# Cost and Productivity Impacts of Product Sorting on Conventional Ground-Based Timber Harvesting Operations

Randy D. Cass
Shawn A. Baker
W. Dale Greene

## Abstract

The impacts of additional log sorting on production and cost per ton for mechanized, tree-length southern pine harvesting systems were evaluated. The analysis included evaluation of extensive data sets of weekly production along with short-term field time studies to directly measure the impacts of sorting on production. For this study, a product separation, or sort, was defined as a separate pile generated by the loader operator. The data were used to create a model to evaluate log sorting impacts on production and costs. Tree-length harvesting systems encountered weekly production losses when sorting more than six products, while modified tree-length harvesting systems using roadside processors lost production after nine product sorts. Hourly production was significantly impacted by both operator technique and the type of product handled. Operators who processed wood in advance of truck arrivals and loaded trucks from processed piles loaded trucks in 60 percent less time than loader operators who processed stems while loading. Increasing the number of sorts often required more processing while loading since the room to store processed wood under stationary loaders is limited. Adding precut sorts significantly reduced production over that seen with an additional tree-length sort, due to the additional processing and loader movement with multiple stem pieces. With the current product price differentials typical to southern log markets, we did not find increased net revenue to the landowner from additional sorts. In fact, we found that at current prices additional sorts can reduce revenue by 6 to 15 percent.

Significant changes in forestland ownership have occurred over the past decade as integrated forest products companies have sold their forest lands to institutional investors. The United States saw over 23 million acres transferred from integrated forest products companies to institutional investors between 2000 and 2003 (Wilent 2004). In the US South alone, over 18 million acres changed hands and these industry divestitures continue (Clutter et al. 2005). Changes in forestland ownership have caused numerous changes in forest management across the United States. Institutional investors strive to maximize the returns solely from timberlands, whereas integrated forest products companies seek to maximize the value of the stump to finished product links of the supply chain.

Harvesting systems in the US South are dominated by tree-length operations (Baker and Greene 2008). Tree-length harvesting systems generally skid tree stems to the landing where loader operators make decisions on the sorting and bucking of products. These systems mostly use stationary knuckleboom loaders that have limited space within their reach for sorting piles of different products. Landowners seeking higher returns from timberlands have impacted logging contractors' operations by requiring additional product separations. Each additional separation beyond what is normal takes time and occupies limited space under the loader.

Contractors also make additional separations to capture new markets or to keep production from being limited by mill quotas. These additional separations may also require more space at the landing, taking land out of timber production when the harvest is a thinning. Raymond (1987) found a linear relationship between landing size and the number of log sorts in New Zealand. For example, a landing

The authors are, respectively, Regional Sales Manager, ForesTech International LLC, Watkinsville, Georgia (rcass@forestech.us); and Research Professional and Professor, Center for Forest Business, Warnell School of Forestry & Natural Resources, Univ. of Georgia, Athens (sbaker@warnell.uga.edu, greene@warnell.uga.edu). This paper was received for publication in July 2009. Article no. 10653.

Forest Prod. J. 59(11/12):108–114.

that processed and stored 10 log sorts was three times the size of a landing with only one log sort.

Some studies have examined the effects of additional product separations on productivity. Williams (1989) reported no productivity loss from six to nine separations with a knuckleboom loader in New Zealand. However, the delimbing and bucking activities were carried out manually, which has mostly been eliminated with fully mechanized crews. Blinn and Sinclair (1986) examined the profitability, productivity, and costs under three levels of sorting intensity (two, five, and six log sorts) in the US Lake States. The study examined five harvesting systems: forwarding, manual fell-chain saw buck, manual fell-mechanized slash, mechanical fell-mechanized slash, and whole tree chip. Their model suggested that profitability increased with sorting intensity as long as the increase in delivered prices of these products exceeded production costs associated with the loss of production when conducting the greater number of sorts.

Product separations are typically conducted to maximize the value for timberland owners through the stumpage prices they receive and for buyers through delivered prices for products. Nonetheless, the increased time to perform these separations usually entails a cost that is partially due to a decrease in productivity. Gingras (1996) examined and compiled information for full-tree, tree-length, and cut-to-length harvesting systems in eastern Canada and found that the additional revenue from producing these sorts generally did not provide any additional benefits to the contractors performing the sorting. Few studies have examined the effects of product sorting on contractor productivity or assessed the costs of performing these sorts in the US South. This report summarizes our findings of a study to quantify these costs of additional product separations.

