

Optimal tree-stem bucking of northeastern species of China

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Abstract

An application of optimal tree-stem bucking to the northeastern tree species of China is reported. The bucking procedures used in this region are summarized, which are the basic guidelines for the optimal bucking design. The directed graph approach was adopted to generate the bucking patterns by using the network analysis labeling algorithm. A computer-based bucking model was then developed based on the bucking procedures and the directed graph of the network analysis. The graphical user interface was used for the front-end of the system and the back-end was implemented via a relational data model. Bucking patterns generated by the computer bucking model were compared with the results from manual bucking for the tree species in the northeast of China. Results suggest that gains of up to about 14 percent were realized by using computer-aided bucking.

Maximizing tree value by using correct bucking strategies has always been a major objective in forest operations. The maximization of tree value is a complex process and requires simultaneous considerations of species, quality of tree, log length, diameter, log price, and other factors. Previous studies have shown that the average manual log bucking practice typically reduced the potential value obtainable from a tree by 20 percent compared to what was considered to be good practice (Faaland and Briggs 1984). Losses of up to 26 percent were also reported in New Zealand (Geerts and Twaddle 1984). A study of 166 northern hardwood trees in Michigan indicated that the gross delivered values of optimal solutions were 39 to 55 percent higher than those chosen by the

buckers (Pickens et al. 1992). Optimal bucking has the potential to greatly increase the revenues of forest product enterprises.

During the last five decades, optimal bucking has been addressed by many researchers. The problem of value loss associated with poor bucking was identified in the United States as early as 1915 (Lawrence 1986), but it was not widely addressed until the early 1950s (Fobes 1960). The concept of optimal bucking

has long been recognized in Sweden and Finland (Haggbloom and Pennanen 1983). In the 1950s and 1960s, it was a common practice to employ a man whose sole responsibility was marking for crosscutting in Nordic countries (Lawrence 1986).

Since the 1960s, computer modeling techniques associated with tree-stem bucking have been introduced, which were mainly derived from operations research. The primary mathematical techniques for tree bucking optimization are linear programming, dynamic programming, and network analysis.

Linear programming applications to tree bucking were first presented in 1961 based on the paper cut and trim programming of Eisman in 1957 (Smith and Harrell 1961), which took into account resource and market limitations. The model assumed that there were a number of known alternatives for converting trees of specific sizes into logs. Given those alternatives and their associated profits, as well as resource and market limitations, the objective was to determine the number of trees of each size to be cut into logs of the desired sizes.

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Table 1. — Grading conditions of log products for northeastern China tree species. (CWSC 1986).

Log type	Species group	Scaling length ^a (m)	Scaling diameter ^b (cm)	Grade code
Supergrade	1, 2	4, 5, 6, 8	∞ 26	0
Processing logs	1, 2, 3, 4, 5	2 to 8, 2.5	∞ 18	1, 2, 3
Mine-prop	1, 2, 3, 4, 5	2 to 6	12 to 24	4
Secondary processing logs	1, 2, 3, 4, 5	2 to 6, 2.5	∞ 18	5
Small diameter logs	1, 2, 3, 4, 5	2 to 6	6 to 16	4
Firewood	1, 2, 3, 4, 5	2 to 6	∞ 6	6

^aSupergrade logs require the lengths of 4, 5, 6, and 8 m while the lengths of other logs are within the specified ranges with a scaling increment of 0.2 m and allowance of between 0.2 cm and +6 cm.

^bThe increment of scaling diameter is 2 cm.

McPhalan (1978) developed a linear programming model based on a column-generating technique that permitted the coordination of log bucking and sawing subject to market demand constraints for lumber. This linear programming model was structured to maximize lumber revenue by considering alternative bucking policies for lumber sizes. A two-stage linear decision model for bucking and allocation was described by Mendoza and Bare (1986). This two-stage optimization procedure simultaneously determined optimal log bucking and allocation. The procedure was based on the column-generation technique. The first stage decision problem was a wood resource allocation model (WRAM) that included log allocation, production, and sale of finished products. The second-stage decision problem was concerned with determining the "BEST" log bucking policy. Models formulated for each problem were interfaced using the structure of the two-level optimization process of the decomposition principle. Maness and Adams (1991) also demonstrated a combined optimization model of log bucking and sawing. The model used a three-stage solution process performed iteratively until identical solution bases were obtained.

