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Simulated Sawing of Squares: a Tool to Improve Wood Utilization

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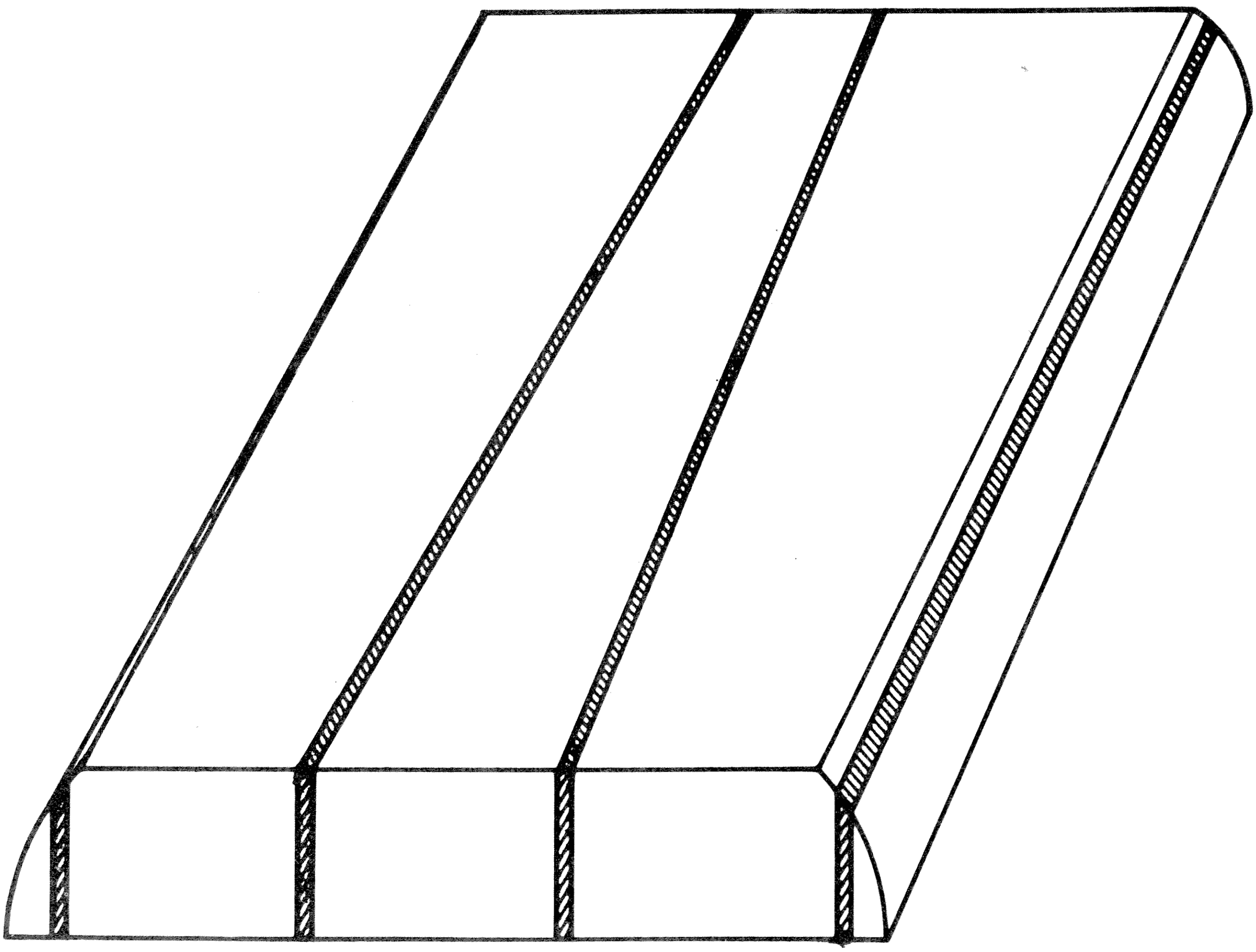

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Abstract

Manufacturers of turning squares have had difficulty finding the best combination of bolt and square sizes for producing squares most efficiently. A computer simulation technique has been developed for inexpensively determining the best combination of bolt and square size. Ranges of bolt diameters to achieve a stated level of yield are given. The manufacturer can choose which bolt sizes to use for sawing squares based on sawing method used, the range of bolt diameters available, and the size of square to be produced.

