Tree-Length System Evaluation of Second Thinning in a Loblolly Pine Plantation

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ABSTRACT: *A productivity study and system evaluation was carried out on a tree-length operation working in a second thinning of loblolly pine near Greenville, North Carolina. The average tree volume was 8.1 ft^3 and the average dbh was 8.4 in. The machines studied in the system were the Tigercat 720B feller-buncher, the Tigercat 630 skidder, and the tracked loader Tigercat 245. The goal was to reduce the standing timber from 225 trees/ac down to 92. Standard time-study methodology and multivariance statistical analyses were used to capture and evaluate the data. The key productivity parameters identified for the feller-buncher was piece volume and number of trees in the bunch, and for the skidder extraction distance, average piece volume and number of bunches picked up to make a turn. The ability of the loader to process increasing number of trees as average tree volume decreased, and the increased difficulty of delimbing the larger trees resulted in no significant variance for average piece size. Productivity functions were developed for the feller-buncher and the skidder. The system evaluation discusses the productivity balance between the machines for the given range of piece size as well as potential operational improvements based on in-field observations. South. J. Appl. For. 27(2):77–82.*

Key Words: Harvest system evaluation, second thinning, productivity functions, loblolly pine, feller buncher, skidder, loader.

Loblolly pine plantations grown with the objective of producing sawlogs in the southeastern region of the United States will typically be thinned twice to provide high value sawlogs. While first thinning is typically at about age 12 and the resulting small material chipped, the second thinning will attempt to maximize sawlog material.

There is a great need to optimize the extraction system for this thinning operation to avoid carrying costs for the duration of the growing cycle. The main system options for this type of operation include the full tree-harvesting system, such as a feller-buncher combined with skidders for extraction, or the cut-to-length harvester forwarder combination. Lanford and Stokes (1996) compared a skidding and forwarding system in 18-yr-old loblolly pine and found the costs to be comparable for short pulpwood but in favor of skidding for longer material. While harvester-forwarder systems have environmental advantages in plantation thinning on moderate terrain (Lanford and Stokes 1996), they remain more expensive compared to skidder extraction on a cost per unit basis (Hartsough et al. 1997).

Establishing the key parameters that affect machine productivity allows the results to be transferred and provides meaningful productivity estimations at other sites and operations. Removal intensity and tree size are key parameters that affect productivity and cost (Gingras 1988, Tufts 1997, Kluender et al. 1998), as does thinning pattern (Winsauer et al. 1984).

Previous feller buncher studies have focused on the single machine and not the system as a whole, which is critical for determining the maximum potential of the system in changing stand conditions. The interaction between the machines can result in significant differences in machine utilization and hence overall production.

The aim of this study is to develop productivity models for all machinery involved in tree-length extraction in a typical second thinning operation in loblolly pine. In addition, a system evaluation will be carried out to show how changing

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stand parameters affect the machine combination efficiency, as well as identify improvement opportunities.

Methodology

Stand Description

The stand was loblolly pine, planted in 1981 at approximately 550 stems/ac (1,375 stems/ha) and first thinned in 1993. The first thinning removed every fifth row (“outrow” thinning) and reduced the stems/ac to 225 (562 stems/ha). The trees had been pruned to 25 ft (7.5 m) after the first thinning. The second thinning (Figure 1) goal was 92 stems/ac (230 stems/ha).

Tree dbh was recorded for three sections of the stand totaling 812 trees, each section being approximately two complete corridors. The average dbh was 8.4 in. (21 cm). A height curve was established for the trees by measuring 31 trees on the ground ($R^2 = 0.57$):

$$Tree\ Height\ (ft) \ = \ 25 \ \times \ dbh(in.)^{0.34}$$

Stem volume was obtained from tables (Clark and Souter 1996) using the dbh and height (inside bark and to a 4 in. top). The average tree volume removed from this stand was 8.15 ft^3 (0.24 ton). [Note: Piece size is given as ft^3 but is also converted to tons (equal to 2,000 lb or 907 kg). For loblolly pine, green weight is approximately 59 lbs/ft^3; there are 37.1ft^3 in one m^3. Therefore there are approximately 1.1 ton/m^3 for green pine.]