Clemmons (1966) first proposed using a dynamic programming routine for optimizing tree-stem conversion. The first detailed dynamic programming model for optimal tree-stem bucking was developed by Pnevmticos and Mann (1972). The optimization was based on log values and bucking cost. Although lacking refinement in some of the basic assumptions and detail, it was the forerunner of a number of similar models (Lawrence 1986). Pnevmticos and Flann (1974) and Pnevmticos (1975) also studied the effects of cross-

cutting of various combinations of log lengths on volume yields from subsequent processing and methods to improve crosscutting.

In the Pnevmticos and Mann (1972) model, the stem was considered to be made up of a sequence of stages, each stage representing a single minimum length of log, and then the bucking problem was viewed as a sequential decision process. This process contained as many stages as there was minimum length of logs. Thus, at each decision point, one had to decide whether or not to make a cut. Whenever a cut was made, the number of remaining stages was reduced by the number of minimum lengths that had been removed from the stem. Gluck and Koch (1973) showed that the model developed by Pnevmticos and Mann (1972) was effective in their study. Following the work of Pnevmticos and Mann, dynamic programming has been proven to be the most popular of the techniques for solving the problems in this field. Deadman and Goulding (1979) also developed a dynamic programming model for accessing the recoverable volume by log types of a single-species stand of trees shortly before harvesting. This method considered the influences on yield of stem quality and malformation, and of log specifications and preferences.

Faaland and Briggs (1984) integrated a dynamic programming bucking model and a sawing model that could simultaneously optimize log bucking, sawing of logs into live-sawn lumber, and edging lumber into finished dimensions. Their model allowed for variation in tree-stem shape and quality. A VISION system was developed to link the computer modeling approach with bucking practice by Lembersky and Chi (1984). This system enabled a graphic view of a stem

to be rotated, rolled, cut, and allocated using either a single saw or multiple saw. The same dynamic programming approach was later developed into a more general regional allocation model (Hay and Dahl 1984, Lawrence 1986). Eng et al. (1986) used dynamic programming in a system for determining crosscutting strategies consistent with resource characteristics and markets, which maximized returns subject to various constraints.

Network analysis techniques have been introduced into optimal tree-stem bucking since the mid-1980s (Nasburg 1985, Sessions 1988, Sessions et al. 1989). It was proven that network analysis was an effective way for solving optimal bucking problems. "BUCK" is a well-known version of an optimal bucking program developed with network analysis techniques (Sessions 1988). Garland et al. (1989) compared value recovery from manual log making and from using "BUCK" on a handheld computer. Olsen et al. (1990, 1991) extended the bucking strategies generated by "BUCK" to mechanized harvesting, site preparation, and timber sale bids.

The log value loss due to poor bucking decisions has been considered one of three major problems of timber production in the northeast of China since 1950 (Che et al. 1990). However, emphasis on research related to optimal bucking in the region did not start until the late 1980s. Wang and Xu (1990) reviewed and summarized the characteristics of bucking models with dynamic programming and network analysis and presented their potential applications in the northeast of China. A first simple tree-stem bucking model using network analysis for the northeastern species of China was developed and programmed with BASIC under the DOS environ-

Table 2. — Log grades and defect limitations for northeastern China tree species. (Che et al. 1990, CWSC 1986).