The computer program described in this publication is available on request with the understanding that the U.S. Department of Agriculture cannot assure its accuracy, completeness, reliability, or suitability for any other purpose than that reported. The recipient may not assert any proprietary rights thereto nor represent it to anyone as other than a Government-produced computer program. For cost information, please write: Northeastern Forest Experiment Station, Forestry Sciences Laboratory, P.O. Box 152, Princeton, West Virginia 24740.

Introduction

What sizes of bolts are best for producing hardwood turning squares? Does one sawing method produce significantly better yields of squares than another? Until now, these questions could not be answered completely because of the limited analytical techniques. Some manufacturers analyze potential yields by diagraming small-diameter end sections of bolts on paper and plotting squares and kerf to exact scale. But even with this method, manufacturers have difficulty finding the best combination of bolt size and sawing method for squares of different sizes.

We have developed a computer system to determine the yields that can be obtained from sawing bolts into squares of various sizes. The system calculates the amount of material recovered from a bolt. Bolt sizes and square sizes must be specified as input data to the computer. The yield can be calculated from any input combination of bolt and square dimensions. This paper describes how the computer calculates yields, and it compares two sawing methods for a number of bolt and turning-square size combinations.

General Procedure

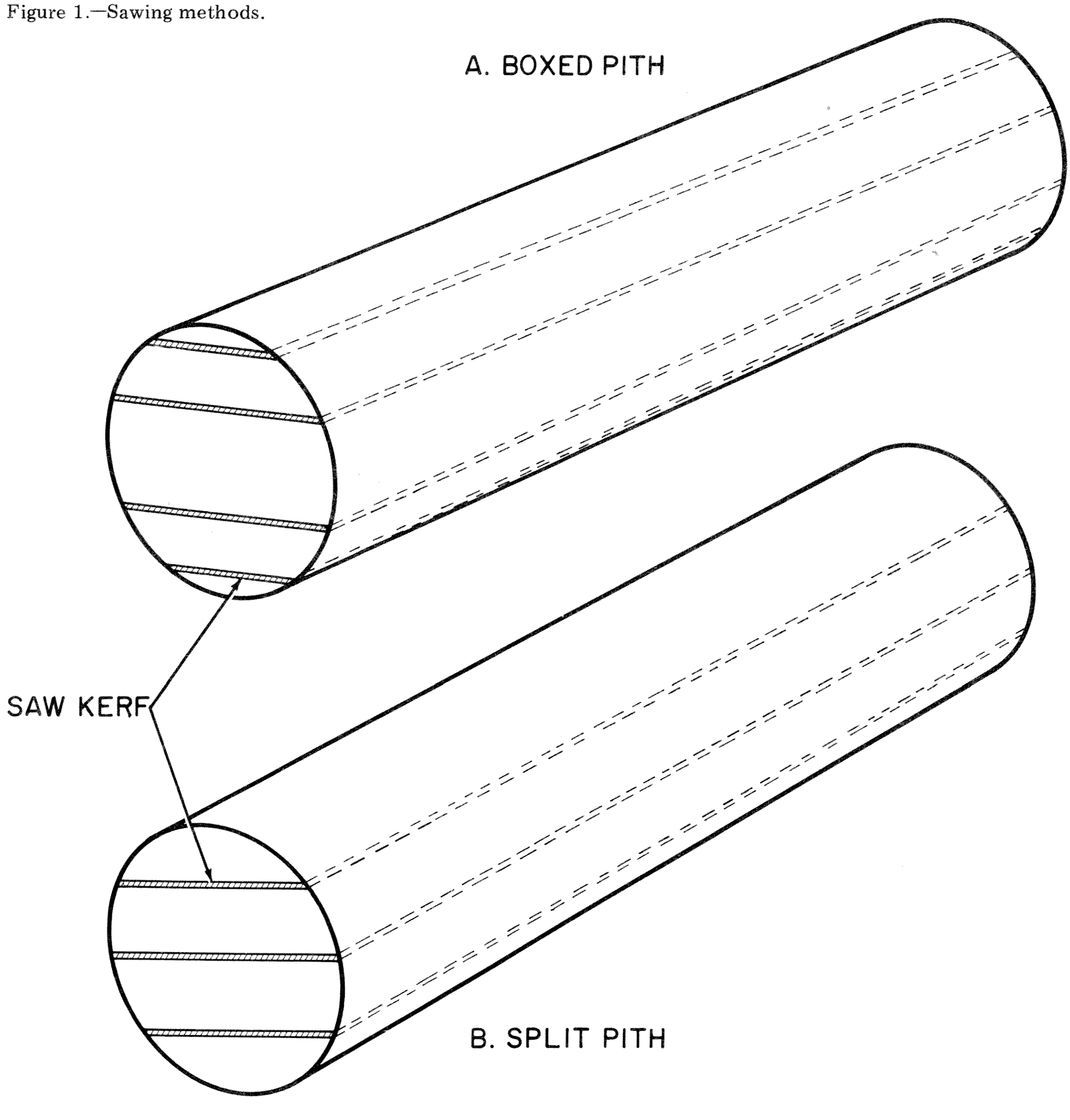
In developing the computer program, we made two assumptions which would not be true in actual sawing of bolts. These assumptions were made so that we could understand clearly the relationship between the number of squares produced and the changes in square and bolt sizes. First, we assumed that the bolts were perfectly clear truncated cones, 4 feet long with a large-end diameter 1/2 inch larger than the small end. Second, we did not consider defects because our main interest was to find how many squares of a specific size could be obtained from a bolt with a given small-end diameter. We considered such factors as bolt sawing patterns, cant sawing patterns, saw kerf, square size, and bolt diameter.

