MATCHING SKIDDER SIZE TO WOOD HARVESTED TO INCREASE HARDWOOD FIBER AVAILABILITY: A CASE STUDY

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ABSTRACT

Integrating what we know about growing trees with what we know about harvesting them can increase the economic availability of wood fiber and add value to future crops. Results for the oak/hickory forest type in West Virginia show that up to 1,736.61 ft.^{3}/ac. of wood fiber can be harvested 10 years sooner than usual by simply matching the size of the machine to the size of the wood harvested. Specifically, the study focused on the gains that can be made by matching the size of machines to size of the wood harvested, by utilizing harvesting machines better and more efficiently, and by training machine operators to be more efficient. Gains of up to 40 percent in present net worth can be attained by early thinning of a stand when harvesting machines are matched to wood size harvested.

As global human population increases, worldwide demand for wood and wood products will continue to increase. Because the majority of the hardwood forested land in the United States is owned by non-industrial private forestland (NIPF) owners (1), they will be asked to increase the availability and quality of wood fiber harvested from their lands. The challenge for forest industry and NIPF owners is to meet these demands while simultaneously meeting their own short- and long-term economic and ownership goals (13). Another challenge is to communicate silvicultural and harvesting technology advances to the forest industry and NIPF owners so they can continue to provide wood products to society in a sustainable manner over time (2).

Researchers have accumulated volumes of knowledge about how to regenerate and grow many hardwood species (14). We know a great deal about how different species of hardwoods respond to alternative silvicultural treatments. Stocking guides have been developed to maximize tree growth for selected species (5,12). Over the same time, research in logging methods has been accumulated on production, cost, and applicability for cable logging (6), ground-based systems (3), and cut-to-length/forwarding machines (4) operating in eastern hardwood stands. Harvesting studies in clearcuts, thinnings, shelterwoods, and group-selection applications (8,9) evaluate these different processes and silvicultural systems. We know a great deal about how to regenerate, grow, and harvest trees in environmentally acceptable ways. The need is to integrate what we know about silviculture with what we know about logging technology and then to get the information to loggers, land managers, forest industry, and NIPF owners.

Our objective in this study was to integrate what we know about silviculture with what we know about logging technology to increase fiber availability and to add value to future crops. Specifically, we evaluated the economic benefits of matching machines to the size of wood harvested, the economic benefits of early thinnings, the impact of alternative machine utilization rates, and the sensitivity of alternative real discount rates for a stand in the oak/hickory forest type in West Virginia.

METHODS

DESCRIPTION OF MODELS

ECOST Version 3 and MANAGE were the models used in this study. ECOST Version 3 is a stump-to-mill logging cost-estimating model for eastern hardwoods (10). ECOST Version 3 allows for stump-to-mill cost estimation for cable and ground-based systems. The difference from previous versions is that it includes skidding cost and production functions for four small farm/skidding tractors and for three skidders with small, medium, and large capacity. Specifically, ECOST Version 3 allows the user to estimate the felling, bucking, limbing, yarding/skidding, loading, hauling, and unloading costs for several cable yarders, small tractors, and skidders. The costs can be estimated in components or as stump-to-mill for most con-

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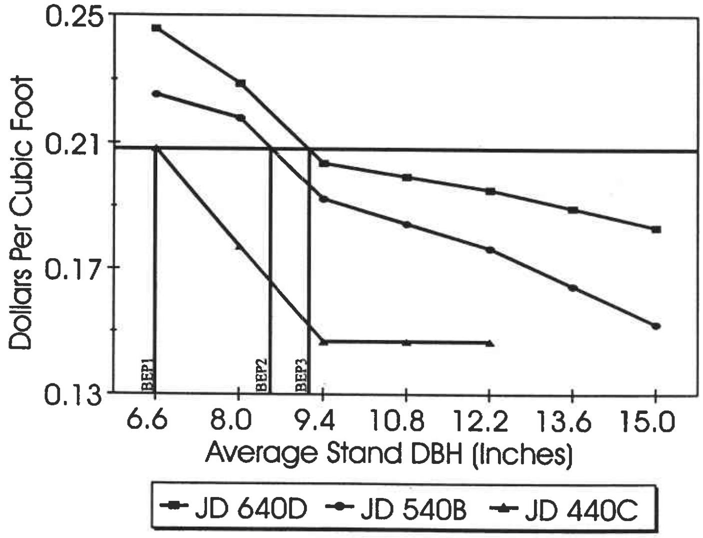

Figure 1.— Simulated delay-free skidding cost curves for JD 440C, JD 540B, and JD 640D skidders by average stand DBH; BEP1 = break-even point for JD 440C; BEP2 = break-even point for JD 540B; BEP3 = break-even point for JD 640D.

ditions loggers will encounter when logging eastern hardwood stands.

