 495 cycles did not vary significantly by horsepower. Load sizes were also not a consistent function of machine power, indicating that the larger capacity machines were not fully utilized. The authors noted that travel speed may have been limited by operator comfort while load size may have been constrained by the gate delimbing function.

Load size, and the basic bunch size developed by the feller-buncher, are recognized as critical determinants of skidder productivity. Optimizing bunch size was studied by Gingras (1988). He observed four operations and the effect on both feller-buncher and skidder productivity from varying bunch sizes was evaluated. In summary, for skidder productivity, results indicated that with smaller bunches on longer skids it is best to accumulate two or more bunches, but on short skids (less than 50-m) optimum productivity occurs with a single bunch since the terminal elements (position and grapple and ungrapple) represent a larger portion of the cycle.

The previous studies documented limitations on achieving higher productivity with larger skidders. Generally, maximizing potential payload was constrained by other system functions such as the feller-buncher or delimbing capacity. As total system productivity has increased, however, these constraints may be less limiting. Current large skidder designs may be a more efficient fit for modem forest operations. Therefore, the objective of this study was to examine the operational performance of two sizes of grapple skidders on a whole-tree chipping operation and develop inferences about production efficiency.

METHODS

The Harvesting System

Two Timberjack[1] 60-series grapple skidders were studied while operating in stands of plantation loblolly pine performing a clearcut harvest. The 60-series was introduced in 1996 with improved weight distribution, power shift transmissions with EGS electronic shift modulation, and significantly larger cabs with improved operator comfort. This study examined a 660 (the largest 60-series skidder) and a 460 (Table 1).

Table 1. Grapple skidder specifications

Feature	Model 460	Model 660
Engine	130-kW	160-kW
Grapple	305-cm Esco	330-cm Esco
Tires	Firestone 67x34-26	Firestone 30.5Lx32
Weight	13,923-kg	16,570-kg

The harvesting operation consisted of two Hydro-Ax feller-bunchers (411 EX and 611 EX) with shear heads, three Timberjack grapple skidders (450C, 460, and 660 models), one Timberjack 330 knuckleboom loader with a pull-thru delimber, one Peterson Pacific DDC 5000 delimber/debarker/chipper coupled with a Prentice 180D knuckleboom loader, and one Caterpillar D6C dozer. The logger utilized eight chip vans and four log trucks and averaged 15-20 loads of chips per day. Trees were skidded whole-tree to the landing and sorted into either pulpwood or sawlogs. The skidders performed some gate delimbing on the way to the landing.

Stands

The harvesting operations were conducted in Macon and Lee counties in east-central Alabama. Both machines were observed while clearcutting loblolly pine plantations on gently rolling terrain typical of coastal plain conditions. Slopes ranged from 0 – 10% on both sites. Soil conditions on both sites were very dry during data collection. The model 460 skidder was evaluated while operating in a 15-yr-old plantation (Stand 1) while the 660 was observed in a

[1] The use of commercial names is for the convenience of the reader and does not imply any endorsement by the USDA Forest Service.

24-yr-old plantation (Stand 2). Both skidders had different but experienced operators. Stand 2 had a small component of sawlogs harvested from it. Table 2 summarizes characteristics of each stand.

Table 2. Stand characteristics. [1]

Stand	Age (yrs)	DBH (cm)	Trees per ha'	Tons per ha Pulp	Tons per ha Saw	Site Index (m)	Bunch Size # Trees	Bunch Size Tonnes
1	15	15.7	1791	168	-	18	25.6	4.61
2	24	17.8	642	67	7	16	18.0	3.50

*ha represents hectares

Data Collection and Analysis

Standard time and motion study techniques were used to measure the following elements: Travel Empty, Position and Grapple, Travel Loaded, Delimbing, and Delays for both skidders. Elemental times were summed to estimate total cycle time. Delay times were recorded but not summarized.

Independent variables measured included weight per tree, weight per bundle, skid distance, trees per bundle, number of bundles, DBH per tree, DBH per bundle, basal area per tree, basal area per bundle, horsepower, and grapple size.