Grade code	Species	Defect Limitations						
		Sound and unsound knots ^{a,b}		Sapwood rot ^c	Heartwood rot ^d	Worm holes ^e	Sweep ^f	Wounds ^g
		(no.)	(%)	------(%)-----			(%)	
0	Softwood	4	15	0	0	0	1	3 cm
	Hardwood	2	15	0	0	0	1.5	3 cm
1	Softwood	5	15	0	1 (butt)	0	1.5	20%
	Hardwood	2	20	0	1 (butt)	0	1.5	20%
2	Softwood	10	40	10	16	20	3	40%
	Hardwood	4	40	10	16	5	3	40%
3	Softwood	--	--	20	36	--	6	--
	Hardwood	--	--	20	36	--	6	--
4	--	--	--	10	9 (butt)	10	6	--
5	--	--	--	--	30	50	--	--
6	--	--	--	--	--	--	--	--

^aThe number of knots per log for grade 0 and the number of knots per meter grades 1, 2, and 3.

^bThe size of the knot never exceeds that percentage of scaling diameter.

^cThickness cannot exceed that percentage of scaling diameter.

^dArea cannot exceed that percentage of area based on scaling diameter.

^eThe number of holes per meter allowed.

^fThe maximum percentage of the maximum departure over the distance between the butt and the top of the sweep log.

^gWounds never exceed 3 cm for grade 0 and the specified percentage of scaling diameter.

ment in 1990 (Wang et al. 1991, Wang and Xu 1992). Another FORTRAN model was then developed based on the BASIC model (Yang 1993). This model was run under the DOS environment. However, it was a compiled program and did not require programming knowledge for the user to run it. Optimal bucking of northeastern tree species of China has not been adequately explored with today's computer techniques. Accordingly, this paper presents an application of a user-friendly Windows-based tree-stem bucking system, and compares its efficiency with manual bucking for the northeastern species of China.

Bucking operations

Production conditions

Tree bucking is traditionally carried out in a centralized log yard in the northeast of China. There are mainly 16 commercial tree species in the region, which are classified into 5 groups depending on market price and their commercial uses:

1. Amur cork-tree, Manchurian walnut, Korean pine, Manchurian ash;
2. Yeddo spruce, Manchurian fir, Siberian spruce, Manchurian linden, Mongolian oak;
3. Dahurian larch, Siberian fir, Manchurian maple, Chinese elm;
4. White poplar;
5. Manchurian birch, willow.

The grading conditions for log products are based on species, scaling diameter, scaling length, and defects (Table 1). Common defects measured for grading include knots, rot, sweep, wormholes, and others (Table 2). The sweep is expressed as a percentage of the maximum departure over the distance of a line segment between the top and the butt of the log. In general, the increment for scaling diameter is 2 cm, and for scaling length is 0.2 m. The allowance for scaling length is -2 cm or +6 cm. Log volume (V) in cubic meters is calculated by the following equations (CWSC 1986):

[1] If the scaling diameter (D) is between 4 cm and 12 cm:

$$V = \frac{0.7854L(D + 0.45L + 0.2)^2}{1000}$$

Here, L refers to scaling length (m). The value of the log was determined by log volume and its unit price. The unit log price was directly related to species, grade, scaling diameter, and scaling length, which is decreased as species group and grade varied from 1 to 5 and 0 to 6, respectively.

[2] If the scaling diameter (D) is over 14 cm:

$$V = \frac{0.7854L[D + 0.5L + 0.005L^2 + 0.000125L(14 - L)^2(D - 10)]^2}{1000}$$

Current manual procedures for value maximization

The maximization of both value and volume of logs is the ultimate objective when optimally bucking a tree stem (CWSC 1986). In order to achieve the objective, the bucking manual used by the China Wood Standardization Committee requires that producing a long log of higher quality should always be the first priority during tree-stem bucking. Logs of 4 m or longer are categorized as long logs. The maximum log lengths of softwood and hardwood are 8 and 6 m, respectively. The optimal tree-stem bucking strategy usually moves from the butt to the top of a tree. In order to identify the grade zones (sections) along a tree stem to be bucked, the buckerman needs first to observe its surface characteristics, including the severity and location of defect, butt rot, sweep, and dimensions of the tree stem based on the field bucking requirements and procedures (Wang and Wang 1992). The grade, butt diameter, top diameter, and length need to be recorded for each zone. When planning the bucking for the first section, the first two zones should be considered. If the second section meets the requirement of maximum log length for

