TREE DIAMETER EFFECTS ON COST AND PRODUCTIVITY OF CUT-TO-LENGTH SYSTEMS

MATHEW A. HOLTZSCHER
BOBBY L. LANFORD

ABSTRACT
Currently, there is a lack of economic information concerning cut-to-length harvesting systems. This study examined and measured the different costs of operating cut-to-length logging equipment over a range of average stand diameters at breast height. Three different cut-to-length logging systems were examined in this study. Systems included: 1) feller-buncher/manual/forwarder; 2) feller-buncher/processor/forwarder; and 3) swing-to-tree harvester/forwarder. Operating costs were calculated by generating stands with the stand generator program FCWT/Thin. Once stands were generated, costs for thinning were determined using a computer spreadsheet model known as the Auburn Harvester Analyzer. Each individual system followed different cost trends; however, for all systems, tree size had a significant effect on unit cost of wood produced. As tree size increased, unit cost of wood produced decreased. The swing-to-tree harvester system was much more expensive for small-diameter trees than the other two systems due to individual stem processing and small volume per tree but approached the unit costs of the other systems at larger tree sizes.

LITERATURE REVIEW
Cut-to-length systems can be either highly manual or mechanical. The forwarder, however, is the foundation of all cut-to-length systems. Forwarding is the process of transporting the wood from the stump to roadside with the load supported by the machine. Payloads for forwarders range from 16,000 to 36,000 pounds (5), while large skidders typically only pull around 1 cord (5,350 lb.) or less per cycle. Tufts et al. (19) found that the payloads of skidders ranged from 518 to 10,773 pounds; however, only 30 (7%) of the 416 observed cycles were heavier than 5,350 pounds. The large payload of a forwarder means it needs fewer passes over the ground to move the wood to the roadside (4). Fewer trips into the timber stand corresponds with decreased rutting and decreased soil compaction (10).

Forwarders offer more maneuverability, greater productivity, and less access area requirements than other systems (13). Tree-length systems require straight corridors in order to minimize damage to the residual trees. Forwarders, however, can meander through a stand of timber and do not require straight roads. This is possible for two reasons. First, the material being transported is already bucked to a merchantable length, gener-

The authors are, respectively, Research Assistant and Associate Professor, School of Forestry, Auburn Univ., AL 36849. This paper was received for publication in February 1996. Use of trade names and brands is for reader convenience and is not an endorsement by Auburn Univ. or the authors. Reprint No. 8487.
<table>
<thead>
<tr>
<th>Planting spacing</th>
<th>Site index</th>
<th>Basal area</th>
<th>Trees per acre</th>
<th>Volume</th>
<th>DBH</th>
<th>Age</th>
<th>Stand entry no.</th>
<th>Pattern</th>
<th>Basal area</th>
<th>Trees per acre</th>
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<td>64.9</td>
<td>81</td>
<td>20.20</td>
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</table>

* Site index is base age of 25 years.
* All volume is cords outside bark to a 3-inch top.
* DBH is quadratic mean diameter in inches.
ally under 20 feet, as compared to the tree-length system, which may have ma-
terial over 40 feet in length. Second, the forwarder is articulated and is capable of
turning around in a small area while car-
rying its payload.

Cut-to-length systems range from
those that involve a considerable amount of manual labor to totally mechanized
systems. When totally manual, trees are fell,
delimed, and bucked by chainsaw
operators. Depending upon the final
product, short bolts may be handpicked
while higher valued and larger products,
such as chip-n-saw logs, are left where
they are processed. After all processing
is completed, a forwarder is then used to
collect the merchantable material and
load haul vehicles (5). A more mecha-
nized approach uses a feller-buncher
felling the trees, yet chainsaw operators
are still used to delimb and buck the wood.

Total mechanization of a cut-to-
length system can be achieved by two
methods. In the first system, a feller-
buncher is used to fell trees, a processor
delims and bucks felled trees into logs,
and a forwarder is used to transport the
logs (3). Greene and Lanford (3) exam-
ined the use of a processor for thinning
and concluded that tree utilization was
greater than with chainsaw processing.
The processor also added the benefit of
increased safety, since all operations
were mechanized. The slash from pro-
cessed trees was deposited by the proces-
sor in the travel corridors where the
limbs and tops acted as a bed for sub-
sequent machine traffic.

