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Analysis of mechanical thinning productivity and cost for use at the wildland urban interface

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Abstract

Forest management in many parts of the urbanizing Southeastern U.S. is becoming more difficult due to fragmentation, alternative management objectives, and social conflicts with management activities. However, the public benefits from management of these areas are still high. This study compared the productivity and costs of mechanical thinning treatments using conventional thinning and two alternative thinning approaches in even-aged loblolly pine plantations. The alternative treatments removed more stand basal area and were intended to promote transition to uneven-aged stand management. Production studies and cost analyses were completed for conventional, heavy, and strip treatments. The conventional treatment was a fifth row and select removals to 16 m^2 ha^{-1} residual basal area. The heavy treatment was a fifth row and select removals to 9 m^2 ha^{-1} residual basal area. The strip treatment included a conventional thinning treatment with alternating reserve and clearcut strips established on the contour. The resulting residual basal area was 11.5 m^2 ha^{-1}. The alternative treatments provided substantially lower costs and higher residual values (\$1 to 3 m^{-3}) in the 4 ha stands but smaller advantages in 8 and 12 ha stands. The difference from lower harvest costs for the alternative treatments may enable landowners to attract interest in small acreage sales that result from fragmentation.

Conversion of rural lands to urban uses expands the interface between human population and rural land, termed the Wildland Urban Interface (WUI) (Nowicki 2001). The conditions at the WUI limit opportunities for management (Cordell and Macie 2002) which may be required to mitigate potential forest health problems (Bolding et al. 2003). Across the southeastern U.S. growth near population centers is expected to convert forestland to urban uses and increase fragmentation of nearby forestland (Wear and Greis 2002).

Maintaining active management in fragmented forests requires systems that are socially acceptable and economically feasible. Small parcel sizes increase harvest costs because fixed costs are distributed across less volume (Cubbage et al. 1989, Kittredge et al. 1996, Greene et al. 1997). Logging contractors also have greater opportunity cost since they spend more time moving between harvests and less time logging. Marketing high value products is also more difficult since there may not be sufficient quantity. From thinnings and poor quality stands, low product value and potentially high transportation cost further limit gross income from a harvest. Other harvesting problems typical of the WUI include stand access, log transportation issues, and conflicts with neighbors, all of

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which are likely to increase harvest costs and further reduce the social and economic feasibility of the operation.

Conventional mechanical thinning practices in even-aged pine plantations in the southeastern U.S. typically combine removal of every third, fourth, or fifth row with thinning from below to some specified residual basal area in the remaining stand. Continued even-aged management may defer, but will not avoid the significant visual impact from the eventual stand regenerating clearcut. One potential alternative to reduce the visual impacts of even-aged regeneration methods would be to promote a transition to uneven-aged mixed stands by implementing atypical thinning regimes. A by-product of these alternative treatments is an increase in the tree size and removal intensity that may increase the economic feasibility of these operations.

Table 1. — Stand characteristics for continuous timing study of conventional (Conv.) and heavy treatments.

Site	Stand age	Treatment	Trees	Tree volume	Pulpwood volume	CNS volume	Basal area	
							Pre-harvest	Post-harvest
			(ha^{-1})	(m^3)	(%)		(m^2 ha^{-1})	
1	18	Conv.	1102	0.11	81	19	29.4	14.2
2	14	Conv.	1849	0.07	97	3	32.6	17.0
3	18	Conv.	1683	0.13	93	7	43.6	14.9
4	13	Heavy	1318	0.10	95	5	32.6	8.5
5	14	Heavy	1834	0.11	93	7	38.8	10.1
6	25	Heavy	813	0.22	43	57	34.2	10.2

The overall goal of this study was to examine the harvest cost and residual value (delivered value minus harvest costs) from the typical treatment and two alternative treatments in young loblolly pine (*Pinus taeda*) stands that will eventually lead to uneven-aged stand conversion. The alternatives considered here include a heavy thinning and strip removal to promote recruitment of another age class within the stand. Although product markets, harvesting systems, and costs are dynamic, increasing the commercial attractiveness of these harvests is an important first step in implementing treatments.