We also assumed that a turning square does not need four square corners, particularly if it is used to make a round. Thus, some wane was allowed. The wane was determined by calculating the size of a round that could be made from a given square. We calculated a width for each cant sawed from a bolt. Then we determined the maximum number of turning squares that could be sawed from the cant if some wane was allowed on the outside squares.

The computer was programed to consider a sequence of circles with diameters ranging from 5.6 to 35.5 inches in 0.1-inch increments. These diameters corresponded to the small-end diameters of the bolts to be sawed by simulation. In our analysis, small differences in bolt diameter are real and important. Bolt diameter limits the width of a cant that can be sawed from the bolt. It also directly affects the number of squares sawed from cants. We used 0.1-inch increments in bolt diameters so there would be no doubt where changes in yield occurred. Because hardwood squares manufacturers are probably not concerned with 0.1-inch variations in bolt diameters, the results were grouped into diameter classes. Circles with diameters from 5.6 to 6.5 inches were grouped into a 6.0-inch diameter class and those from 6.6 to 7.5 inches were grouped into a 7.0-inch class. Diameter classes were grouped the same way up to the maximum of 35.5 inches.

Two techniques for sawing bolts to squares were simulated: the boxed-pith method, in which a center cant containing the pith was sawed from the bolt (Fig. 1A), and the split-pith method, in which the bolt was sawed down the middle (Fig. 1B). In both cases, all of the bolts were sawed parallel to the pith. Outside slabs were resawed to cants if they were large enough to yield one or more squares.

Figure 1.—Sawing methods.



