IMPACT OF ALTERNATIVE HARVESTING TECHNOLOGIES ON THINNING ENTRY AND OPTIMAL ROTATION AGE FOR EASTERN HARDWOODS

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Abstract—A complete system simulation model is used to integrate alternative logging technologies, stand data, market prices, transportation costs, and economic concerns in a long-term continuous manner to evaluate thinning entry timing and optimal rotation age. Forest Inventory and Analysis (FIA) stand data for the oak/hickory forest type and time and motion study data for 70, 90, and 120 horsepower skidders, a cut-to-length/forwarding system, and a feller buncher/forwarding system were used in this research. Smaller, less expensive skidders allowed commercial thinnings to be scheduled 15-30 years earlier in the life of the stand and resulted in larger cumulative monetary returns to the landowner. Larger, more expensive skidders and expensive mechanized systems such as cut-to-length resulted in delaying thinning entries by as many as 30 years and in less cumulative monetary returns to the landowner. The results should be valuable to landowners, loggers, managers, and decision-makers.

INTRODUCTION

Much of the world's managed forest is for wood production. In order to remain competitive, large corporate or industrial forest owners must manage forests with careful attention to harvesting trees at their optimal financial age. Large and small forest owners must also pay careful attention to the timing of thinning/intermediate treatments so that a thinning/intermediate treatment returns a profit as well as the benefits of releasing the residual trees accelerating their growth into high quality wood products. It has long been known and understood that strategically timed precommercial thinnings (Daggett and others 2002, Jean-Claude Ruel and others 2002), commercial thinnings (Kenefic and others 2005, Opland and others 2002, Wagner and others 2002), crop release treatments (Desmarais and Leak 2005, Phillips and others 2002), shelterwood harvests (Binot and others 2002, Morin and Binot 2002), and variations of improvement/partial cuttings (Barlow and Nowak 2002, Bevilacqua 2002) all serve to release the residual stand from competition and result in accelerated growth and development of higher quality wood products. Additionally, the array of commercially available logging technology has increased in recent years from skidders, small farm tractors, cable yarders, to highly productive and mechanized systems such as cut-to-length and feller-buncher with forwarder systems (LeDoux 2001, 2002). The challenge to the landowner is to match the logging technology available with silvicultural treatments desired so that a profitable operation results. Landowners must also understand how alternative logging technologies impact commercial thinning entry timing, optimal economic rotation age, and related financial yields. In this paper, we use a complete systems simulation model to evaluate the impact of alternative conventional and mechanized logging technologies on commercial entry timing and optimal economic rotation age for an upland oak-hickory stand.

METHODS

Site and Stand Data

In this study, the stand chosen for demonstration is from the oak/hickory forest type and represents substantial acreage (Schnur 1937) in the Central hardwood region. The species mix includes northern red oak (*Quercus rubra* L.), white oak (*Q. alba* L.), red maple (*Acer rubrum* L.), and hickory [*Carya ovata* (Mill.)] (fig. 1). The average site index of the stand is about 70. The stand is 40 years old and contains 366 trees per acre that are more than 5 inches dbh. The stand has an average tree dbh of 6.15 inches and about 1471.47 cubic feet per acre of merchantable volume. The land is located on gentle-to-moderate slopes (0-39 percent) and ground-based systems can be used for the harvests. It is assumed that new road construction is not required. The stand is located 25 miles from a sawmill/pulpwood mill.

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Logging Technology Evaluated

Three logging systems were used in this simulation (table 1). The first logging technology used in this demonstration was conventional chainsaw felling with cable skidders. The majority of wood harvested in the Eastern United States is extracted with a combination of chainsaw felling and ground-based cable skidding. The 70, 90, and 120 horsepower John Deere® skidders such as the ones used in these simulations are representative of contemporary logging technology and are large enough to handle the size of logs from the thinnings and final harvest (LeDoux 2000). With this system, trees are chainsaw felled, limbed, and topped. The cable skidder then drags the logs to a central landing. The second technology used was a highly mechanized cut-to-length (CTL) system with a forwarder for transporting the wood to the landing.

