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Converting among Log Scaling Methods

Scribner, International, and Doyle versus Cubic

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ABSTRACT

Sawlogs in the United States, whether scaled on the ground or cruised on the stump, have traditionally been measured in terms of their lumber yield. The three commonly used measurement rules generally underestimate true recoveries. Moreover, they do so inconsistently, complicating the comparisons of volumes obtained by different board foot rules as well as by the cubic rules used internationally. In particular, for smaller log diameters, the undercount of board foot volume by US log scales can rise sharply. As sizes available to sawmills have declined, the ratios between scaled and actual volumes have changed. Thus, the factors used to convert volumes from one system to another have become outdated. A transition to cubic would improve domestic log market transparency by reducing the worst inequities of board foot scales and making regional comparisons easier, and would create a level playing field internationally.

Keywords: conversion factors; inventory; marketing

Accurately measuring logs for their potential yield of salable products has challenged generations of foresters. Yet sizing up irregular, roughly round and tapered logs for their potential to yield standardized rectangular lumber was necessary to estimate their fair value. Log scales in North America were developed in the 19th century, when logs tended to come from old-growth trees of large girth, and residues from milling them for lumber had little value. Consequently, rules measured logs in terms of their lumber yield; three such rules are still in common use. By contrast, in much of the rest of the world, logs are measured for their total cubic volume. Comparing volumes and values with these different approaches poses a challenge, and changes in the resource itself can affect the factors used to convert values.

Log Scales

Of the many log scales developed, the Scribner rule remains the most widely used. Volumes are based on the number of 1-inch-thick boards, spaced ¼ in. apart, that can fit into a circle defined by the inside bark diameter of a log's small end (hereafter referred to as diameter). By summing the widths (in inches) of each board, dividing by 12 and multiplying by the length (in feet), an estimate of the board foot yield from within a log's scaling cylinder (the area of the small end times its length) is obtained. It is immediately apparent,

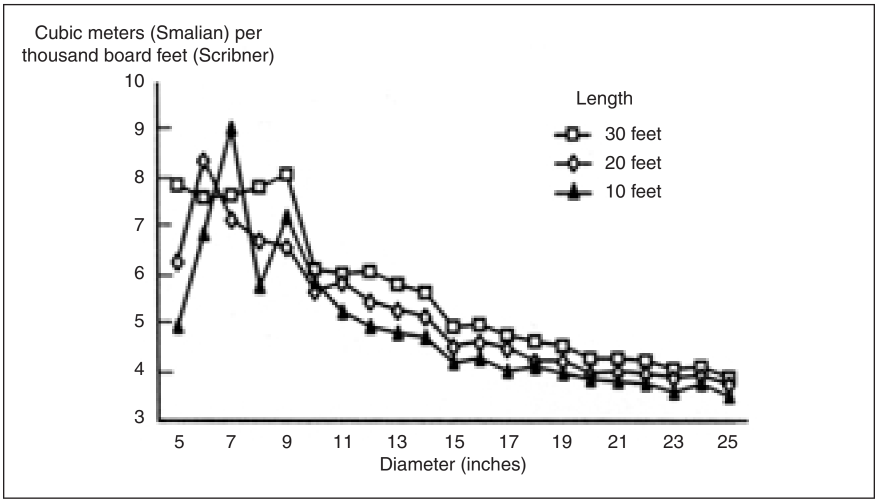

Figure 1. **Effect of changing log diameter at three log lengths on cubic volume to board foot conversion (no defects, no trim, taper 0.125 inch/foot).**

however, that, because logs are tapered, the rule misses volumes outside the scaling cylinder. Thus, the longer and more tapered a log is (up to defined limits allowed by the rule), the more full-width, although shorter, lumber is ignored. For a given length and taper, the omission becomes proportionally greater as log diameter declines. Consequently, ratios of actually recoverable board feet or total cubic foot volumes to Scribner board feet generally increase as log dimensions get shorter and narrower, albeit irregularly because of the stepwise gradations of the Decimal C version of the rule (Cahill 1984).