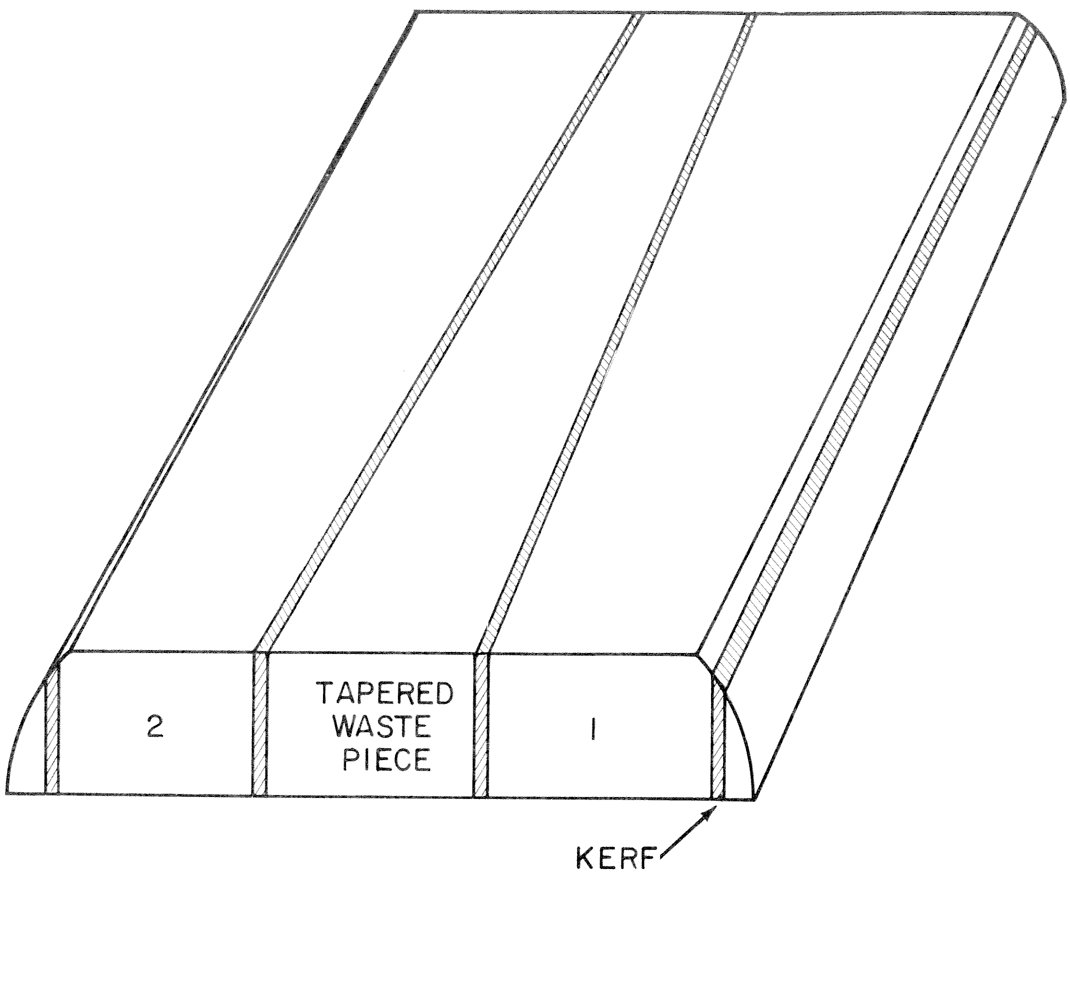
The simulation of sawing squares from cants was the same for both sawing methods. Squares were sawed from alternate sides of the cant and sawing was parallel to the bark. A tapered waste piece occurred in the inside of the cant (Fig. 2). Square sizes were simulated in 0.5-inch increments from 3.0 to 6.0 inches.

Saw kerfs were held constant for all runs with a headrig kerf allowance of 0.375 inch, a slab resaw kerf allowance of 0.3125 inch, and an edger kerf allowance of 0.1875 inch.

Results

Seven different sizes of turning squares ranging from 3 to 6 inches in 1/2-inch increments were evaluated. Because the results were consistent throughout, we chose to report only on the 3- and 6-inch square sizes since they represent the extremes tested. Data for each individual bolt diameter and square size are available from the Northeastern Forest Experiment Station, Forestry Sciences Laboratory, P.O. Box 152, Princeton, West Virginia 24740.

Figure 2.—Squares sawed from alternate sides of the cant.



Comparison of sawing methods

The boxed-pith method produced an initial center cant that had an effective width equal to the bolt's small-end diameter. The split-pith method initially produced two half-round sections from which cants could be resawed only if the sections were thick enough to produce one or more squares. The number and yield of 3- and 6-inch squares from each sawing method are given in Tables 1 and 2. These findings are summarized by bolt diameter class. Because the diameters were increased in 0.1-inch intervals, the number of squares given for each diameter class is the total number of squares sawed from the 10 bolts in that class. The volumetric yields are average yields calculated by considering the total bolt volume in a class and the volume of squares sawed in that class.

No sawing method was best for all sizes of squares or for all diameters of bolts. The total number and distribution of squares from each sawing method were not identical. However, they were too similar to show overall superiority of one method.