The second totally mechanized cut-
to-length system uses only two ma-
tines. A swing-to-tree harvester fells,
delims, and bucks the wood (2,11,12).
The processed wood is then transported
by a forwarder. Of the two totally
mechanized systems, the swing-to-tree
harvester and forwarder combination
has received the most attention
(4,11,15,17). Two articles that appeared in
Timber Harvesting (8,14) discussed
both the advantages and disadvantages
of the swing-to-tree harvester/forwarder
systems compared to more conventional
skidder systems.

Advantages included: 1) more eco-
onomical on small tracts of timber; 2) less
total labor cost, since only two employ-
ees are needed; 3) less fuel consumption
by machines; 4) easier to merchandise
highest valued products from trees; 5) the
lowest worker's compensation rates; 6)
safe and comfortable work environment;
and 7) minimal site and stand damage.

Disadvantages included: 1) some-
what longer learning curve for operators;
and 2) high initial cost of individual cut-
to-length equipment.

**METHODS**

For this study, the thinning costs asso-
ciated with three different cut-to-length
machine combinations over a variety of
harvested diameters were compared. A
widely accepted measure of the average
diameter at breast height (DBH) of the
timber being harvested is the quadratic
mean diameter of the removed wood. The
quadratic mean DBH is a measure of the
tree of average basal area. Har-
vested quadratic mean diameters were
calculated with the following formula:

\[
Q_m = \frac{[\text{basal area removed/(tree per}
\text{acre removed} \times 0.005454)]^3}{5}
\]

The influence of eight different tim-
ber stands with harvested quadratic
mean DBHs representing approximately
4, 5, 6, 7, 8, 9, 10, and 11 inches was used
to compare the three cut-to-length log-
ging systems. The computer growth and
yield model PCWthin (1) generated all of
the stands.

Harvesting patterns were chosen that
matched the equipment and system be-
ing used. The feller-buncher/manual/for-
warder and swing-to-tree harvester/for-
warder systems used a fifth row pattern
where 20 percent of the stand was clear-
cut and the remainder was thinned from
below to the designated residual basal
area of 65 ft.²/acre. The feller-
buncher/processor/forwarder system
was capable of a ninth row pattern. One-
ininth of the stand was clearcut and the
remainder was thinned from below to the
desired basal area.

The harvested quadratic mean diame-
ters representing 4, 5, 6, and 7 inches
were obtained from stands that were be-
ing row/low thinned for the first time.
The remaining four quadratic mean di-
ameters representing 8, 9, 10, and 11
inches were obtained from stands being
thinned for the second time. A second
thinning was necessary to obtain the
larger diameters.

Table 1 contains a summary of the
stand information used for all thinning
patterns, as well as information concern-
ing the harvested and residual stands.
Based on advice from practitioners with
considerable thinning experience, a tar-
get of harvesting 10 cords per acre for all
diameter classes was established for both
economical and silvicultural concerns.
As shown in Table 1, this target was
attained for all diameters except for the
4- and 5-inch quadratic mean diameter
classes.

Aer stands were generated, cost and
productivity associated with thinning
each stand was determined by using the
Auburn Harvesting Analyzer. This
spreadsheet is capable of determining
the productivity and unit cost for a tract
of timber based on the type of logging
system used, the size of timber being
harvested, and other operation variables
(18).

SISU Valmet cut-to-length equip-
ment was used for system comparisons
whenever possible due to the availability
of published information. Table 2 lists

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**TABLE 2. — Equipment specifications.**

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<thead>
<tr>
<th>Equipment</th>
<th>Description</th>
<th>Suggested retail price</th>
<th>Source</th>
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<td>Valmet 546 Woodstar forwarder</td>
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<td>Valmet 546 Woodstar forwarder</td>
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<td>650 Cmnh load with extension 22' 6' each</td>
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<td>Valmet 546 Woodstar forwarder</td>
<td>28-ft. front tires</td>
<td>Cranb-36 in. grapple w/dumper</td>
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<td>28-ft. front tires</td>
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Sources: Valmet Equipment: George Ahay, Re-
genial Sales Manager (Mobile, Ala.), Chansaw
and har. King Power Equipment (Lafayette,
La.). Safety apparel: Granfor Brus, Inc.
(Summerville, S.C.). Suggested retail prices as of
TABLE 3 — Production equations.