A second board foot rule remaining in contemporary use is the International ¼ inch. It also assumes that logs are cylinders based on the lengths and diameters from which 1-inch boards are extracted. But whereas the Scribner can be applied to lengths of up to 40 feet without taper adjustment, the International ¼ inch estimates volumes based on summing partitioned 4-foot-long log segments with the diameter of each obtained from the scaling diameter and an assumed taper of 0.125 inch per foot. This provision reduces taper-related volume omissions, and the rule is consequently more accurate. However, even its volume estimates of smaller logs drop sharply relative to total cubic volumes or lumber recoveries.

A related formula rule, the Doyle, is considered the least accurate at the small-to-medium range of diameters because of a deduction for waste that, being invariant over all diameters, becomes disproportionately large in small logs.

Unlike those board foot lumber rules, firmwood cubic scales measure total utilizable fiber. Like their board foot counterparts, cubic rules assume that logs are cylinders but with a cross section that is an average of diameters at several points, thus taking greater account of taper (Bell 2002). Several alternative formulas exist, based on the assumed shape of the log (conic, neiloid, paraboloid). Among them, the Newton formula is considered the most accurate, but because it requires three diameter measurements, including one at the not easily accessible middle, it is not used in general practice. Instead, the Smalian formula, requiring measurements at only the two ends, has been most widely applied in North America.

Cubic rules are regarded as superior to board foot measurements because they generally give more consistent estimates of log volumes across the range of diameters and lengths (Orchard 1953; Garland 1984). This reduces possible bucking strategies, such as segmenting logs as long as possible to minimize scale volume for stumpage payment or "manufacturing" volume by cutting logs short to boost payments to loggers (Garland 1984; Briggs 1994). Being more accurate, cubic measurements are better correlated with weight, facilitating conversions to volume when logs are weight scaled (DeLong and Skillicorn 1984).

The shortcomings of board foot scales posed relatively few practical problems as long as timber was large, with diameters in a range where the tendency toward undercounting recovery was relatively constant (Bolsinger and Oswald 1984). But in recent decades, the log supply in the United States has been changing (Briggs 1994); smaller second-growth trees now constitute most of the supply (Spelter 2002). At the same time, the residues that once represented a waste stream have acquired value as furnish for pulp and composite panels (Combes 1984). Thus, accounting for the full value of logs meant imputing the value of the missing volumes into the fraction of the log that the rule was designed to calculate, which itself was shrinking with log sizes.

Many timberland owners therefore switched to cubic measurements (Johnston 1993). Yet the use of board foot scales in the United States for log transactions remains. As estimates for the same log differ by scale and measurement convention, comparing regional wood costs is necessarily complex and imprecise. These difficulties carry over into comparisons with cubic values in other countries. With the volumes of imported wood products rising, inaccurate comparisons with foreign log costs can put US producers at a disadvantage. This was illustrated in the lumber trade dispute with Canada; a North American Free Trade Agreement panel concluded that "by basing its price comparison on prices in the U.S., adjusted inadequately to account for differences in market conditions, Commerce has construed the statute in a manner contrary to law" (Pinkus et al. 2003).

Thus, it is timely to review the intricacies of US log measurement practices and conversions between them, with particular focus on those that relate board foot product rules to total volume cubic rules.

Cubic versus Board Foot Volume

Calculated ratios between cubic and board foot volumes for any log length and diameter combination can be derived from tables found in scaling handbooks (e.g., Northwest Log Rules Advisory Group 1982). As the relationships of the various board foot rules to cubic follow similar trends, I illustrate these using values obtained from the Scribner rule (Decimal C version). For comparisons with cubic volumes, I use values derived from the Smalian formula, based on a taper of 0.125 inch per foot of length.

Effect of diameter and length. Figure 1 illustrates, for three log lengths, the effect of changing diameters on the ratio of cubic meters (Smalian) to 1,000 board feet (Scribner, Decimal C). The graph illustrates three complicating factors affecting conversions between the systems: (1) their often erratic changes, especially at smaller diameters, which follow from the stepwise increases in tabulated board foot volumes; (2) the general increase in the ratios as diameters decrease, stemming from the proportionately growing effect of taper-related volume omissions; and (3) the general tendency for the ratios to be bigger for longer lengths, again because of taper. These effects are the inverse of board foot–cubic volume relationships, which may be more familiar to some.