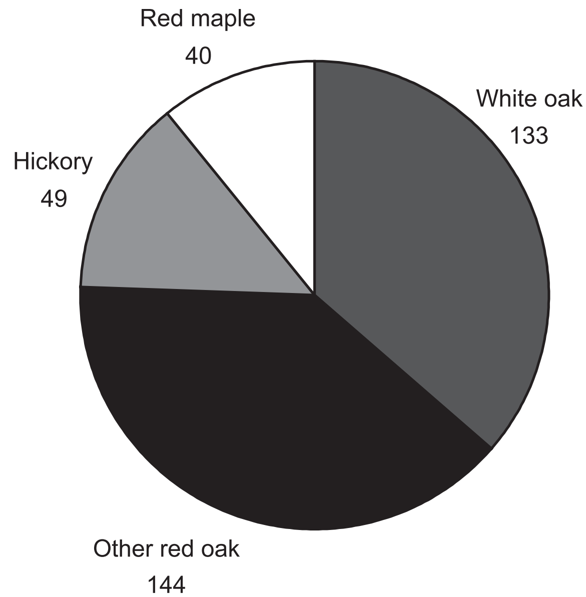

Figure 1—Tree species distribution for oak-hickory stand.

Table 1—Logging technology machine configurations used to simulate the thinnings and final harvest by hourly rate

Logging technology system and description	Machine rate
	$/hour
System 1	
Chainsaw felling with John Deere 440C skidder	59.55
Chainsaw felling with John Deere 540B skidder	65.45
Chainsaw felling with John Deere 640D skidder	81.18
System 2	
Modified John Deere 988 with Peninsula saw head and Valmet 524 forwarder	225.00
System 3	
Timbco 425 feller buncher, chainsaw limbing and topping, and Valmet 524 forwarder	259.17

Cut-to-length systems are expensive, highly productive, requires less personnel in the woods, are safer, and are becoming more popular in harvesting of Eastern hardwoods (LeDoux 2002, LeDoux and Huyler 2001). The CTL system used in this evaluation was a medium-sized modified John Deere 988 with a Peninsula design roller processing saw head and a Valmet 524 forwarder. This CTL system can work efficiently in large or small tracts in thinning and final harvest treatments. This system fells the tree, bucks it into product lengths and piles the sorted wood products into bundles. The piles/bundles are then loaded on the forwarder and transported to a central landing. The third system used was a mechanized feller buncher and forwarding system with chainsaw topping and limbing. Feller bunchers are expensive, highly productive, and safer than chainsaw felling (Bell 2002). The feller buncher cuts the trees at the stump and places them in piles that are later picked up by the forwarder for transport to the landing. A chainsaw is used to limb and top the trees. Feller buncher systems are becoming popular in harvesting applications of Eastern hardwoods (Long 2003). These logging technology configurations were selected because we have robust time and motion data for each, and because they represent contemporary methods being used by loggers to harvest Eastern hardwood stands. All of the above machines are capable of handling the size of logs coming from the thinnings and final harvested simulated. The hourly machine rates used in this study are shown in table 1, as calculated using methods by Miyata (1980). All costs are in 2005 U.S. dollars and reflect new equipment.