## Methods

We collected data on logging operations performing product sorting using two basic approaches. The first approach involved a group of contractors sharing weekly production information with us so we could identify any trends or relationships between the number of sorts and total weekly production. For this study, a product separation, or sort, was defined as a separate pile generated by the loader operator. If two products were differentiated at the landing, they qualified as discrete product sorts. The second approach involved short-term time studies on a subset of the operations providing weekly data to directly measure the impacts of sorting on production, specifically of the knuckleboom loader using common delimbing and bucking attachments. Finally, we used data from each of these approaches to create a model to evaluate log sorting impacts on production and costs.

### Weekly production

We assembled a group of contractors using logging companies recommended by our industry cooperators. Each was considered to be above average in performing product sorts for the company. A total of 11 contractors from Georgia ($n = 7$) and South Carolina ($n = 4$) agreed to participate in the study. Weekly data were collected for periods of 3 months to over 3 years from the 11 crews. Of these crews, nine were traditional tree-length harvesting systems that used stationary knuckleboom loaders with pull-through delimbers and ground saws at the landing to process material. The remaining two crews were modified tree-length systems utilizing a processing head mounted on a tracked shovel that operated at the landing or roadside. Contractors reported the product type for each load, market destination for each product, loads per day, total loads delivered, number of workers on site, and hours worked per week. We examined the impacts of sorting intensity from the collection of weekly production data using linear regression. In the analysis, tree-length harvesting systems were differentiated from modified tree-length harvesting systems by using dummy variables.

### Time studies on loading and processing

Short time studies were conducted on five loader operators for a period of 2 to 4 days to record data on at least 25 loads of wood for each operator. Two contractors operated in the piedmont of Georgia and three worked in the coastal plain of Georgia or South Carolina. Four of the crews were performing clearcuts while the other crew was performing a first thinning. Each harvesting system included a knuckleboom loader with a pull-through delimber and a hydraulic ground saw. Generally, skidders performed some delimbing functions by backing stems through a delimbing gate and/or using the blade to shear limbs off skidded wood to potentially decrease loader processing times for each product.

We observed some differences in loading and processing work methods from our sample of five operators. Four of the operators took wood from the skidder, delimbed it, cut it to limiting product top diameters, cut it with the groundsaw if needed, and sorted the products into specific processed piles. The fifth operator took wood from the skidder and sorted it into unprocessed piles. Processing with that operator was then conducted only after a truck arrived at the landing to be loaded.

Recorded data included product, loading time, stems per load, swings from processed piles to truck, swings from unprocessed piles to truck, swings from unprocessed piles to processed piles, and swings of wood from the truck to a processed pile. Typically, unprocessed wood was delimbed, topped, and placed in either the appropriate piles or loaded onto trucks. We obtained weights for each truckload from mill delivery tickets shared by each contractor.

We performed a work sample of the loader at 2-minute intervals. Activity codes were used to simplify data analysis and included loading, sorting, delimbing, mechanical delays, and other common activities for log loaders. We also performed time studies on processing performance to better understand product separation impacts on production. Continuous time-study data were recorded on three processing actions: delimbing, bucking, and sorting.

Delimbing began when the loader started swinging toward skidded wood and ended when wood was lifted out of the delimber. Bucking began when wood was lifted from the delimber and lasted until it was lifted from the ground saw after the bucking cut took place. Sorting began when wood was lifted either from the ground saw or delimber and ended when the loader began to swing to the next operation. Other data collected during processing included the number of stems or logs and the product in the loader grapple.