MANAGE (7), a computer program written in FORTRAN V, integrates harvesting technology, silvicultural treatments, market price, and economic concerns over the life of a stand. The simulation is a combination of discrete and stochastic subroutines. Individual subroutines model harvesting activities, silvicultural treatments, growth projections, market prices, and discounted present net worth (PNW) economic analysis. Specifically, the model allows the manager to evaluate how alternative harvesting technology, silvicultural treatments, market price, and economic combinations affect costs and benefits over the life of a stand. The model uses a detailed, individual user-specified tree list and then projects stand growth based on some user-specified silvicultural treatment, harvests the desired volume or stems with the logging system specified, sells the wood, and conducts an economic analysis for the respective treatment and entry. MANAGE was run for a stand in the oak-hickory forest type with alternative combinations of logging technology.

Using ECOST Version 3, the user obtains information on skidding costs for alternative logging machines and for any set of silvicultural/stand conditions. Using MANAGE, the user can project the costs and benefits of alternative combinations of silvicultural treatments and logging technology for any stand of interest.

Harvest treatments

The harvesting treatments evaluated include no thinning and an area-wide low thinning that removed all trees below an average diameter at breast height (DBH) of 12 inches to achieve a residual stand basal area stocking level of about 68 ft.^{2}/ac. 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 sawlogs. The stand was logged with ground-based logging technology. Specifically, the stand was logged with JD 440C, JD 540B, and JD 640D skidders. The John Deere machines are all articulated frame, four-wheel drive cable skidders manufactured in the United States. The John Deere 440C is a 70-horsepower skidder, the 540B is 90-horsepower, and the 640D is 120-horsepower. The hourly machine rates used in this study were $50.42, $34.93, and $29.10 for the JD 640D, JD 540B, and the JD 440C, respectively, as determined by Miyata (11). These three machines are representative of the types of cable skidders found on logging jobs in the eastern United States.

Site and stand conditons

In this study, the stand chosen for demonstration is from the oak/hickory forest type in West Virginia and represents 2,971 acres in total land area. The species mix includes northern red oak (*Quercus rubra* L.), American basswood (*Tilia americana* L.), white ash (*Fraxinus americana* L.) , and black cherry (*Prunus serotina* Ehrh.). The average site index of the stand is about 70. The stand is 60 years old and contains 257 trees per acre that are more than 5 inches DBH. The stand has an average tree DBH of 11.13 inches and about 4,412.42 ft.^{3}/ac. of merchantable volume. The land is located on gentle-to-moderate slopes and requires ground-based systems for harvesting. It is assumed that new road construction is not required. The stand is located 25 miles from a pulpmill/sawmill.

Results

Matching machines to wood size

The thinning was simulated at alternative average stand diameters using JD 440C, JD 540B, and JD 640D skidders. The resulting delay-free skidding costs were graphed by machine and the average stand diameter (**Fig. 1**). The cost curve for the JD 440C is truncated at 12.2 inches because turns containing multiple logs of this tree size exceed the capacity of the machine. At a break-even stump-to-road cost of $0.20/ft.^{3} (the prevailing price for small-diameter wood products in West Virginia at roadside), the JD 440C would break-even when operating in stands that average 6.6 inches DBH. The JD 540B would break-even in stands that averaged about 8.5 inches, and the JD 640D would break-even at an average DBH of about 9.1 inches. By matching the smaller, less-expensive skidder with smaller average stand diameters/younger stands, the manager/logger can enter younger stands earlier to conduct economical thinnings. Using a larger machine such as the JD 640D for the thinnings would require that the stand contain bigger trees before reaching break-even conditions (**Fig. 1**). Matching skidding machines to tree size could allow managers/loggers to enter younger stands and capture all the benefits of thinning and yet break-even. Matching the size of machine to the size of wood harvested also makes the wood from the thinnings economically available to fiber markets earlier in the life of a stand and increases the economic availability of wood fiber to markets.