Individual trees within bunches were measured for obtaining weight estimates. Butt diameter and DBH were measured to the nearest 0.25-cm. Total tree length was measured to the nearest 0.03-m. Since trees were bunched together, with more than 20 trees on some occasions, not all DBH's and lengths could be measured. To estimate DBH for unmeasured trees, a regression equation was developed with butt diameter as the predictor variable. To estimate total length for unmeasured trees a regression equation was developed with DBH as the predictor variable. Volume per tree was calculated using appropriate equations from Clark and Saucier (1990). Bunches were numbered using fluorescent paint on the butts of trees for determining total volume skidded per cycle. Travel empty and loaded skid distances were measured to the nearest 0.3-m.

General Linear Models procedure was used to determine which independent variables accounted for the most variation in predicting total cycle time. A 0.05 level of significance was used during the analysis. Duncan's Multiple Range Test was used to compare one-way distance, tons per cycle, DBH per cycle, and number of stems per cycle.

RESULTS

A total of 35 observations were collected on the model 460 skidder and 32 observations on the model 660. Table 3 summarizes the time study, load and stand variables for the two skidder models. Mean one-way skid distance was slightly greater for the model 660, but was not significantly different than that for the model 460. Mean load size was greater for the model 460 as compared to the model 660. A significant difference in load size was found between the two models. Mean DBH of trees skidded by the model 460 was greater than the model 660 and was significantly different.

Table 3. Summary of time study variables for the two skidder models.

	Model 460		Model 660	
Variable	Mean	Range	Mean	Range
Time study variables				
Travel empty, min	2.69	1.02 - 4.97	1.98	0.56 - 3.80
Pos. and Grap., min	0.73	0.33 - 2.37	0.84	0.27 - 2.22
Int. travel, min			1.04	0.24 - 2.70
Travel loaded, min	3.03	1.46 - 4.27	2.64	0.73 - 5.13
Delimb, min	0.21	0.15 - 0.26	0.88	0.12 - 1.62
Total time, min	6.47	2.87 - 10.47	6.47	1.81 - 12.86
Productivity, tonnes/PMH[1]	46.5	23.4 - 92.1	45.7	14.2 - 106.9
Travel loaded speed, kph	6.50	5.23 - 7.77	8.03	4.18 - 11.58
Load variables				
Weight, tonnes	4.68	2.89 - 7.01	4.16	1.79 - 5.86
DBH/tree, cm	16.8	5.1 - 30.0	17.8	6.1 - 39.4
Total length, m	14.8	7.0 - 19.8	13.4	7.7 - 18.5
Weight/tree, tonnes	0.18	0.01 - 0.72	0.20	0.01 - 1.19
No. of trees	25.1	12.0-41.0	20.5	8.0 - 40.0
No. of bundles	1.0	1.0 - 1.0	1.25	1.0-2.0
Stand variables				
Empty distance, m	303	39-551	333	105 - 718
Loaded distance. m	329	148 - 473	355	115-732
One-way distance, m	316	94 - 454	344	110-705

[1] includes delimbing

Stand 1 had a density of 1791 trees per hectare. This resulted in a mean bundle size of 25.6 trees built by the feller-buncher. This bundle size challenged the capability of the 305-cm grapple on the model 460, making the skidder unable to grapple a full bundle 11 percent of the time. This resulted in a mean of 25.1 trees per cycle skidded by the model 460. Stand 2 had a density of only 642 trees per hectare. This caused the feller-buncher to build smaller bundles, which averaged 18 trees. For this reason the model 660 grappled two bundles 25 percent of the time in order to more fully utilize its grappling capability and increase its payload, which resulted in a mean of 20.5 trees per cycle skidded. Of the total number of observations where two bundles were grappled, 83 percent occurred at one-way skid distances that exceeded 610-m. Mean number of bundles per cycle was 1.25 for the model 660 skidder. Hauling two bundles did not have an impact on travel loaded speed for the model 660. Even though its payload was increased by 3 1 percent, travel loaded speed was 8.50 kph, compared to 7.92 kph while hauling one bundle.