During the course of the field studies, five product separations were observed: (1) tree-length pine pulpwood, minimum 20-foot length to a 3-inch top diameter; (2) tree-length pine super pulpwood, minimum 25 feet to a 5-inch top diameter; (3) tree-length pine chip-n-saw, minimum 29-foot length to a 6-inch top diameter; (4) tree-length pine sawtimber, mini-

*Table 1.—Allocation tables used for the base case and a higher percentage of precut products in the Auburn Harvesting Analyzer model.*

| | Base case percentage/higher percentage[a] | | | | | |
|---|---|---|---|---|---|---|
| DBH (in.) | Pulpwood | Super pulpwood | Chip-n-saw | Precut chip-n-saw | Sawtimber | Precut sawtimber |
| 3 | 100 | | | | | |
| 4 | 100 | | | | | |
| 5 | 100 | | | | | |
| 6 | 100 | | | | | |
| 7 | 50 | 50 | | | | |
| 8 | 50 | 40 | | 0/10 | | |
| 9 | 20 | | 65/50 | 15/30 | | |
| 10 | 20 | | 65/50 | 15/30 | | |
| 11 | 20 | | 55/30 | 15/30 | | 10/20 |
| 12 | 10 | | | | 80/70 | 10/20 |
| 13 | 10 | | | | 80/70 | 10/20 |
| 14 | 5 | | | | 85/75 | 10/20 |
| 15 | 5 | | | | 85/75 | 10/20 |
| 16 | 5 | | | | 85/75 | 10/20 |
| 17 | 5 | | | | 85/75 | 10/20 |
| 18 | 5 | | | | 85/75 | 10/20 |

[a] The first or single value was used in the base case model with a lower percentage of precut products. The second value was used to evaluate the effect of a stand with a higher percentage of precut products.

mum 25 feet to an 8-inch top diameter; and (5) precut pine sawtimber, minimum 12.5 feet to an 8-inch top diameter.

We estimated average stem weight on a truckload basis using the number of stems in the load and the total load weight obtained from the mill delivery ticket. We were unable to record individual piece dimensions without our study itself affecting the production of the operation being studied. Delay times were not directly recorded but rather were estimated using data from the loading work sample.

We evaluated loading and processing data separately using graphs of data followed by linear regression to determine the most influential factors. We performed a stepwise regression using an improvement in $r^2$ as a variable selection factor. The optimal model form was selected by examining $r^2$ values and the Mallows statistic ($c(p)$) to ensure that the model was not overparameterized (Freund and Littlell 2005).

## Productivity and cost model

We modified the Auburn Harvesting Analyzer (Tufts et al. 1985) to model the impacts of product sorting using the traditional tree-length harvesting systems such as those studied in the field. Our model took the perspective of a forest landowner, thus we used stumpage prices from Timber Mart-South (Harris et al. 2008). The owner of the timber at time of harvest is the party who stands to gain or lose from sorting decisions. This may be a wood buyer or logger instead of the landowner, but to simplify the analysis, we use the perspective of the landowner.

Stand and stock tables were generated using SIMS 2006 for stands with no previous thinnings, one previous thinning, or two previous thinnings to evaluate multiple management regimes (ForesTech International, LLC 2006). The management regimes assumed a site index of 65 feet (base age 25) in the lower coastal plain, planting 726 trees per acre of first-generation bare root loblolly pine seedlings, 90% first-year survival, and site preparation using a root rake and double bedding. Thinnings reduced basal areas to 80 square feet and were timed to optimize net present values in SIMS.

We estimated the tons of each product available for harvest using product diameter specifications and product allocation tables (Table 1). These allocation tables specify desired product percentages based on the stand characteristics and available product markets. Two scenarios were used in the allocation tables to compare a base case to a higher percentage of precut products. The base case price per ton for tree-length pulpwood, super pulpwood, chip-n-saw, and sawtimber was $6.50, $13.00, $21.50, and $40.00, respectively. A more useful metric is often the price ratio of a product compared with the pulpwood (the product with the lowest value). Using the prices just mentioned suggests ratios of 2.0, 3.3, and 6.2 for super pulpwood, chip-n-saw, and sawtimber, respectively. We also performed sensitivity analysis by increasing the price ratios for chip-n-saw and sawtimber (precut products) to 0.25 and 0.50, respectively, for each scenario. Precut products are cut to desired mill lengths during harvesting as compared with tree-length stems that are bucked to length at the mill.