IMPACT OF UTILIZATION RATE ON ENTRY TIMING

Clearly, few logging operations/machines operate in delay-free environments. Delays range from total machine malfunction resulting in a major breakdown/delay to the machine operator taking too many breaks or failing to service the machine. The thinning was simulated at different average stand diameters (ages) with a JD 540B skidder at utilization levels of 90, 80, and 60 percent (**Fig. 2**). Utilization rate is measured as the percentage of working time that the machine is actually being used in a productive mode as opposed to being nonproductive while in a delay mode. A machine with a high utilization rate will generally produce more wood volume per unit of time and cost less per unit produced than the same machine at a lower utilization rate. For this study, at a cost/ft.^{3} of \$0.20, the JD 540B at 90 percent utilization would break-even while operating in stands that averaged about 11.5 inches DBH. For the same machine and conditions, but at an 80 percent utilization rate, the break-even point occurs at about 14.0 inches DBH. At a utilization rate of 60 percent, the JD 540B would not break-even. Operator training strategies to increase the utilization rate of machines can allow managers/loggers to operate in younger/smaller DBH stands, thus making wood fiber economically available to wood markets earlier in the life of a stand.

IMPACT ON ROTATION AGE AND WOOD QUALITY

The advantages of entering a stand earlier in its life by matching machine size to wood size were further studied by inputting the costs from **Figure 2** at the 90 percent utilization level into the MANAGE model. Initially, the stand was not thinned and was projected to its Optimal Economic Rotation Age (ORA) using a real discount rate of 3 percent. The stand was then thinned using a JD 440C and a JD 540B skidder at the earliest age possible that would result in an economic/break-even entry to illustrate the impact of matching machines to wood size on rotation age, financial returns, and resulting quality development. The stand was thinned at age 60 with the JD 440C. The stand was thinned at age 70 with the JD 540B because of the higher skidding costs. The thinned stands were then projected to their ORA. The delivered product prices used in this study by species and log quality are shown in **Table 1**. The results from simulations for the no-thin and thinning treatments with MANAGE are summarized in **Table 2**. Matching machine size (JD 440C) to wood size would allow the stand to be thinned at age 60 yielding 1,736.61 ft.^{3}/ac. of wood fiber. Under the same conditions but thinning the stand at age 70 (with JD 540B), the yield is 2,325.37 ft.^{3}/ac. Using the smaller skidder and thinning all 2,971 acres could yield 5.1 million ft.^{3} of wood fiber that would be economically available 10

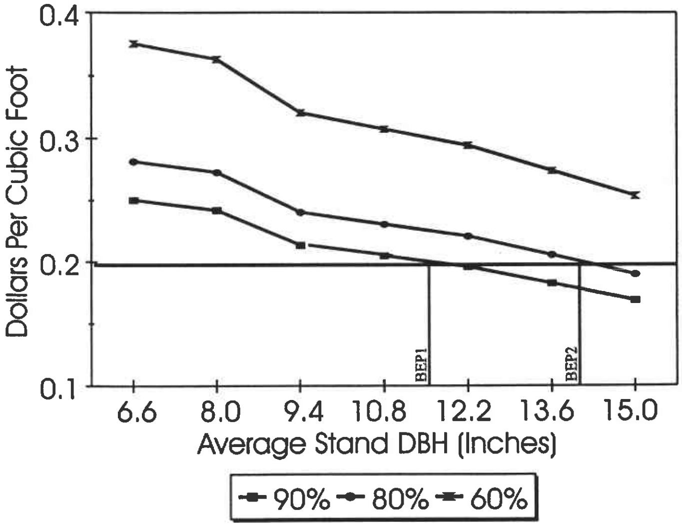

Figure 2. — Simulated skidding cost curves for JD 540B skidder at three utilization levels by average stand DBH; BEP1 = break-even point for utilization of 90 percent; BEP2 = break-even point for utilization level of 80 percent.

TABLE 1. — Delivered log prices by species and grade, international 1/4-inch (15).

Species group	Grade 1	Grade 2	Grade 3	Pulpwood
		($/MBF)		($/cord)
Red oak	561	397	225	40
Basswood	321	239	143	40
Black cherry	571	400	259	40
Ash	420	297	169	40

TABLE 2. — Simulated results by size of skidding machine.

Machine	JD 440C	JD 440C	JD 540B
Thinning age (yr.)	No thinning	60	70
Average stand DBH (in.)	- -	8.78	10.09
Trees cut per acre	- -	172	169
Volume removed per acre (ft.^{3})	- -	1,736.61	2,325.37
Present net worth (PNW)($)[a]	- -	38.28	20.84
Cash flow per acre ($)	- -	38.28	28.01
Optimal economic rotation age (ORA)(yr.)	90	100	110
Average DBH at ORA (in.)	14.03	20.32	20.80
Volume per acre at ORA (ft.^{3})	5,507.94	4,355.94	4,288.41
Total volume per acre removed (ft.^{3})	5,507.94	6,092.55	6,613.78
PNW per acre at ORA ($)[b]	1,360.67	1,872.98	1,695.15
Cash flow per acre at ORA ($)	3,302.70	6,109.72	7,431.38

[a] Real discount rate = 3 percent.
[b] Discounted to age 60.