Table 1.—Estimated number of 3-inch squares and yield per bolt from each sawing method

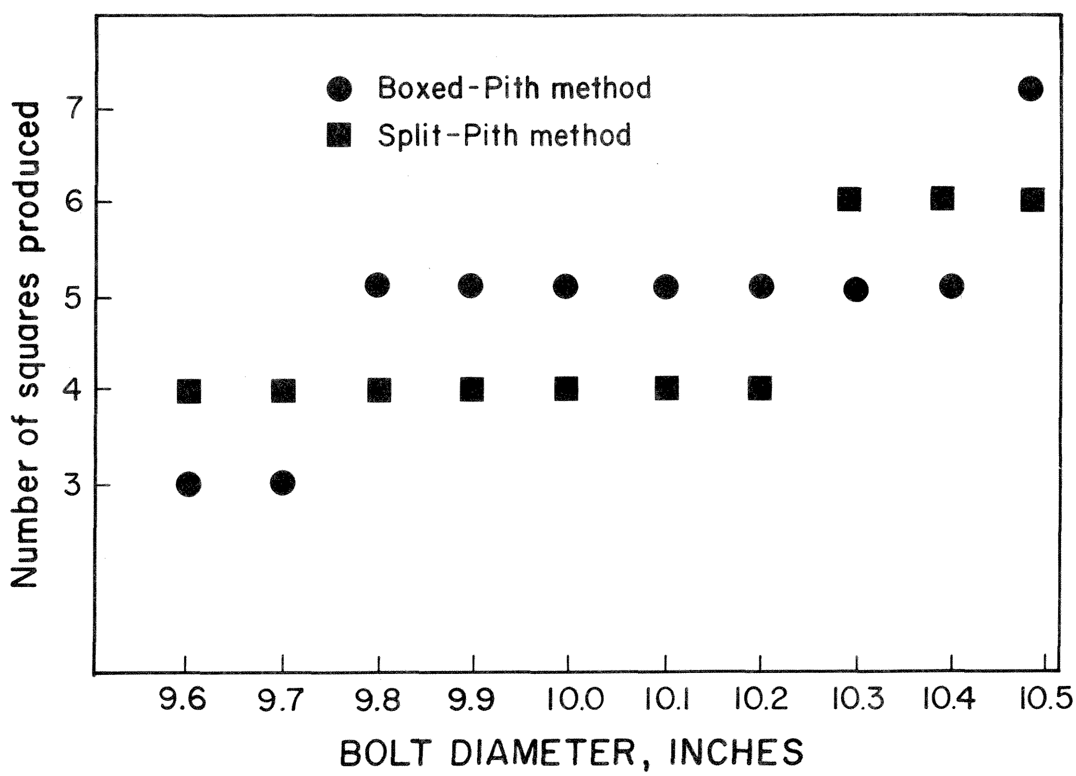
Bolt diameter class (inches)	Boxed pith		Split pith	
	Number of squares	Volumetric yield	Number of squares	Volumetric yield
		Percent		*Percent*
6	1.4	40.2	0.4	11.5
7	2.0	42.8	2.0	42.8
8	2.0	33.2	3.8	63.0
9	2.2	29.1	4.0	52.9
10	4.8	51.7	4.6	49.6
11	7.0	62.7	6.0	53.7
12	7.6	57.5	6.0	45.4
13	10.0	64.7	7.8	50.4
14	10.0	56.0	12.0	67.2
15	11.6	56.7	13.4	65.5
16	13.2	56.9	14.8	63.8
17	16.8	64.2	17.4	66.5
18	20.4	69.7	18.0	61.5
19	21.8	67.0	19.2	59.0
20	24.4	67.8	25.0	69.4
21	26.2	66.1	27.4	69.1
22	28.4	65.4	30.4	70.0
23	31.4	66.2	34.0	71.7
24	37.6	72.9	35.2	68.2
25	40.0	71.5	38.0	68.0
26	42.8	70.8	41.8	69.2
27	47.6	73.1	47.0	72.2
28	48.1	68.8	51.2	73.2
29	52.4	69.9	55.6	74.2
30	58.6	73.1	58.4	72.8
31	63.4	74.1	62.0	72.5
32	67.7	74.3	65.4	71.8
33	73.2	75.6	69.8	72.1
34	75.0	73.0	78.4	76.3
35	78.7	72.3	81.6	75.0