The specific objectives of this study were to: 1) generate production models for the skidder and the feller-buncher; 2) compare harvesting productivity and costs of two alternative treatments to conventional thinning; and 3) evaluate changes in residual value with respect to treatment, stand type, and stand size.

Material and methods

Treatments

The conventional thinning (conventional) is a fifth row removal and a thin from below of the remaining rows to a target residual basal area of 16 m^2 ha^{-1}. The heavy thinning (heavy) requires the same row removal and a more intensive removal from the remaining rows to a target residual basal area of 9 m^2 ha^{-1}. The strip treatment (strip) creates corridors or strips within the stand that are oriented along the contour and approximately 14 m wide. Leave strips between the removal strips are 36 m wide and are thinned using the conventional thinning method. The strip placement and dimensions could be arranged to obscure view of the cut areas and exact dimensions would be determined by row and tree spacing. Across the strip treatment, the target basal area was 11.5 m^2 ha^{-1}.

Production study

Production data were collected on six harvests across the Piedmont and upper coastal plain regions of Alabama, Georgia, and Mississippi (**Table 1**). The selection of the harvesting sites was based on thinning treatment, but limited to the following conditions: even-aged loblolly pine plantation; wheeled feller-buncher/skidder/knuckleboom loader systems; first thinning; and gentle terrain with average slope ≤ 10 percent.

Harvest sites (**Table 1**) were sampled to describe pre and postharvest stand conditions. On each site we located 10 point samples (10 BAF prism (English)) 50 m apart along random azimuths before and after the harvest. Classification as chip and saw (CNS) considered DBH greater than 25-cm, stem quality (defects, forks, sweep or crook), and merchantable height (7.5 m to a 15 cm top dib). Trees with DBH >25 cm that did not meet specifications for CNS and all trees with DBH 10 to 24 cm were classified as pulpwood.

All six sites were harvested by crews utilizing similar harvesting systems composed of one wheeled feller-buncher, one wheeled grapple skidder, one knuckleboom loader with a pull-through delimber, and three or four crew members. The feller-buncher cut the trees and placed multiple full trees in a bunch. The bunches were skidded to the deck area, where the trees were delimbed and topped by the loader and sorted as pulpwood or CNS.

Gross time study data were collected by observation of the operation for one to 3 days on each site. Gross time study data categories followed those from Miyata et al. (1981).

Cycles from the skidder and the feller-buncher were collected using a video camera system inside the machine cabin. The camera was focused on the grapple in the skidder and the felling head on the feller-buncher. Video was recorded with a digital 8-mm recorder attached to the operator's seat. The videos were replayed, and the cycles and elements recorded and time calculated from the time stamp on the tape. The total cycle time was summed from the elemental time.

The skidder activities were recorded for sample periods of 1.5 hours until approximately 50 skidder cycles were recorded on each site. Five elements were defined for the skidder elemental analysis (travel empty, grapple and load, travel loaded, delays, and delimbing time—when applied). The round-trip cycle distance was obtained using a Garmin GPS 12XL equipped with a remote antenna. Average bunch size (number of stems per bunch) was estimated from gross production data.

A feller-buncher cycle included the machine traveling to a tree(s), grabbing and cutting the tree(s), traveling back to the skid trail, and swinging and placing the tree(s). A cycle ended and started with the swing and place element. About 30 feller-buncher cycles were recorded on each site, 15 in the row removal and 15 from the selection cut in the residual rows.

The analyses of the cycle time data involved graphical and statistical tools to identify trends of total cycle times with independent variables. Dummy variable techniques were used to examine differences in qualitative conditions. Stepwise

Table 2. — Skidder production study variables and regression model from stepwise selection (p ≥ 0.15).

	Name	Definition
Variables	Trt	Dummy variable for treatment
	S_i	Dummy variable for logging site (i = 1 to 6)
	SNtrees	Average number of trees/bunch (daily average)
	Distance	Total round-trip skid distance for a cycle (m)
	DistTrt	Interaction distance × Trt
	DistSNtrees	Interaction distance × SNtrees
	$DistS_i$	Interaction distance × site
Model	Cycle (sec) = 171.934 + 0.179 × Distance + 0.0116 × DistSNtrees + 0.0458 × $DistS_3$ + 0.0883 × $DistS_4$ + 0.1477 × $DistS_5$	
	F-value = 55.8; p-value < 0.0001; R^2 = 0.49; n = 297; MSE = 10906	

Table 3. — Feller-buncher production study variables and regression model from stepwise selection (p ≥ 0.15).