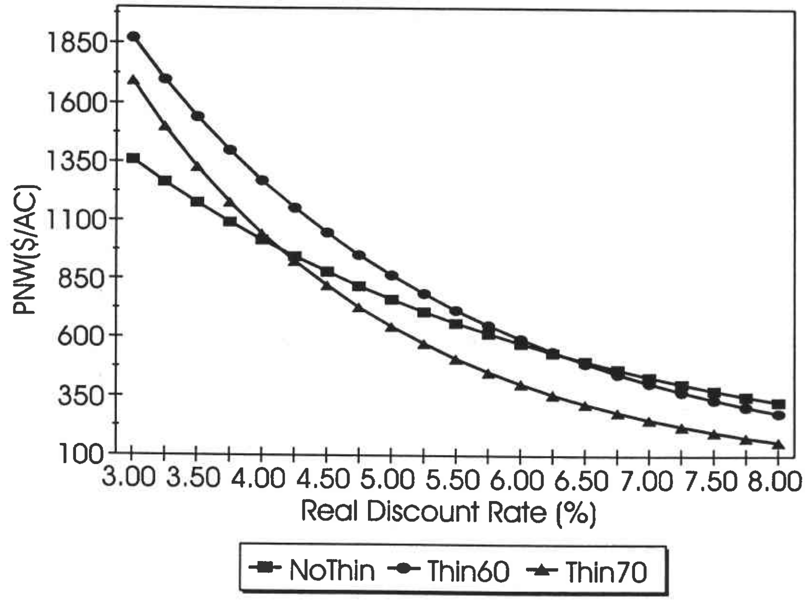

Figure 3. — Impact of real discount rate on thinning decision.

years earlier than if a larger skidder were used in the first thinning. The thinnings do not produce more volume overall, they just make fiber economically available earlier.

The unthinned stand reached its ORA at 90 years. The thinned 60-year-old stand would reach its optimal rotation 10 years sooner than if the stand were thinned with the larger skidder at age 70. Both thinned stands would produce wood that would average 20+ inches DBH compared to 14+ inches in the unthinned stand. The larger 20-inch-DBH trees would yield higher quality logs than those from the 14-inch stand. Since the thinned 60-year-old stand reaches optimal rotation sooner than the thinned 70-year-old stand, the present net worth (PNW) using a 3 percent real discount rate is $1,872.98 compared to $1,695.15, or an increase of 10.49 percent. This could represent a gain of $580,147.17 in cumulative PNW over the thinned 70-year-old stand if all 2,971 acres were thinned at one time. It is unlikely that all 2,971 acres would be thinned at one time, but for this analysis, it demonstrates the potential volume and financial yields possible. The thinned 60-year-old stand produces a cumulative PNW increase of $550.59/ac. compared to the unthinned stand. Although the thinnings do not produce more volume overall, they serve to concentrate the remaining volume on fewer stems but of higher quality.

Impact of Real Discount Rate

The impact of real discount rate on the thinning decision is shown in **Figure 3.** For the range of real discount rates from 3 to 8 percent, it is always advantageous to conduct thinnings at age 60 compared to age 70. Conducting thinnings at age 70 is better than not thinning for real discount rates of 3 to 4.12 percent. At real discount rates of about 4.12 percent it is equally advantageous to conduct thinnings at age 70 as it is to not thin the stand. At real discount rates beyond 4.12 percent it is best to not thin compared to thinning at age 70. Thinning the stand at age 60 is a better alternative than to not thin when real discount rates are in the 3 to 6.25 percent range. At real discount rates of about 6.25 percent, it is equally advantageous to conduct thinnings at age 60 as it is to not thin the stand. When the real discount rate exceeds 6.25 percent it is no longer attractive to conduct thinnings.

Conclusions

Matching machine size to size of wood harvested results in wood fiber becoming economically available earlier in the life of the stand, shorter ORA for similar-size products, and significant gains in PNW: up to 10.49 percent for the oak/hickory forest type in West Virginia. Strategies to improve machine utilization also allow managers/loggers to enter stands earlier, which makes wood fiber economically available earlier and improves the quality and value of the future stands. In addition, the combination of carefully matching the size of machines to the size of wood harvested and implementing strategies to reduce skidding delays allows managers/loggers the same benefits. Up to 1,736.61 $ft.^3$/ac. of wood fiber can be made economically available sooner by simply using smaller, less-expensive skidders to enter the stands at earlier ages. Thinned stands produce larger DBH, higher quality wood and, thus, larger economic returns compared to unthinned stands. Gains of up to 40.46 percent in discounted cumulative PNW can be realized by early thinning versus no thinning.