Table 2.—Estimated number of 6-inch squares and yield per bolt from each sawing method

Bolt diameter class (inches)	Boxed pith		Split pith	
	Number of squares	Volumetric yield	Number of squares	Volumetric yield
		Percent		*Percent*
6	0.6	69.0	0.0	00.0
7	1.0	85.7	0.0	00.0
8	1.0	66.0	0.0	00.0
9	1.0	52.9	0.0	00.0
10	1.0	43.1	0.0	00.0
11	1.0	35.8	0.0	00.0
12	1.4	42.3	0.4	12.1
13	2.0	51.7	2.0	51.7
14	2.0	44.8	2.0	44.8
15	2.0	39.1	3.4	66.5
16	2.0	34.4	4.0	68.9
17	2.0	30.6	4.0	61.2
18	2.2	30.1	4.0	54.7
19	4.6	56.5	4.0	49.2
20	5.8	64.4	5.2	57.8
21	7.0	70.7	6.0	60.6
22	7.0	64.5	6.0	55.2
23	7.0	59.0	6.0	50.6
24	8.6	66.7	6.0	46.5
25	10.0	71.5	7.0	50.1
26	10.0	66.2	10.8	71.5
27	10.0	61.4	12.0	73.7
28	10.0	57.2	12.0	68.6
29	12.0	64.0	13.8	73.6
30	12.0	59.9	14.0	69.8
31	13.2	61.7	14.0	65.4
32	15.8	69.4	16.0	70.2
33	17.0	70.2	18.0	74.3
34	19.0	74.0	18.0	70.1
35	21.0	77.2	18.0	66.2

Although the overall number and distribution of squares were not significantly different, the two methods seldom produced exactly the same number of squares in a given diameter class. These small differences between the two techniques are explained by the relationship between sawing method and bolt diameter. From the smallest usable diameters, the boxed-pith method will always yield a cant that can be sawed into squares. The split-pith method will not yield squares from the smaller diameters, particularly when large squares are produced. As the size of the bolt increases, a point is reached where the split-pith method yields two cants while the boxed-pith method is still yielding only one. The apparent advantage in number of squares produced thus alternates between methods as diameter increases. A more specific example of this relationship is shown in Figure 3. In this example, the advantage one method has over the other, in terms of number of squares produced, alternates four times within the bolt diameter class. As a result, the boxed-pith method produced 48 squares while the split-pith method produced 46 squares. The same number of squares is seldom produced, but the differences are not significant.

Figure 3.—Comparison of the number of 3-inch squares produced within 10-inch diameter class.



Effective squares production

Manufacturers are concerned with getting the greatest amount of usable material out of the raw material input. We have used the number of squares produced to compare sawing methods, but it is not a complete measure of the effectiveness of squares production because it does not define how much usable material was recovered from the total bolt volume. In our analysis, volumetric yield provided the best measure of how much material was recovered in sawing squares from bolts. Expressed as a percentage, this yield was calculated as follows:

$$\text{Volumetric yield} = \frac{100 \times \text{No. of squares} \times \text{Volume of each square}}{\text{Volume of bolt(s)}}$$

In this equation, the number of squares produced directly affects volumetric yield. Bolt diameter, used in calculating volume of bolts, also affects yield although inversely if the number of squares remains the same. As shown in Tables 1 and 2, the number of squares produced did not increase with every 0.1-inch increase in bolt diameter. Thus, volumetric yield decreases when increases in diameter do not produce additional squares.

It would be ideal if a manufacturer could use bolts in the diameter class that had the highest yield of a specific square size. For example, consider the volumetric yields for 3-inch squares shown in Table 1. The highest yield (75.63 percent) from boxed-pith sawing is in the 33-inch diameter class. For split-pith sawing, the highest yield (76.35 percent) is in the 34-inch diameter class. Thus, a manufacturer should produce 3-inch squares by split-pith sawing of bolts in the 34-inch diameter class in order to maximize his volumetric yield.

