Robotics and Computer-Integrated Manufacturing 27 (2011) 746–754

Contents lists available at ScienceDirect

Robotics and Computer-Integrated Manufacturing

journal homepage: www.elsevier.com/locate/rcim

Cost minimization through optimized raw material quality composition ☆

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ARTICLE INFO

Article history:
Received 14 December 2010
Accepted 20 December 2010
Available online 15 February 2011

Keywords:
Cost minimization decision support system (DSS)
Cost models
Cutting stock problem
Decision making
Decision process
Manufacturing
Production planning and control
Component production

ABSTRACT

Lumber, a heterogeneous, anisotropic material produced from sawing logs, contains a varying number of randomly dispersed, unusable areas (defects) distributed over each boards' surface area. Each board's quality is determined by the frequency and distribution of these defects and the board's dimension. Typically, the industry classifies lumber into five quality classes, ranking board quality in respect to use for the production of wooden components and its resulting material yield. Price differentials between individual lumber quality classes vary over time driven by market forces. Manufacturers using hardwood lumber can minimize their production costs by proper selection of the minimum cost lumber quality combination, an optimization problem referred to as the least-cost lumber grade-mix problem in industry parlance. However, finding the minimum cost lumber quality combination requires that lumber cut-up simulations are conducted and statistical calculations are performed. While the lumber cut-up simulation can be done on a local computing workstation, the statistical calculations require a remote station running commercial statistical software. A second order polynomial model is presented for finding the least-cost lumber grade-mix that manufacturers of wood products can use to minimize their raw material costs. Tests of the newly developed model, which has been incorporated into a user-friendly decision support system, revealed that only a limited amount of lower quality raw material (e.g. lumber with a high frequency of defects in boards and/or small board sizes) can be accepted, as otherwise the lumber quality mix cannot supply all the parts required. However, the new model suggested solutions that resulted in lower raw material costs than solutions from older models.

1. Introduction

Manufacturers of solid wood products cut kiln-dried hardwood boards (lumber) into dimension parts of specified sizes, qualities, and quantities according to customer orders, called cutting bills [1]. Dimension parts are slightly oversized rectangular pieces cut from lumber that are further processed through a series of manufacturing steps into final components for products sold by the wood products industry [1]. These parts are cut in rough mills from lumber of varying geometrical sizes (length/width) through a series of guillotine cuts such that randomly dispersed and shaped defective areas (such as knots, splits, or discolorations) are cut out, leaving dimension parts without defects for further processing [2]. Lumber is traded in five quality classes (called "grades" in industry parlance) with First and Seconds (FAS) being the best quality consisting of large boards with few defects, followed, in decreasing order of quality, by Selects (SEL), 1 Common (1C), 2A Common (2AC) and 3A Common (3AC), the lowest quality lumber that can be purchased for appearance products [3]. Fig. 1 displays two boards, the top one graded FAS, e.g. the best quality, and the bottom one graded 3AC, e.g. the lowest quality. The usable areas contained in these boards differ greatly. While the FAS board, according to the quality standards setting body of the industry [3], contains a minimum of 83.3% usable, clear area, the 3AC board must contain at least 33.3% usable, clear area. The amount of usable, clear area for given quality classes is determined in the grading rules for all quality classes, e.g. FAS 83.3%, SEL 66.7% (one side must contain 83.3%), 1C 66.7% (both sides), 2AC 50%, 3AC 33.3%, respectively [4].

Lumber costs are the single largest cost position incurred by secondary wood products manufacturers [5]. Depending on the product manufactured, an estimated 40–70% of total production costs of raw dimension parts in rough mills of the secondary wood industry stem from the procurement of lumber [6–9]. Understandably, the industry undertakes considerable efforts to minimize lumber procurement costs first and foremost by increasing yield from a given set of input lumber. Lumber yield in rough mills is defined as the "ratio of aggregate part surface output to aggregate lumber surface area input ([10] p. 13)" and is

☆ The author gratefully acknowledges the CSU East Bay University for support of the project.

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doi:10.1016/j.rcim.2010.12.013

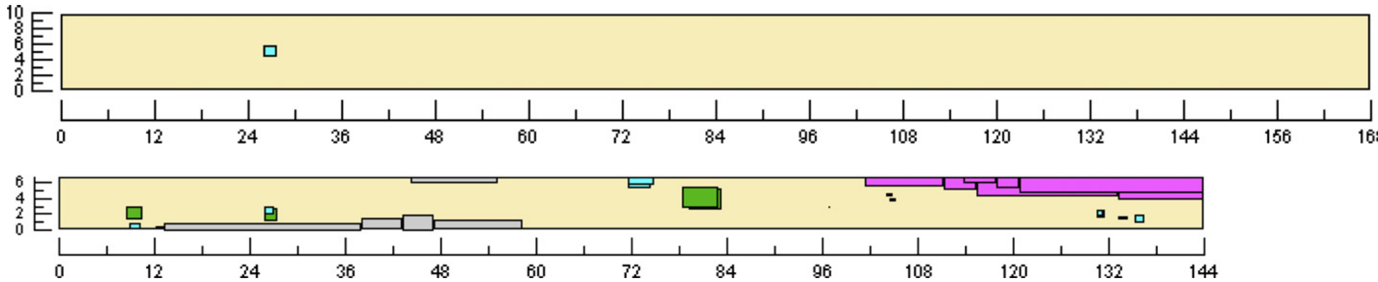

Fig. 1. Digital representation of two kiln-dried lumber boards from the highest (FAS) and the lowest quality class (3A C). The shaded rectangles signify defects, e.g. unusable areas within the board's surface.

