Reciprocal estimation of the raw material cost of producing hardwood lumber using the principles of activity-based costing

Patrick M. Rappold
D. Earl Kline*
Brian H. Bond*
Janice K. Wiedenbeck*

Abstract

This paper presents an experimental method that can be used by sawmill managers to estimate the raw material cost of producing hardwood lumber products more precisely than current cost allocation techniques. Based on the concept of activity-based costing, the proposed costing technique, termed the lumber yield method, enables allocation of raw material costs incurred during a production run to the lumber products produced. In contrast to current costing techniques used by hardwood sawmills, the proposed methodology does not use volume of lumber produced as the matrix for allocating raw material costs. Rather raw material costs are allocated based upon the estimated yield of products from the raw material input into the sawmill system. Through the use of discrete-event simulation, the precision of the lumber yield method was tested against two cost accounting methods (activity-based costing method and traditional costing method). Analysis of the output from the simulation models illustrated that with the lumber yield method, the amount of raw material costs allocated to the products was not significantly different from the amount allocated by the activity-based costing method. The calculated raw material costs of the products were, however, found to be significantly different between the lumber yield method and the traditional volume costing method. These results illustrate that the lumber yield method more precisely allocates raw material costs to the products than the traditional cost accounting method.

In a hardwood sawmill system, logs of varying quality and size are used as the input material for the production of lumber. As a general rule, the price that hardwood sawmills pay for logs is a function of size and quality. Log quality (grade) is evaluated differently between sawmills but is generally based upon the number and location of defects that can be visually detected on the ends and faces of the logs. Each sawmill has a well-established understanding as to how these defect types and locations would subsequently affect the overall market value of the products to be sawn from their logs. The scaling diameter and length of a log are the common variables by which log size is quantified by a hardwood sawmill. Collectively, the size and quality of a log determines the components for the log grade industry descriptor. Typically, hardwood sawmills are willing to pay more for what is termed high-grade logs which have a minimal amount of external defect and large clear areas between defects.

Hardwood logs differ in quality not only between logs but also within individual logs. Because of the natural variability of the wood raw material, lumber products of different quality are simultaneously recovered from logs during the manufacturing process. The fact that a log will produce low-value and high-value lumber along with other low-value waste by-products (e.g., sawdust, bark mulch) has been termed the "sawmill paradox" (Grönlund 1992). Often the quality, and hence market value, of the products are not known until the material exits the sawmill system. The general randomness of products recovered from logs makes it

The authors are, respectively, former Graduate Research Assistant, Professor, and Associate Professor, Dept. of Wood Sci. and Forest Products, Virginia Tech, Blacksburg, Virginia (prappold@vt.edu, kline@vt.edu, bbond@vt.edu); and Research Scientist, Northern Research Sta., U.S. Forest Serv., Princeton, West Virginia (jwiedenbeck@fs.fed.us). This paper was received for publication in December 2008. Article No. 10554.
*Forest Products Society Member.
©Forest Products Society 2009.
difficult in the industrial setting to track raw material costs during the process of converting logs into lumber. It is generally recognized within the hardwood industry that the less defects a log has, the greater the potential for high-value product recovery (Malcolm 2000). Despite this generally accepted concept, the conventional method of allocating raw material costs to the lumber products manufactured from logs is based upon traditional cost accounting techniques, referred to as the volume costing method, where costs are assigned based upon the volume of the product manufactured.

The principles of traditional cost accounting assume that costs vary in proportion to the volume of products manufactured and should be allocated accordingly (Lere 2000). Developed in the late 1980s, activity-based costing is an accounting methodology which "derives product costs as the sum of the activities that occur to make the product" (Deakin and Maher 1991, Wessels and Vermaas 1998). Unlike traditional costing, the principles and methodology of the activity-based cost accounting system recognize that there are other measures, besides volume, which can cause costs to change. One of the limitations of implementing the activity-based costing system into a business is the time and knowledge required. Changing from a traditional cost accounting system to an activity-based costing system is a daunting task that requires changes in the record keeping procedures of each department within a business (Lere 2000). The activity-based costing method does not take into account capital cost and investment risk, which are of particular interest to shareholders of stock, but are of minimum importance to a plant floor manager who needs a tool to track costs (Roztocki and Needy 1998).

A case study conducted by Wessels and Vermaas (1998) at a softwood sawmill analyzed the benefits of implementing activity-based costing into a sawmill manufacturing environment. The case study concluded that the planning, control, and decision-making abilities of management would improve under the activity-based costing method in comparison to the traditional costing method already in use. It was, however, noted by Wessels and Vermaas that fully implementing the activity-based costing technique across all facets of the sawmill business (log procurement, sawing, drying, and sales) would be expensive and time-consuming.