	Name	Definition
Variable	Trt	Dummy variable for treatment
	S_i	Dummy variable for logging site (i = 1 to 6)
	FNtrees	Number of trees cut in a cycle
	DBH	Average site DBH (cm)
	Method	Dummy variable for row vs. selection felling
	$FNtreesS_i$	Interaction FNtrees × site
Model	Cycle (sec) = 15.411 + 9.456 × Method + 7.6938 × FNtrees + 1.5784 × $FNtreesS_1$ − 0.9831 × $FNtreesS_2$ + 2.2461 × $FNtreesS_3$ + 0.7998 × $FNtreesS_4$ + 0.4388 × $FNtreesS_6$	
	F-value = 553.7; p-value < 0.0001; R^2 = 0.66; n = 195; MSE = 324	

Table 4. — Machine cost assumptions and after tax cost calculations for the first year of machine ownership.

	Skidder	Feller-buncher	Loader
Purchase price ($)	195,361	204,604	135,816
Economic life (years)	6	6	6
Scheduled machine hours (SMH/year)	2000	2000	2000
Insurance (% of machine value)	6	6	6
Salvage value (% of purchase)	20	20	20
Fringe benefit (% of labor rate)	30	30	30
Discount rate (%)	7	7	7
Finance APR (%)	7	7	7
Marginal tax rate (%)	25	25	25
Utilization rate (%)	70	70	70
Labor cost ($/SMH) (after tax)	17.95	17.95	17.95
Fixed cost ($/SMH) (after tax)	17.85	19.13	11.10
Variable cost ($/SMH) (after tax)	21.60	21.26	16.17

selection technique (p-value ≥ 0.15) identified significant variables from the list in **Tables 2** and **3** for the skidder and feller-buncher, respectively. Statistical Analysis System (SAS System for Windows V8.2 1999 to 2001) was used to perform the analyses.

System productivity and cost analysis

To conduct the productivity and cost analysis we selected three harvesting sites as examples of the range of applicable conditions. The "low" productivity site was a high density plantation with low volume per tree, site 2 in **Table 1**. The "medium" site had density similar to the low site but with a higher volume per tree, site 5 in **Table 1**. These two sites were considered to be a good representation of first thinning conditions in the Southeast U.S. The "high" site was a deferred first thinning with lower density, higher volume per tree, and consequently a larger volume of CNS, site 1 in **Table 1**.

Stand sizes of 4, 8, and 12 ha were selected for the analysis because the vast majority of the private forest ownerships in the Southern U.S. are less than 20 ha (49 acres) (Birch 1997). Assumptions for generating the distribution of round-trip skid distances included square shaped stands with a single landing located in the middle of one side.

The system that was modeled consisted of three machines and operators, one wheeled feller-buncher, one wheeled grapple skidder, and one knuckleboom loader with a pull-through delimber without gate delimbing. Machine productivity was estimated using the total cycle time equations for the skidder and the feller-buncher. System productivity was determined by the limiting machine on a daily basis where the scheduled machine hours (SMH) of each machine and operator were the same. The maximum utilization rates (UR) used for analysis were 79 percent and 76 percent for the feller-buncher and the skidder, respectively. The equations derived from the production study determined cycle times where the values of the site interactions were 0. Loader/delimber productivity was estimated from the gross production data at 30 m^3 SMH^{-1} and was not a limiting factor in production.

To determine feller-buncher productivity the analysis specified the proportion of the diameter distribution removed and the proportion of trees harvested from removed rows vs. the residual stand. In the conventional and heavy treatments, removed rows accounted for the harvest of 20 percent of trees across all DBH classes. Additional trees were removed from smaller DBH classes until the respective target basal areas of 16 and 9 m^2 ha^{-1} were achieved. In the strip treatment, removed rows accounted for the harvest of 40 percent of trees across all DBH classes for the strips and throughout the residual stand (60%) trees were removed from smaller DBH classes. The target residual basal area for the strip treatment (including both strips and the residual stand) was 11.5 m^2 ha^{-1}. Trees per cycle (FNtrees) were determined from observed data and volume per cycle was calculated from tree size information from the site.