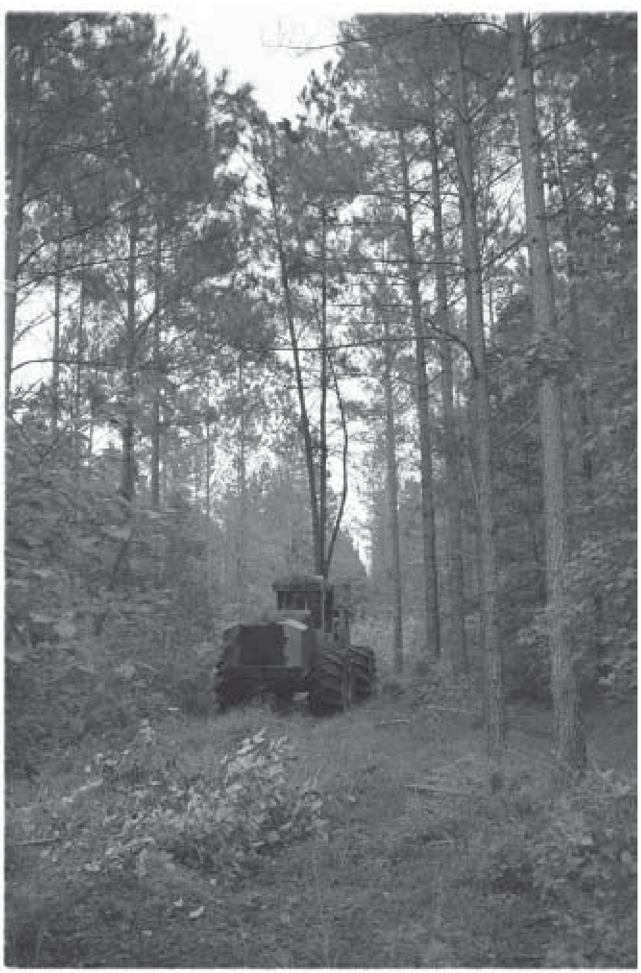

Figure 1. Feller-buncher carrying out a second thinning in an 18-yr-old loblolly pine plantation just north of Greenville, NC.

System Description

TLC Logging had the following machinery on site:

1 Feller-buncher:	Tigercat 720B
3 Skidders:	Tigercat 630 with 120 in. grapple.
	Timberjack 380C, and Timberjack 450B
2 Tracked loaders:	Tigercat 245
2 Static delimbers:	Trailer mounted CTR 400 and 500

One skidder was considered spare and used only in case of breakdown. All machine operators were considered experienced. The basic layout of the system is shown in Figure 2.

The feller-buncher drives to the end of each corridor and then works its way back, making forays into the stand to complete the thinning. Typically it will cut either 2, 3, or 4 trees, back out of the stand, and place them in the corridor as a “bunch.” Bunching leads to significant increases in productivity of the subsequent skidder extraction (Kluender and Stokes 1994).

The skidders start at the front of each corridor and work their way back. They turn around at a convenient location and accumulate between 1 and 5 bunches to make a full turn to extract to the landing. The skidders must place the turn of timber within reach of either knuckle boom loader. The mobility of the tracked loaders was not used on the landing.

Depending on tree size, the loader will pick up one, two, or three trees and delimb by pulling them through the static CTR delimber. The stems are then placed in the sawbuck and cut to length to meet either pulpwood or chip-and-saw specifications, and stacked separately. The loaders are placed in such a way that a log truck can be backed between them and loaded from both sides. Loading a truck takes priority over processing the trees brought in by the skidders.

