INTEGRATED LEAST-COST LUMBER GRADE-MIX SOLVER

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Abstract.—Hardwood lumber costs account for up to 70 percent of the total product costs of U.S. secondary wood products producers. Reducing these costs is difficult and often requires substantial capital investments. However, lumber-purchasing costs can be minimized by buying the least-cost lumber grade-mix that satisfies a company's component needs. Price differentials between National Hardwood Lumber Association lumber quality classes (grades) change based on market pricing and thus a different least-cost lumber grade-mix solution may be obtained at different times. The U.S. Forest Service's ROMI free rough mill simulation package contains a least-cost grade-mix solver that allows hardwood lumber processors to find the least-cost lumber grade mix. This software, however, currently requires calculations performed on a Forest Service server using the SAS statistical package. R, a new open-source statistical software package similar to SAS, allows the least-cost lumber grade-mix solver to run on the users' computer without a connection to a Forest Service server. Use of the program is thus simplified, and company information is kept confidential.

INTRODUCTION

The U.S. manufacturing sector has seen challenging years over the past decades, with manufacturing employment reaching its lowest level since 1950 (Forbes 2004). The major driver behind the decline of U.S. manufacturing prowess is the ongoing globalization of trade, which has brought the comparative disadvantage of the United States as a manufacturing location to the forefront. Unfortunately, many U.S.-based hardwood lumber-consuming industries, such as furniture, flooring, and millwork industries, are hard hit by the worldwide opening of markets for goods and services (Schuler and Buehlmann 2003, Buehlmann and others 2004a, Buehlmann and Schuler 2009). With the decline in manufacturing operations producing hardwood-based products comes a decline in the demand for hardwood lumber, affecting the industries and forest landowners upstream from the manufacturer (Grushecky and others 2006).

According to U.S. Forest Service calculations, approximately 5.3 billion board feet of hardwood lumber is consumed annually in the United States for the production of wooden products other than pallets (i.e., appearance-grade lumber). Assuming that the average cost of this lumber is $750 per thousand board feet (MBF), the nationwide total lumber expense to rough mills is approximately $4 billion. An increase in operating efficiency (yield) of 1 percent would reduce the amount of lumber required by 53 million board feet with potential lumber-cost savings of $40 million, on an aggregate level. On an individual manufacturing location level, Kline and others (1998) estimated that a 1- to 2-percent yield increase in an average rough mill saves $150,000 to $300,000 annually. However, increasing operation efficiency often requires investment before savings can be captured. One immediate step to increase the competitive position of producers using domestic hardwoods is to enable them to find the lowest raw material cost solution possible, a problem

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referred to as the least-cost lumber grade-mix problem. This solution, unlike the quest for increased efficiencies mentioned above, requires only minimal capital outlays, can be implemented immediately, and can save significant amounts of capital.

In the past decades, researchers have developed several programs to solve the least-cost lumber grade-mix problem (Englerth and Schumann 1969, Hanover and others 1973, Martens and Nevel 1985, Carino and Foronda 1990, Steele and others 1990, Timson and Martens 1990, Harding 1991, Fortney 1994, Suter and Calloway 1994, Lawson and others 1996, Hamilton and others 2002). Buehlmann and others (2004b, 2010) and Zuo (2003) created the least-cost lumber grade-mix solver, a statistical solution that answered several shortcomings of older models (Zuo and others 2004). Buehlmann and others' (2004b, 2010) solution has been shown to perform better than other optimizers (Buehlmann and others 2008). The U.S. Forest Service has incorporated Buehlmann and others' (2004b) least-cost lumber grade-mix solver solution into the widely used ROMI rough mill simulation software (Weiss and Thomas 2005, Thomas and Weiss 2006). However, Buehlmann and others' (2004b, 2010) least-cost lumber grade-mix solver relies on advanced statistical software (SAS Institute 2009) to build a polynomial response surface to find the least-cost solution. Thus, a user employing ROMI and running the least-cost lumber grade-mix solver needs a working internet connection to run the least-cost optimization hosted on a U.S. Forest Service server equipped with the SAS statistical package (SAS 8.2, 2002, SAS Institute, Cary, NC). This set-up forces industry users to be connected to the Internet and the U.S. Forest Service to maintain a server running the SAS software; industry users also must pay licensing fees to SAS. The industry participant sends yield data derived on the user's local computer to a Forest Service server. The Forest Service computer then derives the least-cost lumber grade-mix solution and returns it to the user.