To determine skidder productivity we sampled from the distribution of skid distances (Distance), including short and long distances in each of the study sites, so hourly productivity would be even as the harvest progressed. Trees per skidder cycle (SNtrees) were based on observed data. Average volume per tree was estimated from the site data. The distribution of round-trip skid distances generated average skidding productivity (cycles per productive machine hours (PMH)). The

Table 5. — Skidder productivity estimates ($m^3\ PMH^{-1}$) for treatment, site (low, medium, and high), and stand size (4, 8, and 12 ha).

Stand size (ha)	Conventional 4	Conventional 8	Conventional 12	Heavy 4	Heavy 8	Heavy 12	Strip 4	Strip 8	Strip 12
Site									
Low	21.0	18.4	15.5	23.4	20.4	17.2	23.7	20.8	17.5
Medium	23.4	20.7	17.7	25.9	22.9	19.6	25.4	22.5	19.2
High	23.8	21.1	18.0	27.6	24.5	20.9	27.2	24.1	20.6

Table 6. — Feller-buncher productivity estimates ($m^3\ PMH^{-1}$) for treatment and site. Average productivity is the weighted average from row and selection components determined by the treatment.

	Conventional Selection	Conventional Row	Conventional Average	Heavy Selection	Heavy Row	Heavy Average	Strip Selection	Strip Row	Strip Average
Site									
Low	23.6	27.5	25.5	26.2	30.6	27.7	26.6	31.1	29.6
Medium	32.1	37.1	34.6	35.6	41.0	37.4	34.9	40.2	38.4
High	41.5	49.8	45.6	48.1	57.6	51.3	47.4	56.8	53.7

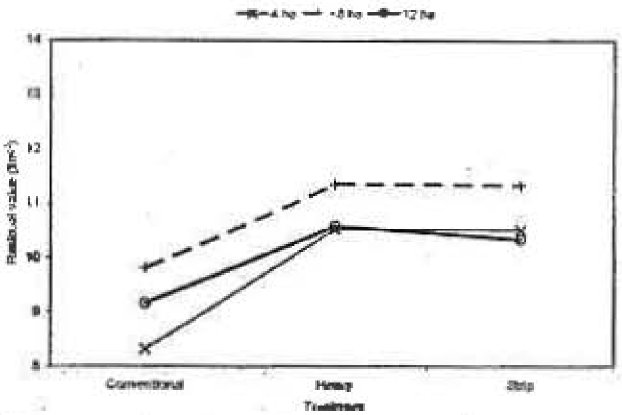

Figure 1. — Low site residual values ($\$\ m^{-3}$) for the 4, 8, and 12 ha stands for the conventional, heavy, and strip treatments.

production rate was calculated from cycles per PMH, average volume per tree, and observed trees per cycle.

Hourly costs were estimated using an after-tax cash flow method (Tufts and Mills 1982). The method was incorporated into a spreadsheet developed by Tufts (unpublished). Cost assumptions and the annual equivalent cost of year 1 are in **Table 4**.

Moving and transportation costs were added to logging costs. Moving cost referred to the cost of moving the harvesting crew and equipment to the harvest site, and includes direct costs for moving equipment and labor time, and indirect costs of lost equipment operation and operational overhead costs during the move. Moving costs were a flat after tax rate of $1,725 per move and covered the expense required to move an average distance of 50 km (Greene et al. 1988). For wood transportation an after tax rate of $3.88 m^{-3} was used.

Twenty-seven scenarios resulted from 3 treatments, 3 sites, and 3 stand sizes. Average gross revenue, logging cost, and residual value ($\$\ m^{-3}$, $\$\ stand^{-1}$, and $\$\ ha^{-1}$) were calculated for each combination. Gross revenue or the value of the wood at the mill was assumed to be $25.00 m^{-3} for pulpwood and $33.00 m^{-3} for CNS.