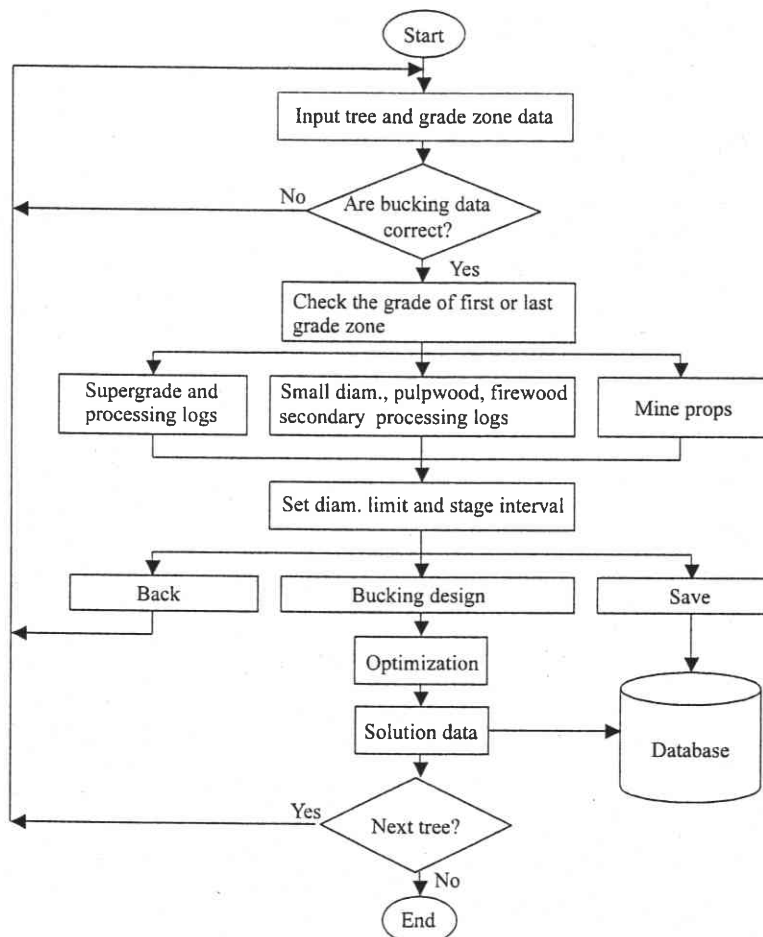


Figure 1. — Flow diagram of the bucking optimization system.

processing logs, the bucking can be started from the end of the second zone. If a portion of section 2 is left over after the bucking cut, that portion could be combined either into section 1 or section 3. However, as a rule, only log segments with higher grades can be combined into the lower grade sections.

One-grade sections. — A long log should always be bucked from a section with one grade. For example, if the first section is 9 m of grade 1 and the second section is 3 m of grade 2, the first section (grade 1, 9 m) is termed a one-grade section and a long log should be bucked. Since the maximum log length for hardwood species is 6 m, the first section should be bucked as a 6-m log of grade 1, the rest this section, 3 m (grade 1), should be combined into the second section and bucked as a 6-m log of grade 2. For softwood species, the maximum log length is 8 m. An 8-m log of grade 1 could be bucked from section 1, and the leftover segment of 1 m should be incor-

porated into the second section and bucked as a 4-m log of grade 2.

Sections with two consecutive grades. — For sections with two consecutive grades, if the length of the higher grade section is at least two times longer than that of the lower grade section, these two sections need to be bucked separately; otherwise, they should be combined. For example, suppose the first section of a tree stem is 4 m with grade 1 and the second section is 4 m with grade 2. Since the length of the first section is not two times as long as the second section, these two sections should be combined and bucked as an 8-m log of grade 2 for softwood species. The bucking pattern will be different for hardwoods because the maximum log length is 6 m. The above two sections should be cut separately based on the bucking regulations. The first section should be bucked as a 4-m log of grade 1 and the second section as a 4-m log of grade 2. If a 6-m log of grade 2 is bucked, the length of the first portion of that log (4 m, grade 1) is

twice as long as the second portion (2 m, grade 2), which violates the rule.