However, thanks to efforts within the open-source software movement (Anonymous 2009), R 2.7.2, a statistical software package (Venables and others 2008) with capabilities similar to SAS, has become available for free and can be installed on individual computers at will. The research reported below investigates the replacement of SAS 8.2 with R 2.7.2 (Venables and others 2008) in the least-cost lumber grade-mix solver software (Buehlmann and others 2004b, 2010) so that users no longer need to connect to a Forest Service server running SAS.

MATERIALS AND METHODS

This project required the use of the U.S. Forest Service's rough mill simulator, Romi-Rip 2.0 (Thomas 1999a,b) and ROMI 3.0 (Weiss and Thomas 2005, Thomas and Weiss 2006), SAS 8.2, and R 2.7.2 (Venables and others 2008), the open source statistical package freely available on the internet.

ROUGH MILL SIMULATOR

The original least-cost lumber grade-mix solver (Buehlmann and others 2004b, 2010) relied on the U.S. Forest Service's ROMI-RIP 2.0 (Thomas 1999a,b) rough mill rip-first simulator. Thus, ROMI-RIP 2.0 was used to find the least-cost lumber grade-mix when using the SAS 8.2 statistical analysis package. With the R 2.7.2 (Venables and others 2008) statistical analysis package, however, it was decided to use ROMI 3.0 (Weiss and Thomas 2005, Thomas and Weiss 2006). While this approach may introduce variability not associated with the switch of statistical software package (from SAS 8.2 to R 2.7.2) because of improvements made to the rough mill simulator (Weiss and Thomas 2005), the research team first wanted to know whether a user can expect comparable results from the older (ROMI-RIP 2.0, SAS 8.2-based) and the newer

(ROMI 3.0, R 2.7.2-based) version of the least-cost lumber grade-mix solver. If needed, future research could resolve any source of variability observed. The simulators, ROMI-RIP 2.0 and ROMI 3.0, employ the same operational settings, i.e., use the all blades movable arbor, obtain parts salvaged through additional processing, use complex dynamic exponential component prioritization (Thomas 1996), and produce no excess and random-length or random-width components.

LUMBER

Data from Gatchell and others' (1998) Kiln-Dried Red Oak Data Bank containing digitized representations of red oak boards (Anderson and others 1993) were employed for this study. Using the Gatchell and others (1998) database, we created randomly composed lumber datafiles for each grade-mix needed in the experiment. To create the necessary lumber datafiles, the MAKEFILE tool in ROMI-RIP 2.0 and ROMI 3.0 was employed (Thomas 1999, Weiss and Thomas 2005). The lumber grades involved were First and Seconds (FAS), Selects (SEL), 1 Common (1C), 2 Common (2C), and 3A Common (3AC; National Hardwood Lumber Association 1998). To assure consistency with Buehlmann and others' (2004b, 2010) and Zuo's (2003) work, the following 2002 prices for red oak lumber found in Hardwood Review Weekly (2002) were used: $1,570 per MBF for FAS, $1,350 per MBF for SEL, $1,000 per MBF for 1C, $748 per MBF for 2AC, and $500 per MBF for 3AC.

CUTTING BILL

For these initial performance assessments, a cutting bill (cutting bill A) used by Thomas (1996) was selected. Table 1 shows details of the cutting bill requirements.

Table 1.—Part sizes and quantities required by cutting bill A.

Width (inches)	Length (inches)	Quantity (units)
2.00	25.50	625
2.25	20.75	750
2.25	27.00	2,250
2.75	16.25	1,500
2.75	32.50	1,500

STATISTICS

A mixture design, a special response surface methodology typically used for optimizing multiple factors simultaneously, was employed (Giesbrecht and Gumpertz 2001). Each individual lumber grade (FAS, SEL, 1C, 2AC, 3AC; National Hardwood Lumber Association 1998) can contribute between zero and 100 percent of the total lumber used and the sum of all lumber grade proportions is one. Since each grade is an individual factor, a five-factor mixed design is established. The 3AC lumber grade was restricted to a maximum contribution of 80 percent since 3AC rarely is able to contribute all the large parts required by a typical cutting bill, resulting in skewed yield results (Zuo 2003, Buehlmann and others 2004b).