Results and discussion

Production study

Stepwise selection of total skidder cycle time without the delimbing and delay elements returned the equation in **Table 2**. The model is typical of previous results, where travel time increased with higher skid distance (Tufts et al. 1988, Lanford and Stokes 1996, Kluender et al. 1997). Total skid distance and the interaction of skid distance and the average number of trees per bunch were prominent in the total cycle time model. No treatment effect was indicated by the selected model for total cycle time, but site effect was indicated by the interaction with skid distance in 50 percent of the study sites. Significance of interaction terms may suggest differences due to system bottlenecks, machine operator, site, or some combination.

Stepwise selection variables and two-way interactions for feller-buncher cycle without delay returned the equation in **Table 3**. The model indicates that selection thinning took more time than thinning the removal row which is consistent with previous results (Greene et al. 1987, Lanford and Stokes 1996). Cycle time also increased as the number of trees cut in a cycle increased. No treatment effect (heavy or conventional) was indicated by the analysis. Significant interactions were present between the principal continuous variable (FNtrees) and most sites. Again interactions may indicate differences due to the system bottlenecks, machine operator, the site, or some combination.

System productivity and cost analysis

The skidder productivity estimates are summarized in **Table 5**. Skidder productivity decreases with increasing stand size because of the longer assumed skid distance. Using a single landing and landing placement for all stand sizes addresses likely restrictions in harvest planning, established landing areas, and no allocation of road building costs in move-in costs. Increased tree size was responsible for productivity increasing from low to medium to high sites. Larger trees meant fewer trees, larger volume per bunch, and consequently fewer bunches per cycle which reduced cycle time and increased productivity.

The feller-buncher productivity was greatest for the strip treatment due to the higher productivity of the row removal and the greater percentage of the site volume removed in rows (**Table 6**). Also, the larger average volume per tree increased productivity within the medium and high sites. In all scenarios skidding limited hourly or daily production, and the feller-buncher and the loader were not fully utilized. There is a fairly wide range in feller-buncher productivity and a narrower range for the skidder.

Residual value was calculated as total delivered value minus total harvesting cost. Residual value would include timber

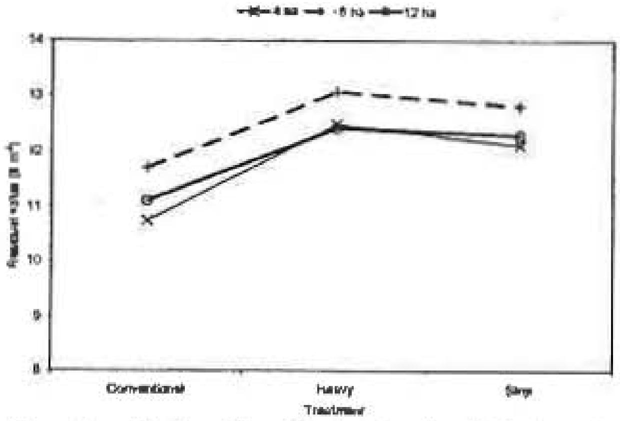

Figure 2. — Medium site residual values ($ m^{-3}) for the 4, 8, and 12 ha stands for the conventional, heavy, and strip treatments.

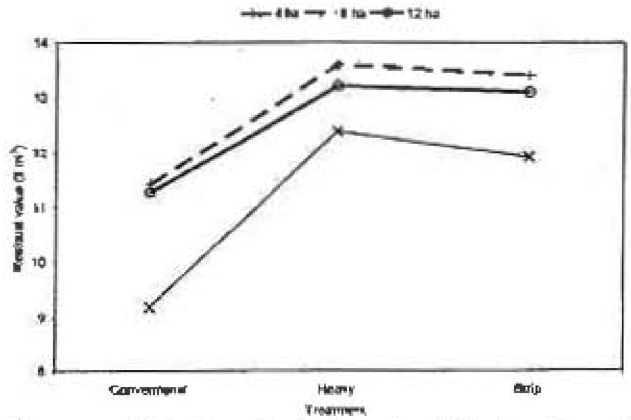

Figure 3. — High site residual values ($ m^{-3}) for the 4, 8, and 12 ha stands for the conventional, heavy, and strip treatments.

Table 7. — Total volume removed and residual stand value and residual value per hectare for all scenarios.