Sections with two inconsecutive grades. — For softwood species, if both sections are long logs (≥ 4 m), they should be bucked as two logs. For example, if the first section is 4 m long with grade 1 and the second section is 4 m long with grade 3, two 4-m logs of grade 1 and grade 3 should be bucked separately. If both sections are short logs (< 4 m), for example, the first section is 2 m long (grade 1) and the second section is also 2 m long (grade 3), these two sections need to be combined and bucked as a 4-m log of grade 3. If one section is a long log and the other section is a short log, two bucking situations may occur. If the grade of the longer section is higher than that of shorter section, these two sections should be bucked separately. Otherwise, they should be combined and bucked as a single long log. For example, if the first section is 4 m of grade 1 and the second section is 2 m of grade 3, a bucking pattern with a 4-m log of

grade 1 and a 2-m log of grade 3 should be bucked. If the first section is 4 m with grade 3 and the second section is 2 m with grade 1, a 6-m log of grade 3 should be bucked.

Cut-off sections. — Logs with rotten butts are classified as secondary processing logs or firewood. If the rot is 1 m deep or less, it should be cut off. If the rot depth is between 1.0 and 1.5 m, it can be cut off or bucked as a short secondary processing log. For example, if there is a hardwood tree-length of 14 m in length, the grade zones (sections) from the butt to the top are as follows: 0 to 1.5 m secondary processing log with rotten butt, 1.5 to 8 m grade 1, and 8 to 14 m grade 2. A bucking pattern should be used that produces a 2-m secondary processing log and two 6-m logs of grade 1 and grade 2, respectively. If the tree-length is 13.5 m long, a 1.5-m-long segment from the butt should be removed and two 6-m logs could be bucked. If there is a softwood tree-length of 16 m long with 1 m deep butt rot, it should be bucked into 2-m-long firewood and 6-m and 8-m processing logs. If that tree-stem is 15 m long, the 1-m-deep butt rot should be cut off, and then 8-m and 6-m logs should be bucked.

Small-diameter and sweep tree stems. — For small-diameter tree stems, the bucking strategy should be based on the utilization of each individual section, such as mine props and pulpwood. For tree stems with sweep, the bucking strategy depends on how much sweep there is. The major objectives here are to reduce the sweep and maximize the value and volume of logs via improving log grades. If the sweep exceeds the limitations listed in Table 2, a "must-cut" point should be considered. The bucking usually starts from the point with maximum departure to both the butt and the top of a tree stem. If a portion with severe sweep is 1.5 m long or less and its quality is poorer than a log of grade 3, it should be removed.

Bucking algorithm

Based on the above modeled bucking procedures, a directed graph of network analysis was adopted for optimal bucking. Suppose the potential cutting points along the tree from butt to top are denoted by X_i ($i = 1, 2, \dots, n$), the interval between two potential cutting points is identified as Y_k ($k = 1, 2, \dots, K$), and the weight on the arc $W(i,j)$ is denoted by the value of the log, then the directed graph

(S) for tree-stem bucking can be expressed by the point set $(X_1, X_2, \dots, X_n) \subset X$, the arc set $(Y_1, Y_2, \dots, Y_K) \subset Y$, and the weight set $W(i,j) \subset W$, i.e., $S = \{X, Y, W\}$. Here, n refers to maximum number of potential cutting points, and K to total number of potential arcs.

Network paths from X_1 to X_n depend on the interval between two potential cutting points and log length. The interval between the two closest potential cutting points is called stage interval. The stage interval is a very important factor in the model. If the stage interval is longer, the solution time will be less and it may not meet the requirements of accuracy, and vice versa. Since 0.2, 0.5, and 1.0 m are the standard increments for scaling lengths for log products in China (Che et al. 1990, CWSC 1986), the stage interval in the model is determined based on these values.