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<tr>
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<td>[ \text{Travel-to-tree} = -0.1493 + 0.9889 \ln(\text{ReaBA}) ]</td>
</tr>
<tr>
<td></td>
<td>[ \text{Travel-to-dump} = 0.0060 + 0.0322 \text{volt} ]</td>
</tr>
<tr>
<td></td>
<td>[ \text{Dump} = 0.0169 + 0.0162 \text{volt} ]</td>
</tr>
<tr>
<td></td>
<td>[ \text{Total} = 0.1063 + 0.0033(\text{DBH}^2 - 72.25) + 0.0889 \ln(\text{ReaBA}) + 0.0468 \text{volt} ]</td>
</tr>
<tr>
<td>Chainsaw</td>
<td>[ \text{Total} = 0.0746 + 0.0589(\text{DBH} - 1.0284 \times \text{branch} + 0.2479 \times \text{DBH} / \text{branch} ]</td>
</tr>
<tr>
<td>Forwarder</td>
<td>[ \text{Loading} = 0.0284 + 0.31935(1/\text{swing volume}) ]</td>
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<td></td>
<td>[ \text{Travel} = 0.428 + 0.0155(\text{distance}) ]</td>
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<td>Processor</td>
<td>[ \text{Total} = -0.341 + 0.1243 \times \text{AvgDBH} ]</td>
</tr>
<tr>
<td>Swing-to-tree</td>
<td>[ \text{Harvester} = 0.223 + 0.0536(\text{DBH}) ]</td>
</tr>
</tbody>
</table>

where:
- \( \text{DBH} \) = diameter at breast height (in.)
- \( \text{ReaBA} \) = residual basal area (ft.\(^2\))
- \( \text{Volt} \) = volume per tree (ft.\(^3\) outside bark)
- \( \text{Branch} \) = proportion of merchantable bole with limbs
- \( \text{Swing volume} \) = average volume grabbed by the forwarder (ft.\(^3\) outside bark)
- \( \text{Distance} \) = average forwarding distance (ft.)
- \( \text{AvgDBH} \) = average diameter at breast height of the harvested wood (in.)

The equipment used, the options selected, and purchase prices. The equipment used for the fell-buncher/manual/forwarder system included Valmet 503 fell-bunchers, Husqvarna 272 chainsaws and safety apparel, and Valmet 546 Woodstar forwarers. The fell-buncher/processor/forwarder system utilized Valmet 503 fell-bunchers, Valmet 546 Woodstar processors, and Valmet 546 Woodstar forwarers. The swing-to-tree harvester/forwarder system included Valmet 546 Woodstar harvesters and Valmet 546 Woodstar forwarers. Table 3 contains a listing of all production equations used and their source documents.

The Auburn Harvester Analyzer calculates the productivity and cost of the entire system. In addition, the utilization of each function is determined by combining machines in the system. By balancing the system to the least productive function, a utilization rate for each function is determined. Cost per cord for each function is obtained by combining hourly machine rates (9) with utilization and system productivity. Finally, the cost of the different functions are combined and the cost for on-board set-out trailers per cord for the system are calculated.

Three different Auburn Harvester Analyzer spreadsheets representing the three cut-to-length systems were developed for this project. All spreadsheets used identical information except for the machine types and the productivity of the different machines. Assumptions such as tract size, load size, taxes, and insurance rates were all identical. Table 4 lists all the variables and values used to represent each system variable.

**RESULTS**

The Auburn Harvester Analyzer combined the stock and stand tables generated by FCWThin, system variables, machine rates, and the production equations to generate estimates of on-board cost for each cut-to-length system. Table 5 is a summary of the on-board cost for each diameter class within each system, as well as a listing of weekly production and the balance of machines needed in each system to minimize cost. It should be noted that the on-board cost is the amount needed to pay all expenses, profit for the owner is not included. Figure 1 is a graphical comparison of the different cut-to-length systems and allows the user to interoperate cost on all harvest diameters within the range examined. As Figure 1 indicates, harvesting cost per cord is highly influenced by tree size for all systems examined. Small trees are very expensive to harvest.