While most of the publications on the topic of activity-based costing recommend finding allocation paths for all of the manufacturing costs, there are limitations on the amount of information individual firms can collect. For some manufacturing costs, it can be difficult to identify and collect the information necessary to assign allocation paths. Also, the benefits gained from collecting the information may be minimal. A more reasonable approach to implementing activity-based costing may be to identify a cost category or component that constitutes a large percentage of total manufacturing costs and for which the activity-based costing methodology would enable strategic manufacturing benefits.

As illustrated in Figures 1 and 2, the raw material cost component of producing lumber constitutes a large portion of total manufacturing costs. The increase in the cost of delivered logs between 1963 and 2002 is not only due to increased production capacity of sawmills in the United States but also rising log costs. Because of the disproportional amount of assets spent on raw materials, it is the objective of this paper to illustrate how a cost allocation technique based upon the principles of activity-based costing can provide more precise information on how raw material costs are consumed by the lumber products.

**Methodology**

**Procedures for implementing the experimental cost allocation method**

An experimental cost allocation method (subsequently referred to as the "lumber yield method") was developed using activity-based costing principles. The lumber yield method differs from current cost allocation methods used by the majority of hardwood sawmills in that it uses the estimated yield of the lumber products from logs with similar characteristics (i.e., scaling diameter and grade) to assign raw material costs. By using estimated lumber yield values, it is possible to approximate the parameters of the log from which the lumber products originated. The total raw material cost incurred during a production run can then be more precisely allocated to the lumber products. Mathematically the lumber yield method was defined by Equation [1]:

\[
TRMC_i = TRMC_k \times \left( \frac{ELY_{jk}}{100} \right)
\]

where:

- \(TRMC_i\) = total raw material cost used to make the \(i^{th}\) product,
- \(TRMC_k\) = total raw material cost for the \(k^{th}\) log parameter or set of log parameter combinations that was incurred during a production run, and
- \(ELY_{jk}\) = estimated yield, in percent, of the \(i^{th}\) product from the \(k^{th}\) log parameter or set of log parameter combinations.

The "product" variable used in the equations throughout this paper refers to different classifications of lumber products. For this project, the classification of the lumber products was based upon the lumber grade categories defined by the
National Hardwood Lumber Association (NHLA). The lumber grades, as described in NHLA (2003), provides buyers and sellers of hardwood lumber guidelines for differentiating between the typical hardwood lumber products manufactured at a sawmill (Table 1). Generally, the NHLA lumber grade standards act as guidelines and the final specifications for the different grades are agreed upon between the buyer and seller.

The relevant information required for the lumber yield method to be implemented in the industrial setting is:

1. Lumber volume and grade yield statistics from logs with similar parameters or characteristics (i.e., species, log grade, scaling diameter, length).
2. A record detailing the parameters or characteristics of the logs that were sawn to produce the lumber for which product costing information is desired.

Gathering the lumber volume and grade yield statistics from logs with similar parameters or characteristics requires that the sawmill management team perform basic lumber recovery studies. Descriptions of how to perform lumber recovery studies are detailed in Mayer and Wiedenbeck (2005). A lumber recovery study involves measuring the volume and grade of lumber recovered from sets of logs with similar parameters or characteristics. It is the prerogative of the sawmill management team to decide on which set of log parameters to focus. For this study, red oak was chosen as the study species and 1) scaling diameter, 2) log grade, and 3) log length were used as log parameters. In regards to the number of logs that should be sampled to accurately estimate lumber volume and grade yield, a minimum of 10 was recommended for each log parameter or combination of parameters. The minimum value of 10 logs is based upon guidelines published by Mayer and Wiedenbeck (2005) to ensure that an accurate distribution of the lumber yield from the logs is collected. The estimated lumber yield from logs with similar parameters or characteristics was calculated using Equation [2]:

\[
ELY_{ik} = \left( \frac{Vol_{ik}}{Vol_k} \right) \times 100
\]  

where:

- \( ELY_{ik} \) = estimated yield, in percent, of the \( i^{th} \) product from the \( k^{th} \) log parameter or set of log parameter combinations,
- \( Vol_{ik} \) = volume in board feet (BF) of the \( i^{th} \) product from the \( k^{th} \) log parameter or set of log parameter combinations, and
- \( Vol_k \) = volume in BF of the products (i.e., grade lumber and pallet cants) produced from \( k^{th} \) log parameter or set of log parameter combinations.