The Dijkstra algorithm known as the labeling algorithm has been shown to be among the fastest algorithms available for solving the minimum path problem and is particularly well suited to being programmed on a computer (Dijkstra 1984). The principle of the Dijkstra algorithm for the shortest path problem was adopted to find the longest path in the directed graph of tree-stem bucking (Sessions 1988).

Bucking system

The optimal tree-stem bucking system used in this research was written with Visual Basic (VB) Version 6.0, an event-driven programming language that runs under the MS Windows environment. An object-oriented structure model using a graphical user interface (GUI) was employed with a three-level hierarchy of built-in methods and custom controls. Error handler and tool tip texts were provided for major controls in the system.

The optimal bucking system consists of the following modules: File, Run, View, and Help. The Run module contains the main part of this tree-stem bucking system, which can be used to edit log prices, analyze defects, and optimize bucking processes (Fig. 1). These procedures can be performed sequentially and independently.

User input to the computer-based bucking system includes species, butt diameter, and the number of grade zones for each tree to be bucked. The user must then enter the grade, butt diameter, top diameter, and length for each grade

zone on that tree. A VB flex grid was used to display the grade zone data. The system allows the user to go back to edit the data, save the data into the database, print the data, and/or proceed to the optimal bucking process. The output of the system is the optimal bucking solution for that tree, which includes number of logs, dimensions, grades, gross values, and volume of each log. The bucking solution can then be displayed on the computer screen once the optimal bucking process is completed. The system was also designed to allow the user to save the solution data in the database and then process the next tree.

The data in the system are stored in an MS Access database. A relational database model is used for holding four entities of Tree_Stem, Grade_Zone, Log, and Log_Price, and it was implemented through the entity-relationship (ER) model (Fig. 2). An entity represents a data table in the ER model and has attributes (fields) that are the descriptive properties of the entity. For example, the entity Tree_Stem has Tree_No, Species, NoOfGZ, and ButtD attributes. Three relationships such as "Contains" and "Has" were built in this ER data model: one-to-many relationship between Tree_Stem and Grade_Zone and Log, and one-to-one between Log and Log_Price. A derived attribute "Value" was used in entity Log to indicate that its value was computed based on other attributes: Grade, Species, Scale_D, and Scale_L.

Since tree-stem and bucking solution data are saved in the database, the system allows the user to view and print out the data for other uses. For example, the bucking production reports could be produced on a daily or monthly basis. Database connectivity is conducted through both VB data control and data access objects (DAO). However, security was set for not deleting a record from the tables. The detailed help file for the system was provided and written in rich text format and displayed using an Object Linking and Embedding (OLE) technique.

Bucking application

Data for a total of 51 trees from 10 different species that were bucked manually by a logger were investigated. The logger is an experienced crosscutter and has many years of experience on bucking operations with the logging company in the region. The distribution of