Productivity Study

Time and motion data were collected on the feller-buncher, one of the skidders, and both of the loaders. Husky HG/HS handheld computers were used for time-study data collection using the software Siwork3 (Danish Institute of Forest Technology). Truck loading time was also recorded for a limited

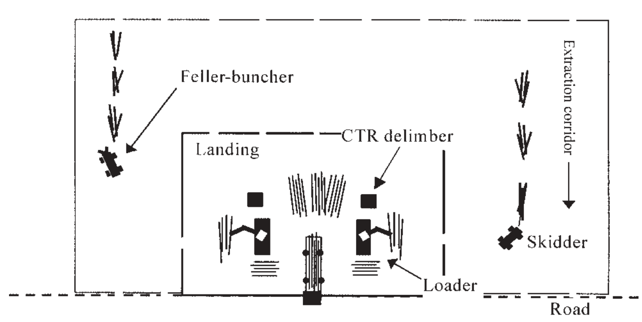

Figure 2. Basic system layout for thinning loblolly pine plantation during period of study.

number of both pulpwood and chip-and-saw loads to help establish the productivity potential of the loader.

The feller-buncher cycle was defined as cutting and accumulating a bunch, placing it in the corridor, and moving back to the next tree to cut in the stand. The skidder cycle was considered to be going out, picking up a turn, returning to and unloading at the landing. The loader cycle was defined as time taken to process a single turn of timber as delivered by the skidder.

In three sections of the stand, all the trees were marked using a letter coding spray-painted onto the stem according to diameter class, commencing at 6 in. (15 cm) and increasing in 1 in. intervals up to 14 in. (35 cm). The letter coding simplified the handheld computer data entry. The feller-buncher thinned the stand, and the time study person noted what diameter trees were cut and accumulated in each bunch.

The felled trees had been prebunched by the feller-buncher in the corridors. The distance the skidder traveled to the furthest bunch from the landing was measured using a laser range finder and known corridor section distances. The number of bunches accumulated to make a turn was recorded, and the total number of trees in the turn were counted at the landing. The letter coding on the trees were used to estimate turn volume. When no letter coding was visible, the dbh was estimated using neighboring stems.

The two loaders were studied with a focus on their ability to process the trees brought to the landing. The number of stems in the turn was counted, and a dbh recorded for each stem as they were processed. Time spent manipulating the timber, which is restacking or moving timber, was recorded but not considered part of the loaders' delimbing and bucking cycle. The activity of loading the truck was measured separately by timing truck turn-around at the landing. Both loaders would typically load simultaneously, as well as some additional sorting (log manipulation). Loading rates can therefore only be considered indicative. The study components are presented in Table 1.

Statistical Analyses

Variance analyses on this data were carried out with S-Plus, whereby the statistical fundamentals are described in Venables and Ripley (1997). For each part of the model, the following analyses strategy was chosen (Stampfer 1999, Heinimann et al. 1998):

- Development of a linear model with all the covariables from Table 1;
- Evaluation on the nonlinearity of the covariables;
- Choosing a number of submodels through the removal of variables that were not significant.

Häberle (1984) states that the tree volume is a major part of all production functions. He also states that the relationship between productivity and tree volume is not linear and therefore a power factor (z) is used on the covariable *bunchvol* or *turnvol*. Häberle (1984) recommends an iterative procedure for the estimation of this power value. Box and Cox (1964) describe a method whereby the optimal transformation is carried out using a maximum likelihood function. Venables and Ripley (1997) show how such a Box-Cox transformation procedure can be carried out in S-Plus. Similarly, this principle of the maximum likelihood function can also be used on the independent variables (Heinimann 1998).

Subsequently, using multiple linear regressions, the parameters of the model are estimated, with which the productivity model under given conditions can best be quantified.

Results

Feller-Buncher

The productivity function for the Tigercat 720B feller-buncher is shown below as a function of average piece size and the average number of trees per bunch (statistically significant at the $P = 0.05$ level, $R^2 = 0.66$). The average value, 5th and 95th percentiles of all variables are shown in Table 2.

$$\textit{Feller-buncher}\ (ft^3 / PMH0) =$$
$$262 + 171 * \textit{piecevol} + 14.4 * \textit{piecevol} * \textit{treebunch}$$

The breakdown of the delay-free feller-buncher activity: 65% of the time is spent cutting and accumulating a bunch and placing it back in the corridor; 27% is spent moving the feller-buncher to a new position, ready to commence cutting a new bunch; and finally, 8% is spent moving between corridors.