Model Used

MANAGE-PC (LeDoux 1986) integrates harvesting technology, silvicultural treatments, market prices, and economics continuously over the life of the stand. The simulation combines discrete and stochastic subroutines. Individual subroutines model harvesting activities, silvicultural treatments, growth and yield projections, market prices, and discounted present net worth (PNW) economic analysis. The model can be used to develop optimal management guidelines for eastern hardwoods. Using the stand data described earlier, MANAGE-PC was used to estimate optimal economic rotation length, volume/production yield estimates, and logging costs for each rotation age. The tree list for the stand and the above logging technology data were used as input to MANAGE-PC and the stand growth and development was projected in 5 year intervals until it reached its optimal economic rotation, that is, the maximization of discounted PNW. At each growth projection interval, the stand was logged, the value of the timber was determined, the stump-to-mill logging cost was computed, and the discounted present net worth was calculated. MANAGE-PC determined the optimal rotation age for the combination of stand and harvesting technology. The average delivered prices for saw logs and pulpwood were estimated from Forest Products Price Bulletins (Ohio Agricultural Statistics Service 2002, Pennsylvania State University 2003, Tennessee Division of Forestry 2003) (table 2).

The stand was thinned once with each logging technology at the earliest entry age that would result in a commercial operation and the residual stand was then projected to its optimal economic rotation. The thinning was an area-wide low thinning that removed all trees below an average diameter at breast height (dbh) of 8 inches to achieve residual stand basal area stocking levels of about 68 square feet per acre. The objective for each thinning treatment was to open up the stand and to accelerate residual tree growth in order to grow quality wood products for the final harvest. The wood harvested was sold as pulpwood and saw logs. The stand was thinned with each logging technology and the residual stands were then projected to their optimal economic rotation.

RESULTS

The simulated growth and yield and economic results are shown in table 3. Using a small, inexpensive skidder such as the John Deere 440C allows a commercial entry into the stand at age 70, optimal economic rotation of age 100, and cumulative PNW of $236.60 per acre. Larger skidders such as the John Deere 540B and 640D delay the commercial entry by 10 and 15 years, respectively, when compared to the smaller John Deere 440C. The 90 and 120 horsepower skidders have optimal economic rotations of 120 and 125 years with cumulative PNW of $159.48 and $136.93 per acre. Using a larger, more expensive 120 horsepower machine delays thinning entry timing by 15 years, extends optimal economic rotation length

Table 2—Delivered prices for saw logs and fuelwood/pulpwood by species

Species	Product			
	Large[a] high-quality saw logs	Medium[b] size and quality saw logs	Small[c] low-quality saw logs	Fuelwood[d]/ pulpwood
Red maple	251	192	131	40
White oak	450	279	138	40
Red oak	561	397	225	40
Hickory	210	160	150	40

[a] Minimum small-end diameter ≥ 13 inches, length ≥ 10 feet.
[b] Minimum small-end diameter ≥ 11 inches, length ≥ 8 feet.
[c] Minimum small-end diameter ≥ 10 inches, length ≥ 8 feet.
[d] 89 cubic feet per cord, minimum small-end diameter ≥ 4.0 inches that will not make large, medium, or small saw logs.

Table 3—Simulated results by logging system

Logging system	Chainsaw felling, JD 440 skidding	Chainsaw felling, JD 540 skidding	Chainsaw felling, JD 640 skidding	Modified JD 988 CTL, Valmet 524 forwarder	Timbco 425 feller buncher, chainsaw topping/ delimbing, Valmet 524 forwarder
Thinning age (years)	70	80	85	100	60
Average d.b.h. (inches)	9.77	10.59	10.98	12.17	8.30
Trees cut per acre	141	131	126	113	151
Volume cut per acre (cubic feet)	1,807.58	2,024.14	2,098.35	2,336.26	1,318.77
Mill value ($ per acre)	806.84	951.58	1,001.14	1,240.31	592.71
Logging cost ($ per acre)	631.27	840.28	928.87	1,180.44	549.41
Present net worth[a] (PNW per acre,$)	54.13	23.18	12.37	5.69	19.76
Optimal economic rotation (ORA, years)	100	120	125	125	100
Average d.b.h. at ORA (inches)	12.91	15.39	15.83	15.74	13.43
Trees cut per acre at ORA	127	112	108	103	131
Volume cut per acre at ORA (cubic feet per acre)	3,064.62	3,976.05	4,130.97	3,850.20	3,486.56
Mill value at ORA ($ per acre)	2,409.16	4,195.72	4,516.86	4,332.59	3,156.16
Logging cost at ORA ($ per acre)	489.66	1,054.09	1,023.65	1,878.38	1,189.16
Present net worth at ORA[b] ($ per acre)	182.47	136.30	124.56	87.51	186.98
Cumulative PNW ($ per acre)	236.60	159.48	136.93	93.20	206.74