We modified the Auburn Harvesting Analyzer (Tufts et al. 1985) to include checkboxes for specific product sorts to give the ability to evaluate multiple separations. Product volumes were estimated by multiplying the tons per acre in each diameter at breast height (DBH) class by the allocation percentage in the product allocation table. These volumes were used to project the revenues that the stand generated by product separations. Based on the products selected, the model provided several measures including the tons and revenue per acre of each product and the percentage of each product on a total tons and total revenue per acre basis. It also estimated total tons per productive machine hour, tons per week by product, and loads of each product per week. The model assumed that sorting impacts were based on observed field studies, product allocation tables were determined by stand dynamics and market conditions, and volume in a stem above any precut product removed was treated as pulpwood.

# Results

## Weekly production data

Eleven crews reported 24,401 loads during 487 operating weeks (Table 2). Weekly production averaged 50.1 loads and ranged from 36.7 to 137.6 loads per week. Product sorts

*Table 2.—Summary of weekly production data provided by harvesting crews.*

| Logging crew | System type[a] | No. of wk reported | Avg. production (no. of loads) | No. of sorts Avg. | Min. | Max. | Avg. no. of workers/wk |
|---|---|---|---|---|---|---|---|
| A | TL | 23 | 79.0 | 5.7 | 3 | 7 | 5.0 |
| B | TL | 27 | 53.9 | 3.7 | 2 | 5 | 4.9 |
| C | TL | 16 | 137.6 | 5.9 | 4 | 10 | 4.0 |
| D | TL | 28 | 65.8 | 4.7 | 2 | 7 | 6.3 |
| E | TL | 12 | 70.6 | 6.4 | 3 | 8 | 3.7 |
| F | TL | 11 | 62.6 | 6.1 | 5 | 7 | 3.3 |
| G | TL | 15 | 91.1 | 4.8 | 2 | 8 | 4.0 |
| H | TL | 17 | 42.5 | 5.5 | 2 | 8 | 4.0 |
| I | TL | 24 | 53.8 | 5.4 | 2 | 8 | 3.6 |
| J | MTL | 151 | 41.0 | 7.4 | 2 | 14 | 3.5 |
| K | MTL | 163 | 36.7 | 7.1 | 2 | 13 | 3.4 |
| Total | | 487 | 50.1 | 6.5 | 2 | 14 | 3.9 |

[a] TL = tree-length; MTL = modified tree-length.

averaged 6.5 per week, but ranged from 2 to 14. The average number of woods workers on site per week was 3.9 but ranged from 3.3 to 5.0 workers. Crews J and K had the highest number of sorts and used a roadside processor with a processing head mounted on a tracked shovel. Traditional tree-length harvesting crews handled 10 or fewer product sorts during the study period.

Regression analysis identified the following set of equations for prediction of weekly production:
Tree-length operations:

$$Y = 3.131 + 0.012 \times w + 0.964 \times \ln(t) - 0.141 \times t$$

Modified tree-length operations:

$$Y = 0.791 + 0.082 \times w + 1.312 \times \ln(t) - 0.141 \times t,$$
$$R^2 = 0.74, \quad P = 0.0001$$

where

$Y$ = weekly production (loads),

$w$ = worker days per week (no. of employees × no. of days worked), and

$t$ = total product sorts.

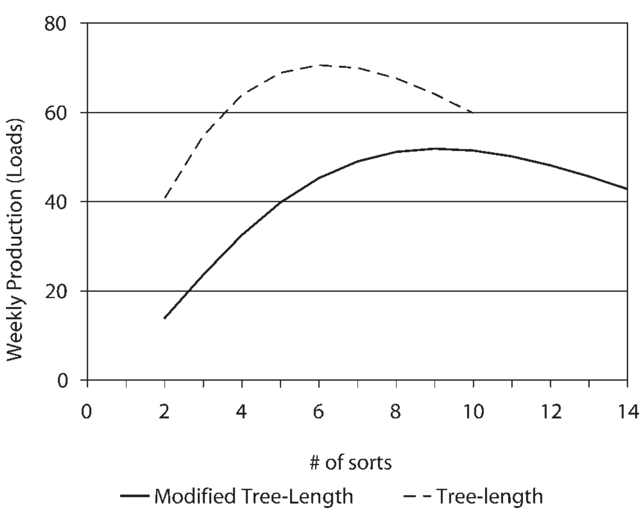


*Figure 1.—Effect of number of product separations on weekly production levels for tree-length and modified tree-length harvesting crews with 20 total worker-days per week.*