Table 1. Description of the numerical variables and time components used in second thinning system evaluation in a loblolly pine plantation.

Type	Name	Description	Unit
Dependent variables	*FBcycle*	Cycle time for feller-buncher to cut trees to form a bunch and place them in the extraction corridor	minute
	skidcycle	Cycle time for skidder extract one turn	minute
	loadcycle	Cycle time for the loader to process a turn	minute
	bunchvol	Sum of the tree volumes that constitute a bunch	ft^3
	turnvol	Sum of the tree volumes extracted either by the skidder or processed by the loader	ft^3
Covariables	*piecevol*	Average tree volume (without bark)	ft^3
	skiddist	Skidding distance	ft
	treebunch	Number of trees cut by feller-buncher to make a bunch	no.
	bunchturn	Number of bunches picked up by the skidder to make a turn	no.
	treeturn	Number of trees per turn of timber	no.
Time	PMH_0	Productive system hours. All time components that are directly necessary for the work.	minute

Table 2. Feller-buncher summary data for second thinning evaluation in a loblolly pine plantation.

$n = 291$	Ave	5th percentile	95th percentile
treebunch (n)	2.63	1	4
piecevol (ft^3)	8.15	4.1	14.1
bunchvol (ft^3)	20.7	9.3	35.2
cycle (minutes)	0.60	0.19	0.72
productivity (ft^3/PMH_0)	1,998	999	3,515

At this location, the average number of stems in a bunch was 2.6. This should be read as reflecting how many trees it can cut on a single foray into the stand. It should not encourage the operator to cut two trees, back down the corridor, re-enter the stand and cut another tree, and then return and place the bunch in the corridor. This practice was shown to reduce productivity. The productivity function is shown graphically for the range of the 5th and 95th percentiles (Figure 3).

The value of the power function is 1.0 and shows that the productivity of the Tigercat 720B feller-buncher is very dependent on the piece size it is working in. Stated differently, if this machine were to move into a stand where the average piece volume was 20% larger, the productivity will be 20% greater. This trend line is expected to curve above this range—when the piece volume starts to influence the productivity.

Skidder: Tigercat 630

A summary of the skidder time study information is presented in Table 3. The average piece volume (*piecevol*), the number of bunches per turn (*bunchturn*) and extraction distance (*skiddist*) were shown to be statistically significant at the $P = 0.05$ level ($R^2 = 0.62$).

$$Skidder\ (ft^3 / PMH_0) = 1,254$$
$$- 1.33 * skiddist + 22.4 * (piecevol^{0.8}) * (bunchturn^{0.8})$$

The productivity function for the skidder is shown (Figure 4) as both a function of average piece volume and the average extraction distance. The productivity (tons/PMH_0) is shown for the piece size range of 4.1 to 9.3 ft^3, which represent the 5th and 95th percentiles for the turn volume data.

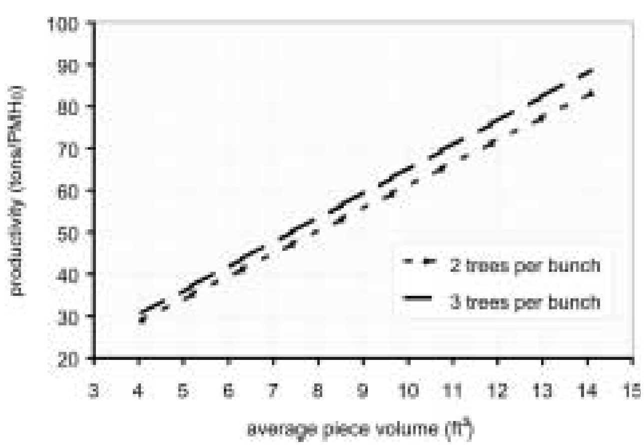

Figure 3. Productivity (tons/PMH_0) of the feller-buncher in second thinning of loblolly pine plantation.