Delimbing only occurred 8.6 percent of the time with the model 460 skidder, while the model 660 delimbed 87.5 percent of the time. Mean cycle time was 6.47-min for both skidders. Total cycle time ranged from 2.87 to 10.87-min for the model 460 skidder. Without delimbing mean cycle time was 6.58-min. for the model 460. Since only three occurrences of delimbing were observed for the model 460, total cycle time with delimbing is not a reliable estimate, and therefore, *is* not reported. For the model 660 skidder, total cycle time ranged from 1.81 to 12.86-min. Eliminating delimbing time, the model 660 averaged 6.07-min per cycle. Performing delimbing resulted in a mean total cycle time for the model 660 of 6.95-min., an increase of more than 14 percent.

Mean position and grapple time for the model 460 was 0.76-min, compared to 0.65-min for the model 660. Of the total nurnber of observations for the model 460, 14 percent had position and grapple times that exceeded 1-min, compared to 9 percent for the model 660.

Total time without delimbing for the two models was best predicted by the following equations:

Model 460: Total time per cycle = 0.946008 + 0.017397 x Distance
R^2 = 0.85 MSE = 0.442280 N = 35
where: Distance = one-way skid distance (m)

Model 660: Total time per cycle = 1.455871 + 0.012316 x Distance
R^2 = 0.84 MSE = 1.29636 N = 32
where: Distance = one-way skid distance (m)

Figure 1 represents estimated total cycle time for the two models over the range of skid distances observed for that model. At skid distances less than about 180-m, estimated cycle time for the model 460 is faster. For skid distances greater than 180-m, the model 660 is estimated to have a faster cycle time. For every 61-m increase in skid distance, total cycle time increases 0.53-min for the model 460 and 0.38-min for the model 660.

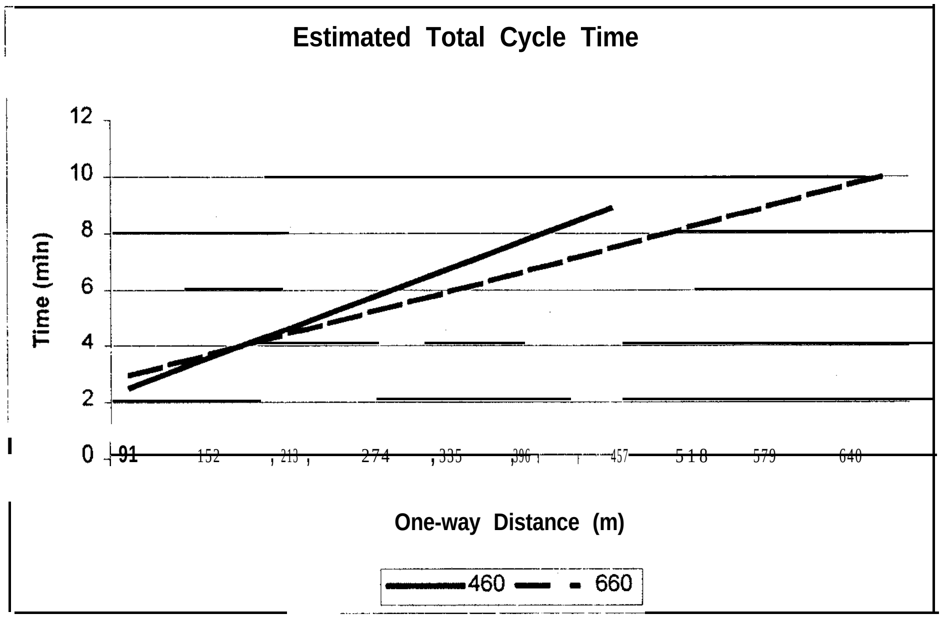

Figure 1. Time per cycle as a function of one-way skid distance.

One-way skid distance accounted for the majority of the variation in total cycle time for both models. For the model 460, 57 percent of the observations occurred at one-way skid distances between 305 to 457-m. The remaining observations occurred at distances less than 305-m. For the model 660, 47 percent of the observations occurred at one-way skid distances between 152 to 305-m. However, 28 percent of the cycles for the model 660 were at distances greater than 305-m, with a maximum of 705-m observed.