We found production increases for both tree-length and modified tree-length operations as the number of sorts increased when production levels were relatively low (Fig. 1). This pattern was explained by the crews avoiding production quotas from a limited number of markets by seeking additional markets for the timber they produced. Tree-length harvesting systems began to encounter production losses when more than six products were separated. At these higher production levels quota avoidance was less of an impact and true production limitations were noticed. Modified tree-length harvesting systems had similar impacts with production increasing to nine product separations but decreasing when more than nine sorts were required. Decreases in production with modified tree-length harvesting crews were less severe than for tree-length harvesting crews.

## Hourly production data

Weekly production data highlighted the importance of markets on potential production and provided some indication of the impacts of additional product separations beyond the level where markets may be limiting. To evaluate true impacts of product separations on hourly production, we examined detailed time-study data from a subset of harvesting crews that participated in the weekly production study.

We collected loading data for a total of 129 loads of wood from 5 of the 11 crews that participated in the weekly production portion of the study. Crews B, C, F, G, and I as identified in Table 2 participated in this portion of the study. Product separations for these loads included pulpwood, super pulpwood, chip-n-saw, tree-length sawtimber, and precut sawtimber (Table 3). Average loading time ranged

*Table 3.—Time study data showing the number of observed loads by product with average load times, standard deviations, total swings, and swings to truck.*

| Product | No. of loads | Mean load time ± SD (min) | Total swings | Swings to truck |
|---|---|---|---|---|
| Pulpwood | 62 | 13.3 ± 7.8 | 19 | 15.3 |
| Super pulpwood | 10 | 14.3 ± 6.4 | 16.7 | 16.1 |
| Chip-n-saw | 34 | 16.3 ± 9.4 | 22.4 | 17.9 |
| Sawtimber | 22 | 12.4 ± 8.6 | 18.0 | 14.9 |
| Precut sawtimber | 1 | 16.0 | 30.0 | 30.0 |

Table 4.—Time study data showing the observed number of sorts and loads by loader operator with the averages for load time, tons per load, total loader swings, and number of swings from a sorted pile.

| Loader operator | No. of sorts | No. of loads | Mean ± standard error of the mean | | | |
|---|---|---|---|---|---|---|
| | | | Load time (min) | Tons per load | Total loader swings | No. of swings from sorted pile |
| A | 3 | 26 | 11.6 ± 0.48 | 29.3 ± 0.35 | 12.7 ± 0.27 | 12.7 ± 0.23 |
| B | 4 | 27 | 25.5 ± 1.35 | 29.5 ± 0.37 | 35.1 ± 2.44 | 16.5 ± 2.18 |
| C | 5 | 27 | 8.9 ± 0.36 | 30.2 ± 0.31 | 16.4 ± 0.68 | 16.1 ± 0.70 |
| D | 6 | 27 | 12.4 ± 1.50 | 27.9 ± 0.33 | 17.9 ± 1.72 | 11.5 ± 0.53 |
| E | 6 | 28 | 10.2 ± 1.08 | 28.7 ± 0.35 | 14.7 ± 1.20 | 9.7 ± 0.39 |

from 12.4 to 16.3 minutes per load but did not vary significantly based on product type ($P = 0.396$). The average loading time did vary by operator with Operator B having the longest loading time of 25.5 minutes, significantly longer than the other operators ($P = 0.004$) (Table 4). Operator B performed delimbing and topping functions only as wood was being loaded onto the trucks. By comparison, the shortest time to load a truck was observed with Operator C who averaged loading a truck in just 8.9 minutes.