Table 3. Skidder summary data for second thinning evaluation in a loblolly pine plantation.

$n = 29$	Ave	5th percentile	95th percentile
treeturn (n)	17	11	23
bunchturn (n)	2.7	1	4.8
turnvol (ft^3)	133	85	181
skiddist (ft)	670	203	1,026
skidcycle (minute)	5.9	2.6	9.4
productivity (ft^3/PMH_0)	1,517	814	2,516

The average piece volume parameter is curved with a power value of 0.8. This indicated that if the average piece volume were to increase by 20%, we would expect a 15% increase in skidder productivity.

Tracked Loader

Table 4 summarizes the data collected on the tracked loader. A strong correlation was found between the turn volume, the number of stems in the turn, and the processing time. However, when dividing the turn volume by the processing time to define productivity, no other variables influenced the outcome. Although we could expect a relationship with average piece size, the reason this data did not yield one is probably because the *average* piece volume of the turn was very uniform and the loader would delimb and buck a larger number of smaller trees at a single time.

System Evaluation

For the purpose of demonstrating the effect of changing stand parameters on overall system productivity, a system evaluation is completed specifically for the average piece size parameter. Using the productivity functions established at this site, with an average piece volume 7.8 ft^3 (0.23 tons), the following system balance can be calculated for this site. The calculations assume 6.5 productive work hours in a workday for the feller-buncher, skidder, and the loader [approximately 0.5 hr each for: (a) refueling, greasing, and other regular maintenance, (b) personal delays such as short breaks and discussions, and (c) major delays such as broken equipment).

The delay-free productivity of the loader for processing (delimbing and bucking) the turns was established as 35 tons/PMH_0. This processing productivity figure was reduced by 9% to account for time spent manipulating the

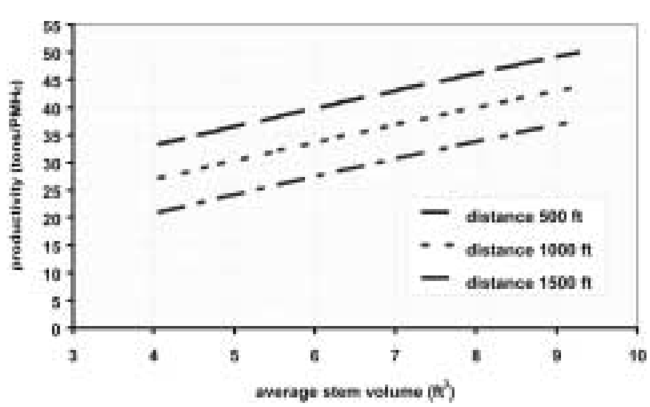

Figure 4. Productivity (tons/PMH_0) of the Tigercat 630 skidder in second thinning of loblolly pine plantation.

Table 4. Tracked loader summary data to process a single turn for second thinning in a loblolly pine plantation.

$n = 41$	Ave	5th percentile	95th percentile
piecevol (ft^3)	8.5	6.3	10.0
turnnum (n)	17	9	24
turnvol (ft^3)	146	79.3	201
cycle (minute)	7.4	3.9	11.4
productivity (ft^3/PMH_0)	1,184	925	1,591

logs—that is, for resorting, additional stacking, or the removal of slash from the static delimber, as was recorded during the turn processing time study. That left a single productivity figure for the loader of 32 tons/PMH_0.

The overall loader productivity was then calculated by combining the productivity of processing and loading out. In our study we measured 12 trucks being loaded out at an average time of 17 minutes using both loaders. This equates to a loading out productivity of 52 ton/PMH_0 per loader. By balancing the processing and manipulation (32 tons/PMH_0) and truck loading (52 tons/PMH_0) activities, it takes 37 minutes to process and 23 minutes to load out 21 tons/PMH_0.