Minimizing costs and not optimizing yields is the objective of the optimization. Thus, the least-cost lumber grade-mix solver converts the yields obtained from 25 test runs conducted by the rough mill simulator (Table 2; Buehlmann and others 2004b, 2010) to lumber costs plus processing costs using Equation 1 (Zuo 2003). Equation 2 then creates a total cost (lumber plus processing costs) response surface employing a second order polynomial equation (Zuo 2003).

$$COST_j = \frac{\sum_i^5 G_i * (M_i + P_i)}{YIELD_j} \qquad (1)$$

where: G_i - the proportion of each lumber grade
M_i - the market price per thousand board feet of each lumber grade
P_i - the processing cost per thousand board feet of each lumber grade
i - 1 for FAS, 2 for SEL, 3 for 1 Common, 4 for 2A Common, and 5 for 3A Common
j - observation of a grade combination run

Table 2.—Twenty-five lumber grade-mix combinations used to establish cost response surface.

RUN	FAS	SEL	1C	2AC	3AC
1	0	0	0	20	80
2	0	0	0	60	40
3	0	0	0	100	0
4	0	0	20	0	80
5	0	0	50	50	0
6	0	0	50	50	0
7	0	0	60	0	40
8	0	0	100	0	0
9	0	20	0	0	80
10	0	50	0	50	0
11	0	50	0	50	0
12	0	50	50	0	0
13	0	50	50	0	0
14	0	60	0	0	40
15	0	100	0	0	0
16	50	0	0	50	0
17	50	0	0	50	0
18	50	0	50	0	0
19	50	0	50	0	0
20	50	50	0	0	0
21	50	50	0	0	0
22	60	0	0	0	40
23	60	0	0	0	40
24	100	0	0	0	0
25	100	0	0	0	0

$$\mu_y = \beta_0^* + \sum_{i=1}^5 \beta_i^* x_i + \sum_{i<} \sum_j \beta_{ij}^* x_i x_j \qquad (2)$$

where: μ_y - the cost of satisfying a given cutting bill
x_i, x_j - the proportions of each lumber grade
β_0^* - the intercept
β_i^* - the coefficient of linear terms
β_{ij}^* - the coefficients of the interaction terms
i, j - 1 for FAS, 2 for SEL, 3 for 1 Common, 4 for 2A Common and 5 for 3A Common

Using the cost response surface created with Equations 1 and 2, the minimum cost location is identified and the respective grade or grade-mix is returned. While SAS 8.2 and R 2.7.2 (Venables and others 2008) use different commands for this purpose, both statistical packages use the same underlying methodologies.

EQUIVALENCE TESTING OF SOLUTIONS

In a first set of tests, it was decided to compare least-cost lumber grade-mix solutions using ROMI-RIP 2.0 (Thomas 1999a,b) and SAS 8.2 with solutions from using ROMI 3.0 (Weiss and Thomas 2005, Thomas and Weiss 2006,) and R 2.7.2 (Venables and others 2008). For both tests, cutting bill A was employed and three repetitions were conducted using the same three lumber datafiles. No statistical comparison of results was planned, as future tests are currently under way that will add to the insight gathered from this study and allow more encompassing conclusions to be made.

RESULTS AND DISCUSSIONS

The least-cost lumber grade-mix solution derived with the ROMIi-RIP 2.0 and SAS 8.2 found a least-cost lumber grade-mix with a cost of $2,101 per MBF with an average yield of 57.11 percent (three repetitions) (Table 3). Using the same datafiles, the ROMI 3.0 and R 2.7.2 found a least-cost lumber grade-mix with a cost of $2,096 per MBF with an average yield of 38.18 percent (three repetitions). The cost difference between these two tests was $5 per MBF, a difference of less than 1 percent. The yield difference between these two solutions, however, was more than 18 percent: ROMI-RIP and SAS 8.2 generated an average yield of 57.11 percent and ROMI and R 2.7.2 generated an average yield of 38.18 percent.