We documented increases in the time required to accumulate a full load of an individual product as the number of separations increased at the landing. When piled wood was not sufficient to fully load a truck with the desired product, the loader processed additional wood from the skidders while loading the truck. In nearly every case, total loading times and the variation in loading times greatly increased in this situation (Fig. 2). Each swing of wood from a processed pile onto the truck added 34.5 seconds to total truck loading time, compared with 41.3 seconds for each swing of wood directly from a skidded pile (a 20% increase). Total loading time was extended 39.6 seconds per swing and no wood was loaded onto the truck when a product other than that being loaded was processed from the skidder pile and moved into a processed pile. When processing and loading directly from the skidder pile, such actions are periodically required to clear the pile so desired stems can be reached.

The loader operator conducting three product separations (Operator A) had little variability in the number of swings and total loading times (Table 4). Operators producing six

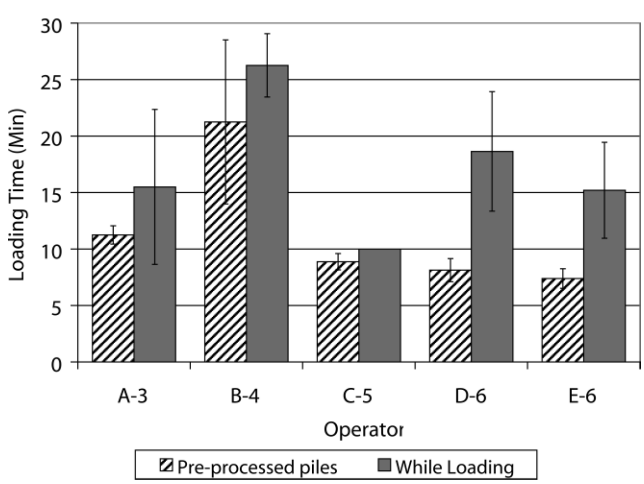


Figure 2.—Average loading time per truckload with 95% confidence intervals for five operators when loading from fully sorted piles of processed wood and when some wood required processing while loading.

product separations (D and E) had to process wood from the skidder pile on 34 and 36 percent, respectively, of the total swings necessary to load a truck. Swings for processing of wood from the skidder pile significantly increased their loading time variability compared with other operators with fewer sorts who also attempted to load from piles ($P = 0.013$; Table 4).

The ability of the loader operators to maximize the total weight of wood moved with each swing also impacted truck loading time. Higher average swing weight significantly reduced loading time per truck ($r = -0.623$; $P < 0.001$). With precut products, the area of the loader grapple was filled before the optimum weight could be attained. Loading time per truck for precut products was 17 percent longer than for tree-length products.

Detailed processing time data were collected on 748 swings of wood (Table 5). Processing productivity was highest for super pulpwood stems that had a larger average piece size than pulpwood and usually required little or no additional processing after the delimbing gate. Both tree-length chip-n-saw and sawtimber stems were processed through the pull-through delimber before sorting, reducing processing productivity as compared to tree-length pulpwood that often required no additional processing after the delimbing gate. Precut sawtimber had significantly lower processing productivity as each piece had to be cut by the ground saw with the resulting greater number of pieces then sorted into piles.

Occasional use of the ground saw to trim damaged butt pieces from the end of tree-length stems also added to the total processing time. Across all tree-length products, end trimming added 32.9 seconds per swing of wood. When it was necessary to trim pulpwood stems, they were typically handled individually, dropping the average weight handled substantially. Only 2 percent of pulpwood stems required end trimming with the ground saw, so the net effect on productivity was minimal.

## Productivity and cost model

The results for the model were similar for the three management regimes. Therefore, we report only the results for the management regime that consisted of two thinnings. This management regime is more typical for the US South where the greatest number of sorts is needed. The base model included the allocation table with a lower percentage of precut products (Table 1). The base model predicted the highest average revenues of \$30.78 per ton with four product separations comprised of the following tree-length products: pulpwood, super pulpwood, chip-n-saw, and sawtimber (Fig. 3). Five product separations included the same products as above with the addition of precut sawtimber. Revenue for this five-sort scenario decreased

Table 5.—Average seconds per swing, percentage of total swings, tons per swing, and processing productivity by product type, broken down into the sorting, delimbing, and cutting functions.