JD = John Deere; CTL = cut-to-length; PNW = present net worth; ORA = optimal rotation age.
[a] Real discount rate = 4 percent.
[b] Discounted to age 40.

by 25 years, and results in $99.67 per acre less PNW when compared to using a smaller, less expensive 70 horsepower machine. Substantial cumulative monetary returns are available to the landowner by careful selection and matching of skidder size to thinning entry timing.

Using an expensive highly mechanized system such as the CTL/forwarding results in a commercial thinning entry age of 100, an economic optimal rotation of 125 years, and a cumulative PNW of $93.20 per acre. Using CTL/forwarding delays thinning entry timing by 30 years; extends optimal economic rotation by 25 years, and results in $143.40 per acre less PNW than thinning with a 70 horsepower skidder. The reduction in cumulative PNW for the CTL/forwarding system is largely because although this system is very productive, the operating cost of such consumes most of the value of the wood leaving the landowners with less cumulative returns. For example, the commercial entry at age 100 returns a low PNW of $5.69 per acre because the operating cost is $1180.44 per acre, or 95.17 percent of the mill value ($1240.31 per acre) of the wood. Landowners must balance these tradeoffs in managing their woodlots.

The use of an expensive, highly productive feller buncher/chainsaw topping and delimbing/forwarder system results in a commercial thinning entry timing of age 60, optimal economic rotation of age 100, and a cumulative PNW of $203.74 per acre. The age 60 thinning is possible because the feller buncher/forwarding combination is very efficient when felling, piling, and forwarding smaller dbh trees. The feller buncher/forwarding system allows the earliest commercial thinning entry age of 60, optimal economic rotation comparable to using the 70 horsepower skidder, and $113.54 per acre more cumulative PNW return than using a CTL/forwarding system. The cumulative PNW return for the feller buncher system is only $29.86 per acre less than using the smaller John Deere 440C skidder.

CONSIDERATIONS FOR MANAGERS

Landowners can schedule commercial thinning entries into young stands as early as age 60 if they use mechanized feller-buncher/forwarding systems. The use of smaller, less expensive 70 horsepower skidders such as the John Deere 440C allow for commercial thinning entry as early as age 70. These early entries into a stand provide a positive cash flow to the landowner, make wood fiber available to markets earlier in the life of a stand, result in shorter optimal economic rotations, and provide the landowner with larger cumulative monetary returns (PNW). Using larger skidders or expensive mechanized CTL/forwarding systems can delay commercial thinning entry timing by as many as 30 years.

Landowners have some flexibility in scheduling thinnings and in determining optimal economic rotation age. For example, figure 2 shows the PNW revenue curves for the logging technologies simulated. Although the optimal economic rotation for the John Deere 440C and the feller-buncher/forwarding system is the same at 100 years, the cumulative financial yields are slightly improved by using the smaller skidder, but using the feller-buncher/forwarding system would allow scheduling commercial thinnings 10 years earlier than the small skidder. The optimal economic rotation for the CTL/forwarding system and the larger 120 horsepower John Deere 640D skidder is the same at 125 years. However, using the John Deere 640D allows the landowner to schedule a commercial thinning 15 years earlier than using the CTL system. The CTL system requires that the value of the stand be large enough to offset its high operating cost. This forces the landowner to wait until the stand is 100 years old before a commercial thinning can be scheduled. It is interesting to note that for late rotation harvests ≥ about 150 years, the choice of using all logging system technologies simulated will yield similar PNW results with the exception of the CTL/forwarding system.