Table 3.—Least-cost lumber grade-mix solutions and yields for ROMI-RIP 2.0 and SAS 8.2, and ROMI 3.0 and R 2.7.2.

Test	Yield (%)	Minimum Cost ($ per MBF)
ROMI-RIP & SAS 8.2	57.11	2,101
ROMI & R 2.7.2	38.18	2,096
Difference	18.93	5

The results derived by the two least-cost lumber grade-mix models using the same underlying statistical methodology resulted in two fundamentally different solutions to the problem. Despite the different solutions, however, the cost difference was less than 1 percent (Table 4). The least-cost lumber grade-mix solution from the ROMI-RIP 2.0 and SAS 8.2-based solver relied on 1C for obtaining all the parts. The ROMI 3.0 and R 2.7.2-based least-cost lumber grade-mix solver solution found an almost equivalent least-cost lumber grade-mix solution (difference of less than $5 per MBF or less than 1 percent) by using 80 percent 3AC and 20 percent 1C lumber, creating a solution with lower yield but also lower costs (Table 4). This solution requires the use of 20 percent higher grade lumber (i.e., 1C) to obtain the larger parts (long and/or wide) required by cutting bill A and cuts the remaining parts from 80 percent of the lowest-grade lumber, 3AC. These results indicate that the two least-cost lumber grade-mix solvers perform equally well in finding a least-cost lumber grade-mix solution. However, questions as to why the two solvers did not produce identical solutions remain. Thus, future research will have to identify the reason for this difference in solutions between set-ups (ROMI-RIP 2.0 vs. ROMI 3.0 and SAS 8.2 vs. R 2.7.2). With solutions between the two least-cost lumber grade-mix solvers differing less than 1 percent, however, Buehlmann and others' (2004b, 2010) and Zuo's (2003) statistical solution to the least-cost lumber grade-mix problem has shown its ability to identify

Table 4.—Details of the least-cost lumber grade-mix solutions and yields for ROMI-RIP 2.0, and SAS 8.2 and ROMI 3.0 and R 2.7.2.

ROMI-RIP 2.0 and SAS 8.2

Lumber Grade					Average Yield	Average Cost
FAS	SEL	1C	2AC	3AC	(%)	($ per MBF)
		100			57.11	2,101

ROMI 3.0 and R 2,7.2

Lumber Grade					Average Yield	Average Cost
FAS	SEL	1C	2AC	3AC	(%)	($ per MBF)
		20		80	38.18	2,096

least-cost solutions from diverging initial yield results. These initial results indicate that the Forest Service can incorporate the free, open-source R 2.7.2 statistical software analysis package into a new version of ROMI 3.0. Industry participants will no longer need to use the internet to access SAS 8.2 on a server for their least-cost lumber grade-mix search.

CONCLUSIONS

Hardwood lumber is the largest expense incurred by U.S. manufacturers of secondary solid hardwood products. Thus, efforts are made to process this material in the most efficient manner, sometimes requiring significant investments. Minimizing cost by buying the least-cost lumber grade-mix does not require any investment, as software for solving this problem is available for free.

The solutions derived by the two least-cost lumber grade mix solvers using the same underlying statistical models but relying on different versions of the USDA Forest Service's rough mill simulation software (ROMI-RIP 2.0 and ROMI 3.0) and two different statistical analysis software packages (SAS 8.2 vs. R 2.7.2) are similar with respect to cost, yet different with respect to the suggested least-cost lumber grade-mix to be used. The minimum cost solution found by both solvers differed by less than 1 percent or $5 per MBF. The least-cost lumber grade-mix solution from the ROMI-RIP 2.0- and SAS 8.2-based solver relied on 100 percent 1C lumber for obtaining all its parts requirements. The ROMI 3.0- and R 2.7.2-based least-cost lumber grade-mix solver solution asked for using 80 percent 3AC and 20 percent 1C lumber.

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