| Product | Seconds per swing | | | % total swings | | | Tons per swing | | | Productivity (tons/PMH) |
|---|---|---|---|---|---|---|---|---|---|---|
| | Sorting | Delimbing | Bucking | Sorting | Delimbing | Bucking | Sorting | Delimbing | Bucking | |
| Pulpwood | 25.6 | 55.6 | 43.3 | 81 | 19 | 2 | 0.74 | 1.51 | 0.40 | 104 |
| Super pulpwood | 20.5 | 48.4 | NA | 84 | 16 | 0 | 0.97 | 1.51 | NA | 161 |
| Chip-n-saw | 18.3 | 45.5 | 32.1 | 11 | 89 | 11 | 0.89 | 0.85 | 0.79 | 67 |
| Sawtimber | NA | 43.7 | 34.7 | 0 | 100 | 31 | NA | 1.11 | 1.10 | 73 |
| Precut sawtimber | 30.6 | NA | 29.3 | 33 | 0 | 67 | 1.04 | NA | 0.40 | 35 |

by 6 percent to $28.86 per ton. The increased ratio values of 0.25 and 0.50 for precut sawtimber products only increased per ton revenues to $28.90 and $28.94, respectively. We found an 8 percent decrease to $28.38 per ton when both precut chip-n-saw and sawtimber were added to provide six product separations. The increased ratio values of 0.25 and 0.50 for precut sawtimber and chip-n-saw products increased per ton revenues to $28.45 and $28.51, respectively.

We also evaluated a precut scenario with higher percentages of precut products in the allocation table (Table 1). This model predicted the highest average revenues with four product separations at $31.08 per ton (Fig. 3). Five product separations decreased revenues by 12 percent to $27.26 per ton. The increased ratio values of 0.25 and 0.50 for five product separations of precut sawtimber products only increased per ton revenues to $27.34 and $27.42, respectively. We saw an even greater decrease of 15 percent to $26.31 per ton under the six product separation scenario. The increased ratio values of 0.25 and 0.50 for six products separations increased per ton revenues to $26.44 and $26.58, respectively.

Revenue decreases as a result of additional sorting may seem paradoxical at first glance. This is caused by the small to nonexistent premium the southern log market currently places on cut logs. While tree-length sorts add value, sorts of cut logs often do not. When a precut log is removed from the lower portion of a tree-length sawlog, the remaining

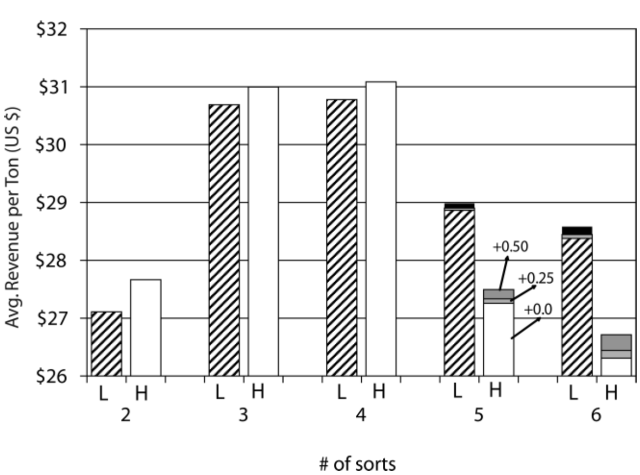


Figure 3.—Effect of the number of product separations on average landowner revenue per ton for the twice thinned management regime under the base case (L) and higher percentage of precut products (H) models. Increased price ratio for precut products compared with pulpwood of 0.0, 0.25, and 0.50 are also shown for five and six sorts.

upper portion becomes pulpwood and loses value. The price differentials do not offset one another. For example, if a 9-inch DBH tree has a 16.5-foot length removed from the butt, about half of the total stem remains above this and becomes pulpwood. The price difference between pulpwood and the least valuable sawtimber in our analysis (''super pulpwood'') was $6.50 per ton. If the value of half of the tree drops by $6.50 per ton and the other half only sees a $1 to $2 per ton increase for a precut log premium, a net decrease results. This simple example overlooks any additional costs the landowner would incur to cover the additional cost of sorting by the logging contractor. Such examples are common with prices typical of the southern log markets today and were much more fully evaluated in a recent article by Hamsley et al. (2009).