We only evaluated one stand, three logging technologies, a fixed real interest rate of 4 percent, and fixed market prices with computer simulation. The results reported here are specific to the conditions simulated and to the models used and should not be generally inferred. However, the results suggest that landowners could schedule commercial thinnings earlier in the life of a stand and realize larger cumulative financial returns by careful selection/matching of logging technology to thinning entry timing and following optimal economic harvests.

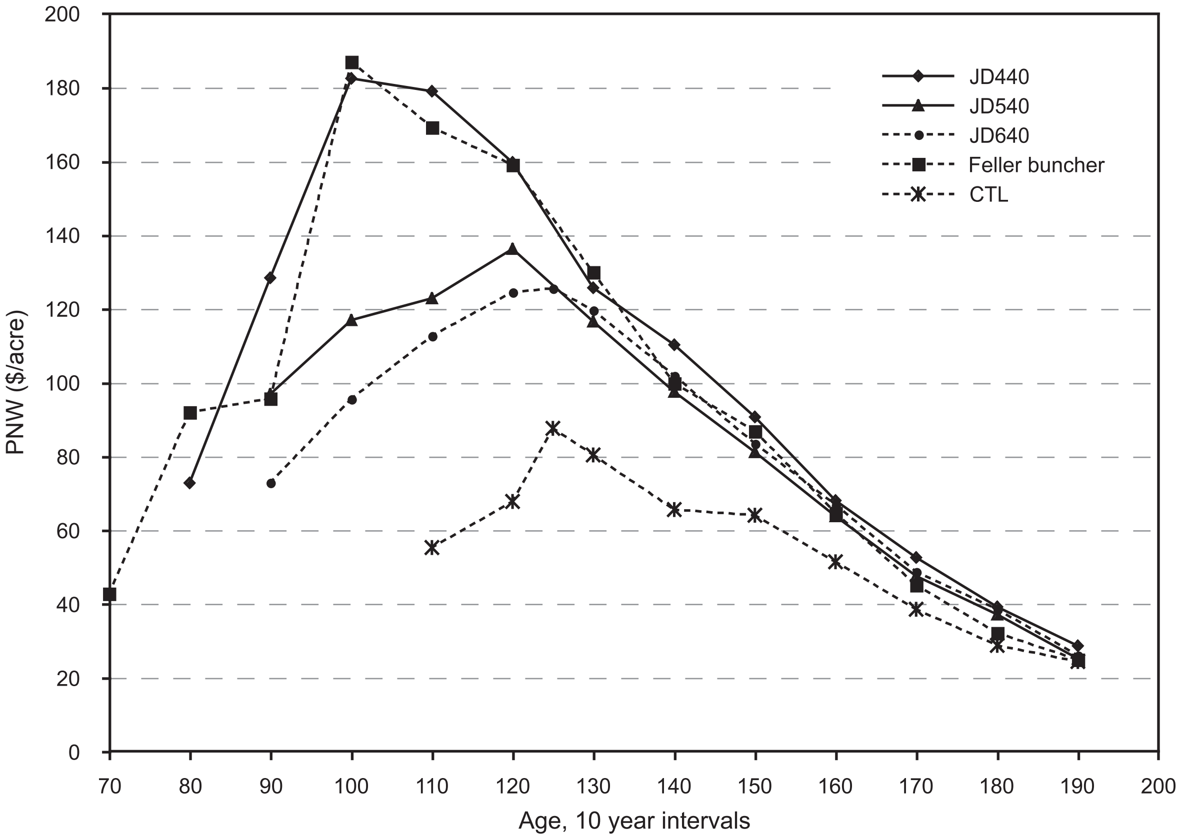

Figure 2—Present net worth (PNW) revenue curves for the oak-hickory stand by logging technology, real interest rate is 4 percent.

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