Recording information on grade, scaling diameter, and length for every log processed is necessary in order to calculate total raw material cost values for each of the log groups. Two methods used by one hardwood sawmill for collecting information on the grade, scaling diameter, and log lengths as they enter the sawmill are presented in Figure 3.

One method is to manually write the net volume and grade of a log on one of its ends with a waterproof lumber crayon. The procedure of marking the logs can be done in the logyard, as logs are being scaled and inventoried. Referring to Figure 3, the net volume of the log in the photograph was measured to be 126 BF (Doyle scale), and the grade of the log was identified with the “m” symbol. At the sawmill where the photograph was taken, the operator of the debarker machine center will visually estimate a log’s length, and with the log volume value marked on the end of the log, interpolate scaling diameter from a Doyle log volume table. The sawmill where this procedure was observed uses the information recorded by the debarker operator to calculate overrun statistics from the production runs. Log information collected by the debarker operator is also used to update the inventory statistics for the logyard. This method of collecting log input information appeared to be fairly easy to implement and did not seem to require much additional effort on the part of the sawmill employees.

Another method of recording information on the material entering a sawmill is with barcode tags (Fig. 3). The barcode tag enables the gathering of information for individual logs from a database stored on a personal computer. In addition to log grade, diameter, length, and volume information, the database may also contain the date the log was scaled, the price that was paid for the log, and the source of the log. Using barcodes as a system for recording log information requires purchasing equipment to read the barcodes and exchange information with the database that contains the log information. In addition, computer software needed to create and manage the database may have to be purchased and updated as necessary. But, the computer software may

Table 1. Specification guidelines and relative market values for commonly used lumber grades.

<table>
<thead>
<tr>
<th>Lumber grade</th>
<th>Relative market value</th>
<th>Minimum percentage of clear defect-free material</th>
</tr>
</thead>
<tbody>
<tr>
<td>FAS</td>
<td>Highest</td>
<td>83-1/3</td>
</tr>
<tr>
<td>No. 1 Common</td>
<td></td>
<td>66-2/3</td>
</tr>
<tr>
<td>No. 2 Common</td>
<td></td>
<td>50</td>
</tr>
<tr>
<td>No. 3A Common</td>
<td></td>
<td>33-1/3</td>
</tr>
<tr>
<td>No. 3B Common</td>
<td>Lowest</td>
<td>25</td>
</tr>
</tbody>
</table>

Figure 3. Example of how one hardwood sawmill uses the manual method and barcode method to monitor the volume and grade of logs sawn.
reduce the time required to produce overrun and log inventory reports. Regardless of which method is used, the overall need is to identify the total raw material cost for each log parameter group or set of log parameter combinations so that it can be allocated to the lumber products.

**Simulation based evaluation of the experimental cost allocation method**

To evaluate the precision of the experimental cost allocation method, the total raw material costs allocated to the lumber products using the lumber yield method was compared to the costs allocated by the activity-based costing method and the traditional cost accounting method. Yet, because it is not feasible in an industrial setting to trace each lumber product back to the log from which it originated, as required for performing an activity-based costing study, discrete-event simulation was used to model the manufacturing processes of an actual hardwood sawmill. The sawmill that was modeled produces 35 million board feet (MMBF) of hardwood lumber annually and utilizes modern optimization technology for log and lumber processing. Over a 2-year period processing information and lumber yield data from red oak logs were collected at the sawmill. Information collected from the sawmill was used to create a simulation model with the general purpose discrete-event simulation software, Arena ver. 7.01.00 (Rockwell Software Inc. 2000). Complete details on the model development and validation processes are available in Rappold (2006).

The simulation model enabled identifying the log from which each lumber product had been derived. Information generated from the simulation model was used as the input for the variables of the activity-based and traditional volume costing calculations. Equation [3] shows the specific method used to allocate raw material costs to products for the activity-based costing scenario. The products manufactured from red oak logs at the cooperating (modeled) sawmill consisted of random width grade lumber and pallet cants. The grade lumber was sorted into five grade classifications: FAS, No. 1 Common, No. 2 Common, No. 3A Common, and No. 3B Common. Pallet cants produced from the red oak logs were 3-1/2 by 6 inches in dimension with lengths varying from 8 to 12 feet.

\[
TRMC_i = \sum_{i=1}^{f} \left( \frac{TVOL_{ik}}{TVOL_k} \right) \times TRMC_k \tag{[3]}
\]

where:

- \( TRMC_i \) = total raw material cost of lumber grade \( i \),
- \( TVOL_i \) = total volume\(^1\) of the \( i^{th} \) product manufactured that originated from log group \( k \),
- \( TVOL_k \) = total volume of the product manufactured that originated from log group \( k \),
- \( f \) = number of log groups,
- \( TRMC_k \) = total raw material cost of log group \( k \),

\[
= n_k \times \left( \frac{LC_k \times LVOL}{MBF} \right),
\]

and:

- \( n_k \) = number of logs processed from log group \( k \).

\[^1\] For this project the volume of the products manufactured was measured in board feet, where 1 board foot is dimensionally equivalent to a 1-inch-thick by 1-foot-long by 1-foot-wide object. In terms of volume, 1 board foot is equal to 144 cubic inches.

In contrast to the lumber yield and the activity-based methods, with the traditional cost accounting method, raw material costs are only allocated to the lumber products based upon the volume of each product manufactured (Eq. [4]):

\[
TRMC_i = \left( \frac{TVOL_i}{TVOL} \right) \times TRMC \tag{[4]}
\]

where:

- \( TRMC_i \) = total raw material cost of the \( i^{th} \) product,
- \( TVOL_i \) = total volume of the \( i^{th} \) product manufactured,
- \( TVOL \) = total volume of materials manufactured,
- \( TRMC \) = total raw material cost incurred during the simulated production run

\[
= n_k \times \left( \frac{LC_k \times LVOL}{MBF} \right)
\]

and:

- \( n_k \) = number of logs processed from log group \( k \),
- \( LC_k \) = purchase price of a single log per 1,000 BF for log group \( k \), and
- \( LVOL \) = volume in BF (Doyle log scale) of a single log.

For purposes of statistical testing, 10 replications of the simulation model were run in order for the output from the simulation to be independent and identically distributed. One replication, or run, of the simulation models represented one complete workday. A complete workday constituted 11 hours for the modeled sawmill.

Using Equation [2], the estimated lumber yield for each of the studied log parameter combinations was calculated from 10 randomly selected logs that had been generated by the simulation models. The number of different log parameter combinations that the models were able to generate was limited by the number of logs that had been sampled at the cooperating sawmill. Lumber yield statistics calculated from the output of the model are presented in Table 2.

The output from the model was also used to calculate the total raw material costs, by log parameter combination incurred during the running of the simulation model. Calculation of the raw material costs for each of the log parameter combinations was executed by multiplying the number of logs processed in the simulations by the individual purchase price for each of the log parameter combinations (Table 3). The individual purchase prices of the logs were derived from dollar per MBF values provided by the cooperating sawmill.

From the output of the simulation model, Equations [1], [3], [4] were used to calculate the raw material costs incurred by the lumber products. The average raw material cost values allocated to the products by the lumber yield method were compared to the values calculated by the activity-based costing method and the traditional volume costing method. Confidence intervals for the differences between the average product cost values for the three costing methods were calculated using a form of the Bonferroni inequality that is valid for analyzing the output of simulation models when the common random number variance reduction technique is used (Banks et al. 2001).
The Bonferroni inequality enables the construction of confidence intervals, for multiple comparison purposes, while maintaining a desired error probability (Banks et al. 2001). With the Bonferroni inequality, the probability of accepting a false conclusion is adjusted to compensate for the number of confidence intervals to be compared.

Results from the multiple comparison tests found that the differences in the amount of raw material costs allocated to the products by the lumber yield method were not significantly different from the activity-based costing method at an alpha level of 0.05. The differences in costs between the lumber yield method and the traditional volume costing method were, however, found to be significantly different. Based upon the statistical results as presented in Table 4, it can be concluded that with the lumber yield method raw material costs are more precisely allocated to the lumber products than with the traditional volume costing method. It should be noted that since the lumber yield information was generated from a simulation model, the variability of the lumber yield from logs is probably greater than was generated by the models due to the limited number of logs sampled. Because of this, it is not known how close in value the raw material costs of the products as calculated with the lumber yield method would be to the values calculated by the activity-based costing methodology, in a real world setting.

Implications for managers of hardwood sawmills

Since hardwood lumber is a commodity product, managers of hardwood sawmills have minimal control over setting the price at which they can sell their products. While quality and service can be used to some extent for product differentiation, the selling price of hardwood lumber is typically governed by market averages. The profits that sawmill managers calculate on the sales of their products are typically based on the traditional cost accounting method, which allocates raw material costs to the products based upon the volume manufactured. Given that raw material costs account for such a large percentage of manufacturing costs, the estimated profit levels of the lumber products can vary depending on how raw material costs are allocated to the products.