the single most important benchmark used in the industry. Most research has focused on efforts to improve lumber yield through finding optimum cut-up patterns for each board, which is a typical cutting stock problem encountered in numerous industries [11,12]. Examples include the paper, glass, metal, and the wood products industries [13–17]. Gilmore and Gomory [18–21] in the 1960s published a series of solutions to the cutting stock problem involving linear and dynamic programming. Over the following years, numerous researchers have added to the methodology and expanded the scope of problems that can be addressed, such as expanding the dimensions in which solutions are sought [22–32].

However, the quest for increased yield from lumber is only one way manufacturers try to minimize their raw material costs. Solid wood products manufacturers also try to minimize costs through optimizing their lumber purchases, in particular through management of the price differential that exists between different lumber quality classes. In general, the better the lumber quality purchased, the higher the per unit price set by the markets. Different industry segments prefer to purchase different lumber qualities dependent on the dimension part sizes they produce. Typically, manufacturers who require a large amount of long and/or wide dimension parts to be cut from their lumber will purchase higher quality lumber. Manufacturers, who need only moderate amounts of long and/or wide parts, will tend to buy lower quality lumber. Since lumber prices fluctuate in absolute terms but also relative to each lumber quality class, an opportunity exists to minimize total lumber costs by finding the minimum cost lumber quality or mix of qualities to obtain the dimension parts needed.

The industry refers to this problem as the least-cost lumber grade-mix problem and much research has been conducted since the 1960s [9,33–42]. In essence, the problem is to minimize the cost of purchasing all the lumber needed to obtain all the required dimension parts for a given production run. Yield obtained from different lumber quality classes is dependent on the part size requirements specified in the cutting bill [10]. Thus, depending on the part size requirements for a given production run, different lumber quality classes or combinations of lumber quality classes result in different levels of yield and thus result in higher or lower total lumber procurement costs. One lumber quality may be better suited to obtain a specific size-range of parts but be expensive to purchase per unit versus another quality that may be good enough to obtain the needed parts and be relatively inexpensive. For example, when a cutting bill asks for long and/or wide parts to be cut, but also requires smaller parts, it is often advantageous to purchase a mix of high quality lumber (i.e. expensive lumber) and lower quality lumber (i.e. less expensive lumber) to minimize total lumber procurement costs.

In the past, the least-cost lumber grade-mix optimization problem was typically solved using linear programming models, which require that both objective and constraint functions are simple linear [43]. However, Zuo et al. [44] found that the relationship between yield and lumber quality or lumber quality mix is not always linear, in fact, an estimated 90% of scenarios tested by these authors were found not to have a linear relationship between lumber yield and lumber quality or quality mix. Thus, the authors suggested that the existing least-cost lumber grade-mix problem solvers using linear programming may not return true minimum cost solutions and the industry may be ill-advised to use those models. The objective of this research was to create a user-friendly least-cost lumber grade-mix Decision Support System (DSS) for industry practitioners that does not rely on linear optimization to find the minimum cost solution.

2. Materials and methods

Solving the least-cost lumber grade-mix problem is dependent on the expected lumber yield results for a given set of dimension part requirements (e.g. cutting bill). For this purpose, Thomas' [45] rip-first rough mill yield simulator (ROMI-ROP 2.0) was used together with digital representations [46] of red oak lumber [47].

2.1. Lumber cut-up simulator

The USDA Forest Service's ROMI-RIP 2.0 (RR2) simulation software [45] was employed in this research to simulate the actual cut-up of hardwood lumber in a rough mill of the secondary wood products industry [1,48]. The study employed commonly used industry operation parameters to reflect actual industry operations. Settings used included movable saw-blade positions; obtain extra dimension parts through additional processing after the first iteration, if possible; employ complex dynamic part prioritization [49]; and do not allow random length and random width parts to be cut.

2.2. Cutting bill

This study used Buehlmann's cutting bill [10,50,51], a theoretical representation of the "average" industrial cutting bill with respect to size and quantity requirements. The part quantity requirements were proportionally adjusted to fit the lumber samples used for this study. Additionally, seven industrial cutting bills were also examined in this study [8,54]. Table 1 summarizes the dimension part requirements of all eight cutting bills and ranks the cutting bills in order of their difficulty to obtain all parts from a given set of lumber [52].

2.3. Lumber data

Red oak, a hardwood species growing widely in Eastern U.S. Forests and used in all segments of the U.S. wood products industry, was the wood of choice for this study [53]. While lumber from