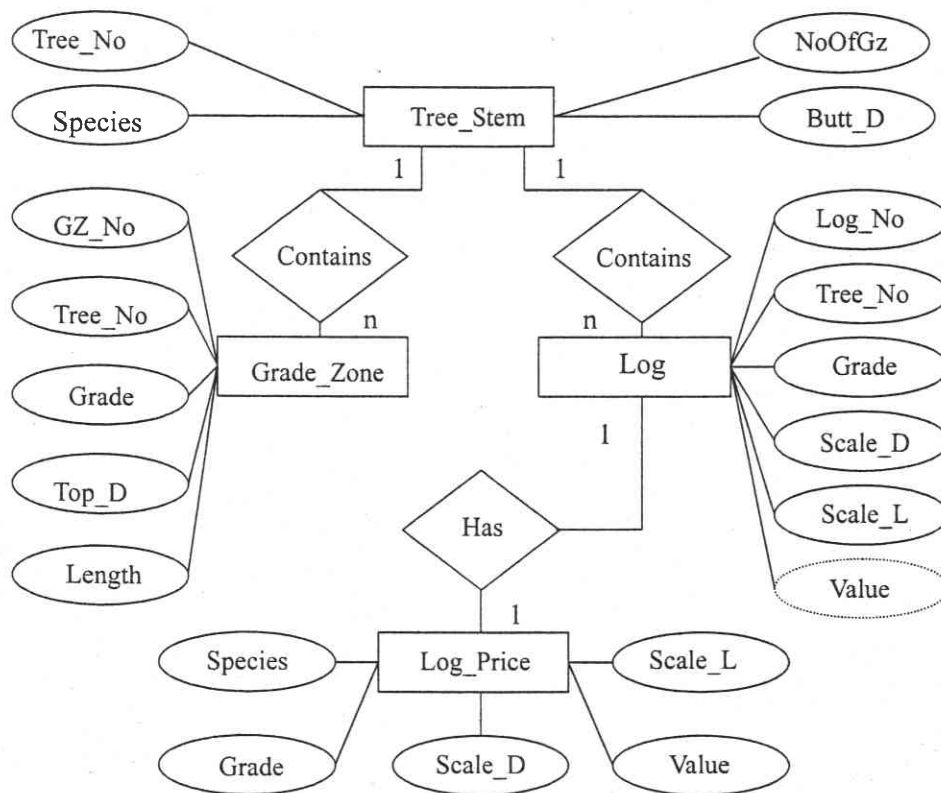


Figure 2. — Entity-relationship data model of the bucking system.

trees by species group is as follows: 14 trees in group 1, 16 trees in group 2, 4 trees in group 3, 5 trees in group 4, and 12 trees in group 5. Accordingly, these 51 trees were virtually bucked by the computer so as to evaluate the optimal bucking model. Variables measured for each individual tree stem include butt diameter, top diameter, length, bucking pattern (number of logs being bucked), volume yield, and the gross value of logs bucked. A general linear model (GLM) was used to test for differences in volume yield and value of logs between optimal and manual bucking operations, among species, and butt diameter classes. The GLM can be stated as follows:

$$\begin{aligned}
 V_{ijkl} = & \mu + SG_i + BK_j + \\
 & BD_k + BK_j * BD_k + BK_j * \\
 & SG_i + SG_i * BD_k + \eta_{ijkl} \\
 i = & 1,2,3,4,5 \\
 j = & 1,2 \\
 k = & 1,2,3,4,5 \\
 l = & 1,2,\dots,n
 \end{aligned}$$

where:

V_{ijkl} = the l th tree-stem of value or volume yield under the i th species group, the j th

bucking method, and k th butt diameter class,

μ = the mean of each response variable

SG_i = the effect of i th species group

BK_j = the j th bucking method

BD_k = the k th butt diameter class

η_{ijkl} = an error component that represents all uncontrolled variability

n = the number of observations within each treatment

The average butt and top diameters of measured trees was 44.94 and 17.61 cm, respectively, and total length of the trees varied from 8.5 to 26.4 m with an average of 17.43 m (Table 3). Butt diameters were regrouped into 30 cm (∞ 30 cm), 40 cm (> 30 and ∞ 40 cm), 50 cm (> 40 and ∞ 50), 60 cm (> 50 and ∞ 60 cm), and 70 cm (> 60 cm) for GLM analyses. About 60 percent of bucking patterns generated by the computer were different from the patterns bucked manually. The gross value of logs bucked from a tree stem by the computer algorithm was 13.8 percent more than the gross value of the bucked logs by the logger. How-

ever, there was no significant difference for gross values between two bucking methods ($F = 0.90$; $df = 1, 101$; $p = 0.3453$). Similarly, volume yield of bucked logs per tree-stem by the computer did not differ significantly from the volume yield per tree produced by the logger ($F = 0.03$; $df = 1, 101$; $p = 0.8621$). The volume yield of 1.43 m³ generated by the computer was about 2.1 percent more than that provided by the logger. The gross value of bucked logs per tree-stem varied decreasingly from species group 1 to 5 while it varied increasingly from butt diameter class 30 cm to 70 cm. The volume yield of bucked logs did not change significantly among species groups but varied increasingly from butt diameter class 30 cm to 70 cm.