Productivity without delimbing was 46.7 tonnes per PMH (Productive Machine Hour) for the model 460 and 5 1.7 tonnes per PMH for the model 660. Observations where delimbing occurred revealed a productivity of 40.6 tonnes per PMH for the model 660, compared to 47.4 tonnes per PMH without delimbing, an increase in productivity of 17 percent. The major factor that enhanced productivity of the model 660 was travel speed. Travel empty and loaded speeds for the model 660 were 41 and 24 percent faster than the model 460, respectively. Productivity over the range of one-way skid distances was estimated using the regression equation for total cycle time and a mean turn volume for each skidder. Estimated productivity for the two models is illustrated in Figure 2.

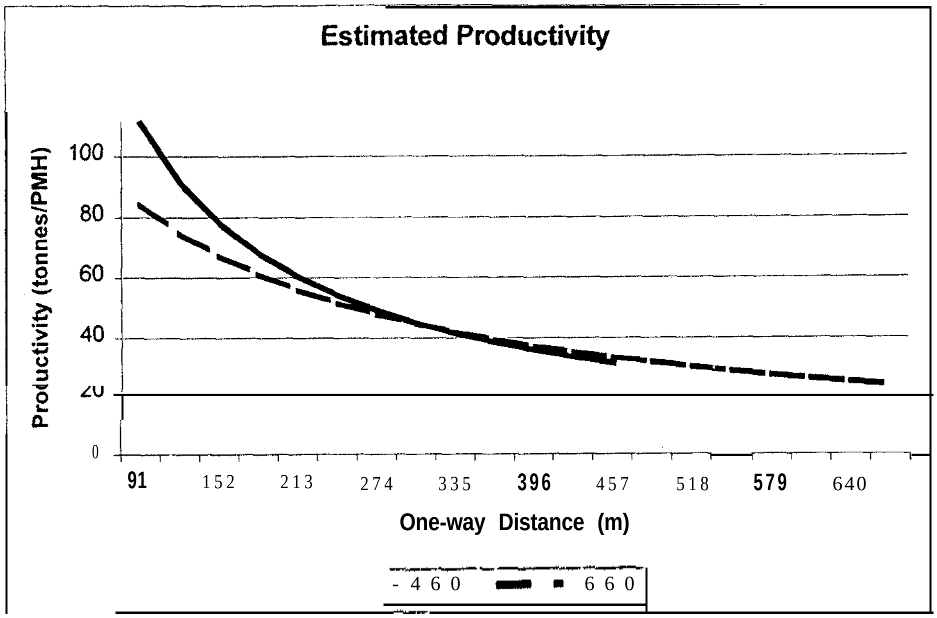

Figure 2. Estimated skidder productivity as a function of one-way skid distance.

Apparently the model 660 skidder was under loaded since, on average, it hauled approximately 18 percent fewer stems and 11 percent fewer tonnes per cycle than the model 460. With a 1 .5-m^2 capacity grapple, 0.4-m^2 more than the 305-cm grapple on the model 460, and an additional 30-kW, the model 660 should have the ability to haul larger loads.

Considering total area at the butt of skidded bundles, using butt diameter outside bark as the independent variable, the model 460 averaged 0.74-m^2 of wood area per cycle, which resulted in a grapple utilization of 67 percent. The model 660 averaged 0.83-m^2 per cycle, which is only 56 percent of its grapple capacity. Since a cord of wood contains about 30 percent air space, a maximum grapple utilization of 70 percent could be expected. Study results indicate the model 460 was able to grapple a more efficient load than the model 660. This is most likely a function of the feller-buncher. Since the feller-b&her had to build bundles that either machine could handle, this limited the grapple utilization of the model 660 skidder. Since, in most instances, grappling two bundles was not possible the model 660 was limited to hauling one bundle the majority of the time. It is critical for the feller-buncher to build the appropriate bunch size so skidders are not underutilized.

ECONOMICS

A standard machine rate analysis was used to estimate hourly owning and operating costs for the skidders (Brinker et al. 1989). Table 4 summarizes the assumptions for determining costs.

Table 4. Machine rate analysis.