To illustrate how the allocation method can affect estimated profit, the market prices of the individual lumber products were subtracted from the raw material costs of the products, as calculated with the lumber yield method and the traditional volume costing method. Results from the profit analysis, illustrated in Figure 4, demonstrate that the estimated profit levels of the products differ based upon cost allocation method. Because the distribution of the confidence intervals for the FAS product does not overlap, it can be said that the difference of the average calculated profit levels between the two costing techniques is significant at an alpha level of 0.05. While the overall profit from all of the products manufactured was calculated to be approximately identical (slight difference due to numeric rounding) between the two cost allocation methods, differences in the profits of individual products do exist.

The practical significance of the differences between the two costing techniques is difficult to quantify because a $500 difference in estimated profit on a product may be of importance to some sawmill managers, and of little consequence to others. A true subjective analysis of the insight that
the lumber yield method provides, in relation to profit estimation, would have to involve interviewing sawmill managers to gauge their opinion of the differences. Based upon the values in Figure 4, it is apparent that the lumber yield method reports higher profit values for the low-market value lumber grades (No. 3A, No. 3B) in comparison with the traditional volume costing method. While these results may only be specific to this study, it is of interest to recognize that low-market value lumber grades may be generating more income for sawmill owners than previously considered.

The insight gained by using a more precise method for estimating the raw material costs and subsequent profits of products may enable sawmill managers to understand true product costs to make better management decisions related to their target product mix and sales objectives. The lumber yield method may also be used to better understand where production opportunities exist to help prioritize and direct future business improvements.

**Summary**

A method of allocating raw material costs to lumber products was presented for the purposes of illustrating how a cost allocation technique based upon the principles of activity-based costing can provide more precise information on how raw material costs are consumed by the lumber products. The proposed methodology, termed the lumber yield method, allocates raw material costs to the lumber products as a function of the estimated lumber yield from the individual logs. To put into practice, the lumber yield method requires recording the characteristics of the logs sawn and an estimation of the lumber yield from logs with similar characteristics. The requirements to implement the lumber yield methodology are not greatly different from the information needed to evaluate hardwood sawmill processing efficiencies such as lumber yield and other hardwood sawmill performance metrics.

Analysis of the output from a simulation model of a hardwood sawmill illustrated that with the lumber yield method, the amount of raw material costs allocated to the products was not significantly different than the amounts allocated by the activity-based costing method. Raw material costs of the products were found to be significantly different between the lumber yield method and the traditional volume costing method.

**Acknowledgments**

The authors wish to acknowledge the U.S. Forest Service, Northern Research Station and the Sloan Forest Industries Center at Virginia Tech for financial support, and Dr. John P. Shewchuk, Associate Professor, Industrial and Systems Engineering, for his assistance with model development and validation.

**Literature cited**


---

**Table 4. — Results of the comparison test for the amount of raw material costs allocated to products using the output generated by the model of the case study sawmill.**

<table>
<thead>
<tr>
<th>Product</th>
<th>Average raw material cost ($)^a</th>
<th>95% confidence intervals for the difference between the average raw material cost value calculated with the Lumber yield method^b</th>
</tr>
</thead>
<tbody>
<tr>
<td>FAS</td>
<td>7,817.22 (-148.44, 67.40)</td>
<td>(844.39, 1,039.86)</td>
</tr>
<tr>
<td>No. 1C</td>
<td>5,888.29 (-77.53, 115.36)</td>
<td>(-305.73, -127.31)</td>
</tr>
<tr>
<td>No. 2C</td>
<td>2,608.99 (-74.45, 49.67)</td>
<td>(-288.16, -136.06)</td>
</tr>
<tr>
<td>No. 3A</td>
<td>405.62 (-21.97, 10.33)</td>
<td>(-95.43, -68.53)</td>
</tr>
<tr>
<td>No. 3B</td>
<td>2,850.68 (-74.45, 49.67)</td>
<td>(-379.97, -232.28)</td>
</tr>
<tr>
<td>Pallet cant</td>
<td>3,479.71 (-33.27, 59.97)</td>
<td>(-165.72, -75.70)</td>
</tr>
</tbody>
</table>

---

**Figure 4. — Average profit levels based upon the calculated raw material product cost values. (Note: The values for the market prices of the lumber products, used in this analysis, were based upon information provided by the case study sawmill. Analysis of the estimated profits for the products assumed that all of the products can be sold.)**