In this study, we did not consider the impact of residual stand damage on financial yields over time. We have found that residual stand damage from thinnings can range from none to very high levels. The impact of residual stand damage is best dealt with on a case-by-case basis. Although most NIPF owners own tracts substantially less than 2,971 acres, the results are applicable to small tracts as well. The increased economic availability of wood fiber along with the value added in quality to the future stand can help meet the world's demand for fiber and quality hardwoods.

Literature Cited

1. Birch, T.W. 1996. Private forest-land owners of the Northern United States, 1994. Resource Bull. NE-136. USDA Forest Serv., Northeastern Forest Expt. Sta., Radnor, Pa.
2. Cantrell, R. 1996. The American Forest & Pulp Association's sustainable forestry initiative and nonindustrial forest landowners. *In*: Proc. Symp. on Nonindustrial Private Forests: Learning From the Past, Prospects for the Future. M.J. Baughman, ed. Univ. of Minnesota, St. Paul, Minn. pp. 397-402.
3. Huyler, N.K. and C.B. LeDoux. 1989. Small tractors for harvesting fuelwood in low-volume small-diameter hardwood stands. *In*: Proc. of the 12th Ann. Meeting of the Council on Forest Engineering. USDA Forest Serv., Southern Region, Atlanta, Ga. pp. 61-66.
4. _________ and _________. 1996. Cut-to-length harvesting on a small woodlot in New England: A case study. *In*: Proc. Planning and Implementing Forest Operations to Achieve Sustainable Forests. Gen. Tech. Rept. NC-186. USDA Forest Serv., North Central Expt. Sta., St. Paul, Minn.
5. Lancaster, K.F. and W.B. Leak. 1978. A silvicultural guide for white pine in the Northeast. Gen. Tech. Rept. NE-41. USDA Forest Serv., Northeastern Forest Expt. Sta., Broomall, Pa.
6. LeDoux, C.B. 1985. Stump-to-mill timber production cost equations for cable logging eastern hardwoods. Res. Pap. NE-566. USDA Forest Serv., Northeastern Forest Expt. Sta., Broomall, Pa.

7. __________. 1986. MANAGE: A computer program to estimate costs and benefits associated with eastern hardwood management. General Tech. Rept. NE-112. USDA Forest Serv., Northeastern Forest Expt. Sta., Broomall, Pa.

8. __________, J.E. Baumgras, J. Sherar, and T. Campbell. 1991. Production rates and costs of group-selection harvests with a Christy cable yarder. Forestry and environment ... engineering solutions. ASAE 09-91:75:84.

9. __________, M.D. Erickson, and C.C. Hassler. 1993. Production rates and costs of group-selection harvests with ground-based logging system. *In*: Proc. of the 9th Central Hardwood Forest Conf. Gen. Tech. Rept. NC-161. USDA Forest Serv., North Central Forest Expt. Stat., St. Paul, Minn.

10. __________. 1987. ECOST - A stump-to-mill timber production cost-estimating program for cable logging eastern hardwoods. The Compiler 5(4):33-34.

11. Miyata, E.A. 1980. Determining fixed and operating costs of logging equipment. Gen. Tech. Rept. NC-55. USDA Forest Serv., North Central Forest Expt. Sta., St. Paul, Minn. 16 pp.

12. Sampson, T.L., J.P. Barrett, and W.B. Leak. 1980. A stocking chart for northern red oak in New England. Univ. of New Hampshire, Inst. of Natural and Environmental Resources, Durham, N.H.

13. Sampson, N.R. 1996. Keynote address: Nonindustrial private forest - learning from the past, prospects for the future. *In*: Proc. Symp. on Nonindustrial Private Forests: Learning From the Past, Prospects for the Future. M.J. Baughman, ed. Univ. of Minnesota, St. Paul, Minn. pp. 3-9.

14. Smith, C.H., A.W. Perkey, and W.E. Kidd, eds. 1988. *In*: Proc. Guidelines for Regenerating Appalachian Hardwood Stands. SAF Pub. 88-03, West Virginia Univ., Morgantown, W.V.

15. Worthington, V.E., C.B. LeDoux, W.H. McWilliams, H. Sloan, and T. Jones. 1996. Methodology for assessing current timber supplies and product demands. Gen. Tech. Rept. NE-226. USDA Forest Serv., Northeastern Forest Expt. Sta., Radnor, Pa.