Feller-buncher

$$6.5 \text{ (PMH/day)} \times 57 \text{ (tons/PMH)} = 371 \text{ tons/day}$$

Skidders (two typically used, one in reserve)

$$2 \times 6.5 \text{ (PMH/day)} \times 44 \text{ (tons/PMH)} = 572 \text{ tons/day}$$

Loaders (two)

$$2 \times 6.5 \text{ (PMH/day)} \times 21 \text{ (tons/PMH)} = 273 \text{ tons/day}$$

This basic system evaluation would suggest that the loaders are limiting the operation, and that there is considerable excess skidder capacity. This was observed to be the case at the site. The standard practice was to have the skidder wait until the loader had finished processing the previous turn (Figure 5). This often resulted in the skidder waiting to enter the landing with the turn, and on many occasions this wait period was longer than actually getting the turn. The loader had the dual roles of processing (delimbing, bucking, and stacking) the turn as well as loading the trucks. Both loaders on site completed these tasks equally—that is, there was no designated loader for loading out the trucks. Although the loaders were tracked, they were both used in the more conventional trailer-mounted loader system layout. Two possible considerations for system improvement are:

1. Using the mobility of the loaders, it may be possible to avoid some of the skidder excess by allowing more than one load to be delivered to the landing.

2. Replace the two static delimbers by attaching a processor head on one of the loaders, which would then process the timber that the skidders have brought to the edge of the landing. The other loader would be placed centrally and dedicated to stacking the processed logs and loading out trucks.

Figure 6 graphically combines the productivity functions for the individual machines. It shows that the system balance should be modified according to piece size.

The graph indicates that at an average piece size of 3.7 ft^3 (0.11 tons), a system of one feller-buncher, one skidder, and one loader would be well balanced. Beyond that the feller-buncher out-produces the other machines, but, over the piece size range studied, never enough to keep two skidders fully occupied. Over an average piece size over 5.6 ft^3 (0.17 tons), the two loaders will limit the maximum productivity of the system as a whole. To help transfer the workload back to the skidders that have the excess production capacity, a gate delimber could be installed to increase loader productivity and decrease skidder productivity.

Conclusion

The goal of this study was to develop productivity functions for a set of typical second thinning operations in southern plantation forests. Tree size was the main factor affecting feller-buncher productivity, while turn volume and extraction distance were the main factors for the skidder. The ability of the loader to process multiple trees, and the fact that this machine was studied at the turn level, meant

Figure 5. Tigercat 245 tracked loader pulling a stem through the static delimber.

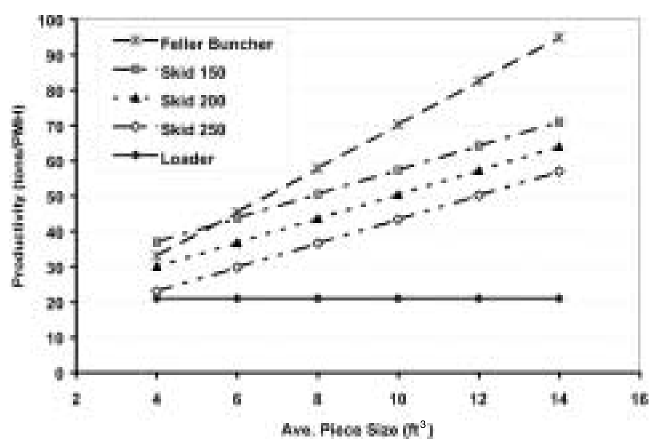

Figure 6. Combined productivity functions for the whole second thinning system.

that stem volume was not found to be significant in determining productivity for the average tree size in the turn for the range tested.

By combining the productivity functions of the machines on site, the need for system balancing was shown in the form of spare productivity capacity for individual machines with changing piece size. Further studies on machinery interaction and the resulting impact on productivity are required to provide a greater understanding of machine delays and for establishing operational improvements.

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