However, maximizing yields by using a specific bolt size for each square size normally is not possible. An overall lower level of yield must result if the bolts available are only in a few specific diameter classes as typically would be the case. Computer analysis has allowed us to specify ranges of bolt diameters that will insure yields at or above some desired percentage of the total bolt volume. The ranges are defined by specifying a lower limit for bolt diameters depending on the size of square desired. If bolts with diameters larger than this lower limit are sawed, yields will be at or above the desired percentage. Such lower limits of bolt diameters were defined for all square sizes when the boxed-pith sawing method was used. If 50 or 60 percent is the smallest acceptable yield, the lower limits of the range of bolt diameters relate to the square sizes as follows:

Boxed-pith sawing for 50 or 60 percent yield, in inches

Square size (inches)	*Diameter class lower limit for 50% yield*	*Diameter class lower limit for 60% yield*
3.0	10	16
3.5	11	19
4.0	13	21
4.5	14	24
5.0	16	26
5.5	17	29
6.0	19	31

These relationships can be expressed in the following form:

For at least a 50 percent yield:

Lower limit of bolt diameter = 0.8 + 3 x square size required

For at least a 60 percent yield:

Lower limit of bolt diameter = 1.40 + 5.0 x square size required

The split-pith technique can also be used where some specified level of yield will satisfy a manufacturer's requirements. In this case, the lower limits of the bolt diameter range relate to the square sizes as follows:

Split-pith sawing for 50 or 60 percent yield, in inches

Square size (inches)	*Diameter class lower limit for 50% yield*	*Diameter class lower limit for 60% yield*
3.0	13	14
3.5	15	16
4.0	17	18
4.5	19	20
5.0	21	22
5.5	23	24
6.0	25	26

These relationships may be expressed in the following form:

For at least a 50 percent yield:

Diameter class lower limit = 1. + 4 x square size required

For at least a 60 percent yield:

Diameter class lower limit = 2. + 4 x square size required

Conclusions

To decide what bolt size to use for sawing squares you must know what square sizes are desired; what range of bolt diameters is available; and if all diameters are available, what level of yield is acceptable in producing the squares. With these factors, predictions of the yield from any distribution of bolt sizes can be generated. The program we have developed is flexible, and a manufacturer can include as program input data the range and distribution of bolt diameters he has available. In addition, squares of different sizes can be specified for production from each bolt. The program does not automatically calculate the optimal combination of bolt and square size. But, by varying the combinations of desired square sizes and running these combinations against the distribution of available bolt diameters, a manufacturer can determine quickly which combination will result in the highest yield.

Certain levels of yield are attainable by choosing proper bolt sizes for a given square size. Remember that the natural variability of the wood raw material was not considered: each bolt was considered as a perfect truncated cone containing no defects. Real bolts contain defects and will have lower yields than those reported in this paper. This, however, does not affect the use of these findings as a general guide for bolt and sawing selection.

Comparison of the two sawing techniques shows that, with certain qualifications, either sawing method is suitable for producing an acceptable squares yield. The location of defects in real bolts will influence the selection of a sawing method more than any variation in yield between the two methods. Inclusion of the pith and associated heart knots in a single waste piece is consistent with current industry practices, and this precludes extensive use of the split-pith method by the squares industry. Comparison of these sawing methods was therefore academic. We had assumed that the yields from the two techniques would be substantially different. The study results do not support that assumption.

The influence of the raw material resource on squares yield is not limited to defects in real bolts. One-half of the hardwood resource in the eastern United States is in logs that are 10 inches or smaller in diameter. Thus, the distribution of bolt sizes available to squares manufacturers is limited compared to the distribution of bolts used in this paper. Using the equations relating square size and bolt diameter, the squares manufacturer can determine whether an acceptable yield can be achieved within the range of available bolt sizes.

The techniques outlined provide an inexpensive means of determining the best combination of bolt size and sawing method of producing squares more efficiently. Minimum acceptable levels of yield can be achieved over a wide range of bolt sizes. Ranges of bolt diameters to achieve a stated level of yield are given for both sawing techniques. Specific bolt sizes have been found that maximize the yield for a particular square size. The choice is up to the manufacturer, depending on the sawing method used, the range of bolt diameters available, and the size of square to be produced.

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- Amherst, Massachusetts, in cooperation with the University of Massachusetts.
- Beltsville, Maryland.
- Berea, Kentucky, in cooperation with Berea College.
- Burlington, Vermont, in cooperation with the University of Vermont.
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