## Discussion and Conclusions

Weekly data suggested that traditional tree-length harvesting crews can perform fewer product separations than modified tree-length harvesting systems without a reduction in productivity. Maximum production was reached at six sorts with traditional tree-length versus nine product separations with modified tree-length harvesting systems. Weekly data alone were not detailed enough to fully quantify this relationship and we needed additional detail to understand how specific product separations affected production.

Our time study data indicated that productivity, particularly processing productivity, was more sensitive to the type of product being sorted than the absolute number of sorts when dealing with fewer than six separations in a tree-length harvesting system. In particular, handling precut products reduced the processing productivity by 48 to 78 percent. The reduced piece size and the increase in the number of pieces created when bucking the tree to length had a negative effect on overall productivity. A reduction in loading productivity was also noticed with precut products, though sample size was insufficient to test statistically. Loading productivity was most sensitive to available processed wood, with all participating contractors reducing truck loading time from 11 to 56 percent when wood did not need to be delimbed and topped during loading.

The model highlighted the importance of specific product separations and how each affected overall production and average revenues. Our model suggested that the addition of precut products decreased net revenues per ton above the four sorts of pulpwood, super pulpwood, chip-n-saw, and sawtimber by 6 to 15 percent. The extra processing and handling of these stems reduced productivity and therefore had a higher ''cost'' for logging contractors. This suggests minimal returns to logging contractors for all the additional effort and possible errors associated with making the additional precut separations on the landing unless production is limited by mill quotas or the price premium increases for those precut products.

We did not find higher revenue to landowners from additional sorts beyond the four traditional sorts given the price structure common today for log products in the US South. Minimal price premiums are paid for precut log products. As a result, cutting a butt section from a tree-length stem often reduces the value of the upper stem portion more than the value increase associated with the butt log that is upgraded. Significantly higher price premiums for precut products will be required to create financial incentives that justify more product sorting.

## Acknowledgments

This research was funded by the Georgia Traditional Industries Program, the Wood Supply Research Institute, and Plum Creek Timber Company.

## Literature Cited

Baker, S. A. and W. D. Greene. 2008. Changes in Georgia's logging workforce: 1987–2007. *South. J. Appl. Forestry* 32(2):60–68.

Blinn, C. R. and S. A. Sinclair. 1986. Profitability of various timber harvesting systems as affected by product sorting and timber stand parameters. *North. J. Appl. Forestry* 3(4):167–172.

Clutter, M., B. Mendell, D. Newman, D. Wear, and J. Greis. 2005. Strategic factors driving timberland ownership changes in the U. S. South. USDA Forest Service, Southern Research Station, Research Triangle Park, North Carolina. 15 pp.

ForesTech International, LLC. 2006. Simulator for Managed Stands (SiMS). Athens, Georgia.

Freund, R. J. and R. C. Littlell. 2005. SAS System for Regression. 3rd ed. SAS Institute, Cary, North Carolina. 236 pp.

Gingras, J.-F. 1996. The cost of product sorting during harvesting. Technical Note TN-245. Forest Engineering Research Institute of Canada (FERIC), Pointe-Claire, Quebec. 12 pp.

Hamsley, A. K., W. D. Greene, and S. A. Baker. 2009. Comparison of value harvested by modified and conventional tree-length systems in the southeastern United States. *Forest Prod. J.* 59(4):1–6.

Harris, T. G., J. Smith, R. Simmons, and S. Baldwin. 2008. Timber Mart-South Publications: 2008 Annual Summary. Timber Mart-South, Athens, Georgia. 4 pp.

Raymond, K. A. 1987. Factors influencing landing size. LIRA Report 12(1):1–6. Logging Industry Research Association, Rotorua, New Zealand.

Tufts, R. A., B. L. Lanford, W. D. Greene, and J. O. Burrows. 1985. Auburn harvesting analyzer. The COMPILER Forest Resources Systems Institute, Florence, Alabama, 3(2):14–15.

Wilent, S. 2004. Investors increase timberland holdings. *The Forestry Source* 9(Dec 2004):1–4.

Williams, M. 1989. An evaluation of a hydraulic knuckleboom loader in high production/multiple log sort operation. Project Report PR-47. Logging Industry Research Association, Rotorua, New Zealand. 42 pp.