		Volume removed			Residual value								
Site	Size	Conv.	Heavy	Strip	Conv.	Heavy	Strip	Conv.	Heavy	Strip	Conv.	Heavy	Strip
	(ha)	------(m^3 stand^{-1})------			---------($ m^3)---------			--------($ ha^{-1})--------			--------($ stand^{-1})-------		
Low	4	348	508	456	7.35	9.67	9.66	640	1228	1102	2559	4912	4406
	8	696	1016	912	8.71	10.36	10.35	758	1315	1180	6061	10523	9442
	12	1044	1524	1368	7.86	9.42	9.19	684	1196	1047	8204	14351	12568
Average	(m^3 ha^{-1})	87	127	114									
Medium	4	488	668	604	9.88	11.72	11.34	1206	1957	1712	4823	7829	6848
	8	976	1336	1208	10.74	12.20	11.93	1310	2037	1802	10483	16296	14415
	12	1464	2004	1812	9.97	11.40	11.26	1217	1905	1701	14601	22855	20409
Average	(m^3 ha^{-1})	122	167	151									
High	4	288	464	400	8.34	11.66	11.18	600	1353	1118	2401	5412	4473
	8	576	928	800	10.47	12.77	12.56	754	1481	1256	6032	11847	10051
	12	864	1392	1200	10.16	12.25	12.12	731	1421	1212	8775	17048	14549
Average	(m^3 ha^{-1})	72	116	100									

buyer and logger profit, logger overhead, and stumpage. With the low site the residual value increased $1 to 2 m^{-3} when comparing the conventional treatment to the heavy and patch treatment (**Fig. 1**). The larger stands resulted in higher residual value. Residual value in the 12 ha stand was adversely effected by lower skidding productivity in spite of lower per unit move-in costs. With the medium site the relationships are similar but the residual values overall are nearly $2 m^{-3} higher than the low site (**Fig. 2**). The higher residual value is due to higher productivity and lower move-in cost from greater volume per hectare. The high site showed the largest effect due to treatment (**Fig. 3**). The delivered value was nearly $1 m^{-3} greater than the low and medium with the increased amount of CNS. Within the high site the residual value increased $2 to 3 m^{-3} when comparing the conventional treatment to the heavy and strip treatments. Most of the treatment differences were again due to lower volume per unit move-in costs. Because the high site was less dense, incremental increases in volume removal had greater impact on costs. High skidding productivity due to bigger bunch volume yielded nearly equivalent residual value for 8 and 12 ha stands.

Table 7 shows volume removal and revenue on a stand and per hectare basis. One objective of these alternative prescriptions was to increase the revenue and financial attractiveness of smaller harvests typical at the WUI. The stand residual value of $2400 to $2600 for the low and high, 4 ha sites would not likely cover the logger risk and pay a minimal stumpage value. The incremental increase in volume per hectare within the medium site is enough to improve residual value to over $4800.

The difference in values between the heavy and strip treatment reflect the more intense removal in the heavy treatment. This difference could be easily narrowed by changing the parameters on the strip treatments (e.g., wider strips or heavier thinning in leave strips). The increased felling productivity in the strips provided minimal benefit since skidding limited production.

Conclusions

We analyzed alternative treatments for the harvesting of small loblolly pine plantations at the Wildland Urban Interface (WUI) using fully mechanized commercial thinning. Consideration in selection of alternative methods was given to harvesting productivity, economics, aesthetics, and practical concerns for long term stand management at the WUI. Skidder productivity limited system productivity on all combinations. Productivity of the skidder was affected by skid distance (stand size) and tree size. Feller-buncher productivity increased as row removal was increased in the strip treatment. Overall, the heavy and the strip treatments resulted in similar residual value. Treatment differences were greatest in the smallest stand size (4 ha) where the difference in volume removed resulted in an increase of up to \$3.20 m^{-3} in residual value.

In summary, the results of this study suggest that there is a potential for landowners and land managers to benefit from alternative thinning treatments. The additional income may make harvesting more available to landowners and attractive to buyers. From the aesthetic and long term management perspectives, these treatments may be suitable to land managers at the WUI. The continuous tree cover aspect of the heavy and strip treatments may result in less visual impact. However, the decision to implement a treatment depends primarily on the landowner objectives. If the alternative treatments proposed here satisfy the objectives they could play an important role in marketing small stands.

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