The effects of three interactions among species group, butt diameter class, and bucking method were tested on gross value and volume yield of bucked logs per tree. The interaction of species group and diameter class significantly affected the gross value ($F = 4.35$; $df = 10, 101$; $p = 0.0001$) while the gross value was not significantly affected by the interactions of species group and bucking method ($F = 0.04$; df

Table 3. — Means and significance levels of statistics of tree stems bucked by a logger and a computer for northeastern China tree species.^a

		Top diameter	Butt diameter	Length	Gross value of bucked logs	Volume yield
		----- (cm) -----	----- (cm) -----	(m)	(Yuan)	(m ³)
Bucking method	Logger	17.61 A	44.94 A	17.43 A	646.68 A	1.40 A
	Computer	17.61 A	44.94 A	17.43 A	735.85 A	1.43 A
Species group	1	18.29 CD	51.14 C	18.47 C	1349.50 C	2.05 C
	2	19.13 C	47.13 D	19.93 C	675.70 D	1.48 D
	3	12.50 E	37.50 E	13.53 C	197.50 E	0.68 E
	4	13.60 DE	34.4 E	17.77 C	241.60 E	0.87 E
	5	18.17 CD	41.67 F	14.06 C	296.10 E	1.08 DE
Butt diameter class (cm)	30	12.40 H	28.20 H	14.75 H	196.90 H	0.53 H
	40	15.50 HI	38.00 I	19.43 H	456.70 HI	1.01 I
	50	18.22 I	45.78 J	15.67 H	549.40 I	1.20 I
	60	19.20 I	54.00 K	17.78 H	928.90 J	1.89 J
	70	28.33 J	75.00 L	18.62 H	1957.40 K	3.51 K

^aMeans with the same capital letter in a column are not significantly different at the 5 percent level with Duncan's multiple-range test.

= 4, 101; $p = 0.9969$), and diameter class and bucking method ($F = 0.17$; $df = 4, 101$; $p = 0.9517$). The interactions of species group and diameter class ($F = 1.0$; $df = 10, 101$; $p = 0.4486$), species group and bucking method ($F = 0.12$; $df = 4, 101$; $p = 0.9762$), and diameter class and bucking method ($F = 0.05$; $df = 4, 101$; $p = 0.9949$) did not significantly affect the volume yield of bucked logs per tree.

Discussion

Although there was no significant statistical difference, the optimal computer-based bucking system resulted in a 13.8 percent increase in potential gross log value. The reason for the differences was due to some straight stems with few defects used for bucking comparisons. For an experienced bucker, he/she will be able to produce the same patterns as the computer system does when bucking straighter stems with few defects. This presents a unique opportunity for forestland owners and forest enterprises to enhance their profitability. It is even more essential and significant for forest companies in China to adopt this bucking system to handle the limited forest resources. Differences of value gain were found across tree species or species groups simply because of market prices of different species. Bucking hardwood trees is inherently more complex than bucking softwoods due to their irregular stem shapes. The value gain

generally decreased from the most valuable to the least valuable species. However, the total value gains depend on the unit value gains and the volume yield for each species. The results suggest that more attention should be paid to valuable species, especially to where the potential gains are, during the bucking processes.

The system developed in this application adopted object-oriented programming (OOP) techniques with a graphical user interface. It provides online documentation and allows the user to access any part of the system while the optimization is performed. The system can be compiled for installation either on a handheld computer that can be used in the woods or on a PC located in a centralized log yard. The system presented here can be used as a training tool for students or loggers. The system could be applied to other species in other regions. However, modifications have to be made to species codes, grading rules, and log prices.

The input of grade zones currently required by the system depends on surface characteristics of a tree and the bucker's views, which affect the bucking accuracy of this program. Since some trees have irregular shapes or complex surfaces and internal defects, a more accurate grading system is needed to integrate these into the bucking program. Efforts should be made to estimate the

implementation costs of this bucking system and to further examine its economic efficiency for different tree species in different regions. Bucking a tree with complex surface conditions by using this system might not yield a satisfactory solution. If a new module or expert bucking system is added to the bucking program, it can further enhance and aid the system to generate the desired bucking patterns.

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