	Skidder Model	
	460	660
Ownership costs[1]		
Depreciation ($/yr)	25,087	34,575
Interest ($/yr)	8,655	11,928
Insurance & taxes ($/yr)	6,690	9,220
Cost ($/SMH)	20.22	27.86
Operating costs[2]		
Fuel & Lube ($/PMH)	7.60	9.39
R & M ($/PMH)	16.13	22.23
Tires ($/PMH)	0.93	0.89
Wage & benefits ($/SMH)	18.00	18.00
Cost ($/SMH)	35.26	40.75
Total machine costs		
($/SMH)	55.48	68.61

[1] A purchase price of $140,000 was used for the 460 and $192,000 for the 660, with an interest rate of 9%, an insurance and tax rate of 5% of the purchase price (Brinker et al, 1989), a machine life of 4 years, a utilization rate of 70%, $15.00 per hour labor plus 30% benefits, and 2000 scheduled machine hours (SMH) per year.
[2] A fuel cost of $1.14 per gallon was used, with a lube and oil rate of 36.8% of hourly fuel cost, and a fuel consumption rate of 0.028 galkp-hr (Brinker et al, 1989).

Cost per tonne was $1.70 for the model 460 and $2.15 for the model 660. These data indicate that the logger is paying an extra $0.45 per tonne to operate the model 660 skidder but it is producing slightly less wood than the model 460. Comparing the two models with delimbing time subtracted, cost per tonne was $1.70 for the model 460 and $1.90 for the model 660, a difference of $0.20 per tonne. Even though productivity of the model 660 was more than 10 percent higher than the model 460, the higher machine rate of the larger skidder more than offset the difference in productivity. Performing delimbing resulted in a cost per tonne for the model 660 of $2.41, an increase of more than 16 percent over the cost without delimbing.

CONCLUSIONS

Mean cycle time was identical between the two skidders at 6.47-min, even though the model 660 performed gate delimbing over 87 percent of the time. The operator was able to compensate for the extra time spent delimbing by a faster travel loaded speed. Not performing delimbing reduced the mean cycle time for the model 660 by 12 percent.

Productivity without delimbing was 46.7 and 5 1.7 tonnes per PMH for the 460 and 660 models, respectively. Eliminating delimbing time for the model 660 resulted in a 13 percent increase in productivity as compared to its production where delimbing was performed. Inferences about productivity for the model 460 while performing delimbing cannot be made since too little data were obtained.

With a smaller capital investment, cost per tonne for the model 460 was 21 percent lower as compared to the model 660. These data indicate that the logger paid an additional $0.45 per tonne for the model 660 to provide about the same amount of wood as the model 460. Without delimbing, productivity for the model 460 was 10 percent lower as compared to the model 660. Cost per tonne for the model 660 without delimbing was lowered 14 percent when compared to cost per tonne with delimbing included.

Productivity of the model 660 could be enhanced in two ways: eliminating delimbing in the woods or making better utilization of its grapple, or both. If the model 660 skidder utilized 67 percent of its grapple, it should have the ability to haul around 5.0 tonnes per cycle, an increase in payload of nearly 20 percent over the observed turn volumes. To meet this payload increase the feller-buncher would have to adjust the bundle size it builds to match the capability of the model 660. If the model 660 was fully loaded, the cost per tonne of the larger skidder without delimbing would be $1.86.

LITERATURE

Brinker, R.W., Miller, D., Stokes, B.J., and Lanford, B.L. 1989. Machine rates for selected forest harvesting machines. Circular 296. Alabama Agricultural Experiment Station. 23 pp.

Clark, Alexander III and Saucier, Joseph R. 1990. Tables for estimating total-tree weights, stem weights, and volumes of planted and natural southern pines in the southeast. Georgia Forest Research Paper 79. Research Division, Georgia Forestry Commission. 23 pp.

Gingras, J.F. 1988. The feller-buncher/grapple skidder system: optimizing bunch size. FERIC Technical Report TR-8 1, Pointe Claire, Que.

Tufts, Robert A., Stokes, Bryce J., and Lanford, Bobby L. 1988. Productivity of grapple skidders in southern pine. Forest Products Journal 38(10): 24-30.