The results from the fell-buncher/manual/forwarder system showed that manual processing required two to four chainsaw operators per fell-buncher. As the harvested trees increased in size, the felling and manual processing became more productive, which required more forwarding capacity. To achieve the lowest system costs, machines were balanced; that is, adequate machines were used in each phase of operation to keep each machine utilized as much as possible. On-board cost decreased as tree diameter increased. Production averaged approximately 50 cords per day per forwarder for all diameters of wood except the 4-inch class.

The fell-buncher/processor/forwarder system follows the same trends as the fell-buncher/manual/forwarder system. In the 4- and 5-inch diameters, more felling capacity is needed to balance the mechanical processing. As the trees become larger, more forwarers are needed to balance the system. On-board costs are very similar to the manual system; however, they are slightly higher for all diameters except in the 4-inch class. Production for the fell-buncher/processor/forwarder system averages slightly over 50 cords per day per forwarder.

The swing-to-tree harvester/forwarder system required considerably more harvesting capacity in small-diameter wood with the swing-to-tree harvester/forwarder system. However, for all system variables, the on-board cost increases as tree diameter increases.
vester, while more forwarding capability is needed in 10- and 11-inch wood. On-board costs per cord were considerably higher in the smaller diameters, but become comparable for tree sizes larger than 8 inches. Production for this system is slightly over 40 cords per day per forwarder.

**CONCLUSIONS**

Three cut-to-length thinning systems were compared in this study. Eight different stands were created by the stand generator PCWThin using fifth row/low and ninth row/low thinning patterns. Harvesting costs and productivity for each stand and system combination were calculated with the Auburn Harvester Analyzer spreadsheet. Tree size had a significant effect on unit cost of wood produced. As tree size increased, unit cost of wood produced decreased.

**FELLER-BUNCHER/MANUAL/FORWARDER SYSTEM**

In general, the feller-buncher/manual/forwarder system had the lowest unit cost of all the cut-to-length systems. Labor requirements are higher for this system. Four to six chainsaw operators are needed to balance with one feller-buncher and one to three forwarders, depending on the diameter of wood being harvested. Manual processing with chainsaws increases the chance for accidents and the potential for workers to experience physical stress and could contribute to worker turnover. Slash that remains with the logs creates downstream problems during loading and hauling.

**FELLER-BUNCHER/PROCESSOR/ FORWARDER SYSTEM**

The feller-buncher/processor/forwarder system had cost and production very similar to the manual processing system. For first thinnings, which typically have cut trees averaging 5 to 7 inches, this system offers the most potential. By having all operators in enclosed cabs, the system puts workers in a safe and comfortable work environment. Slash is separated from the merchantable logs and placed as a mat for machine traffic.

**SWING-TO-TREE HARVESTER/FORWARDER SYSTEM**

The swing-to-tree harvester/forwarder system had the highest unit cost of all the cut-to-length systems. Productivity was less than both the manual and processor systems. The swing-to-tree

**TABLE 5. — On-board cost and productivity.**

<table>
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**Figure 1. — On-board cost comparison for cut-to-length systems.**

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Vol. 47, No. 3
harvester/forwarder system had the lowest labor requirements and consisted of only one operator for each of the two types of machines. The swing-to-tree harvester/forwarder system had the highest initial cost, as tree size increased, the difference in unit costs for all systems decreased and was similar at the 11-inch class. If thinned trees had sawlog-grade material, the computerized measuring devices of the swing-to-tree harvester would be superior to the processing method of the other two systems studied. While both manual processing and mechanized processing have the ability to merchandise plywood and sawlogs from trees, the single-tree processing of the harvester probably measures more accurately. The swing-to-tree harvester/forwarder system would be best used in second thinnings or other cuts where merchandising is important. In addition, swing-to-tree harvesters have the added capabilities of working in steep, rocky, or swampy terrain. The reach of the boom allows the harvester to cover more ground than a machine that drives to each tree.

LITERATURE CITED