Effect of taper. Figure 2 illustrates the effect of taper on conversions. Its influence is greatest at smaller diameters and longer lengths. This is important in the contemporary context because of the increasing use of smaller-diameter logs in sawmilling. Taper for most traditional sawtimber grade logs is in the range of 0.1 to 0.125 inch per foot of length. The upper portions of trees, however, are more tapered (Dell et al. 1979), and cubic–board foot ratios can be significantly boosted by tapers greater than those implied in conversion ratios developed for larger sawlogs from the lower boles.

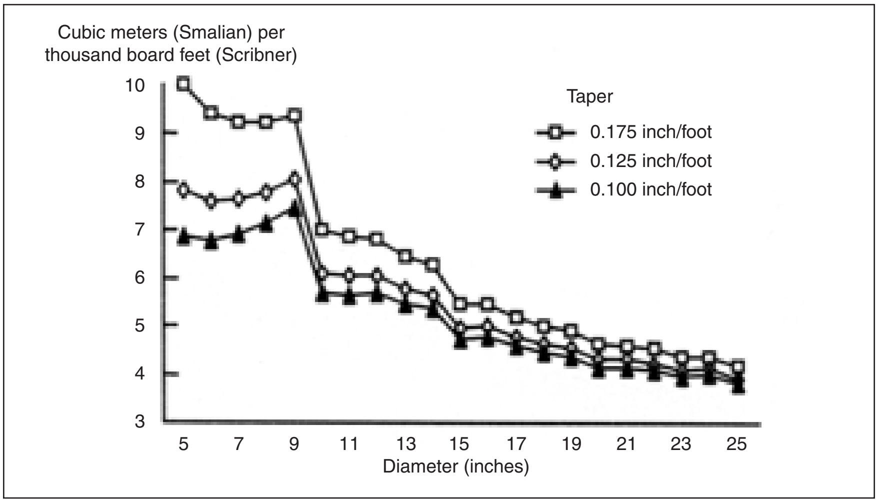

Figure 2. **Effect of log diameter and taper on cubic volume to board foot conversion (no defects, no trim, length 30 feet).**

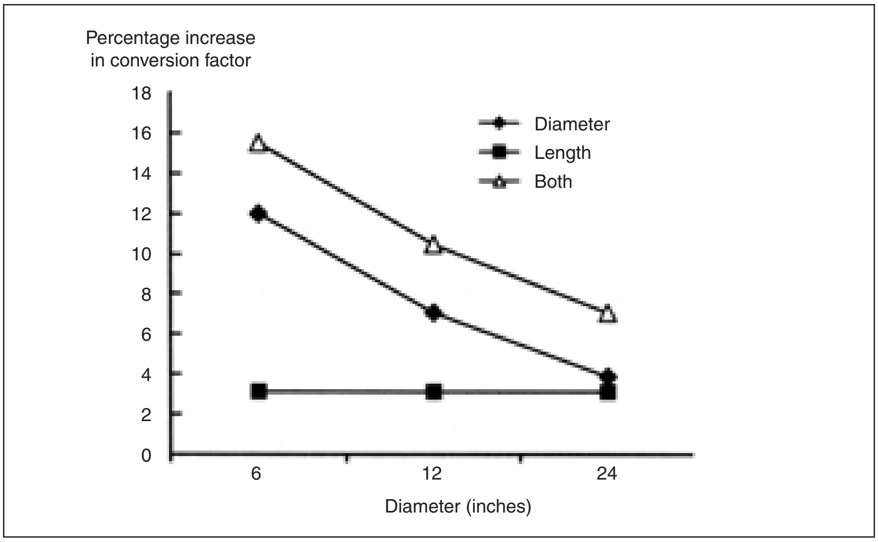

Figure 3. **Effect of ½-inch diameter and 1-foot length differences on cubic volume to board foot conversion (no defects, no trim, length 32 feet, taper 0.125 inch/foot).**

Effect of measurement conventions. When board foot to cubic volume conversions are made, it is often assumed that the diameter and length measurements are identical for each log scaling system. This is not universally true. In Canada, for example, fractional diameter measurements are rounded up or down, which contrasts with the US Pacific Coast practice of truncating fractional scaling diameters. Consequently, the same logs measured by the two systems are, on average, recorded as being about ½ in. smaller under the westside Scribner rule (Jendro et al. 2002). Likewise, Canadian log lengths include the trim; in Scribner, trim allowances are excluded. Such measurement differences extend cubic lengths for the same log by an average of about a foot, depending on length. *Figure 3* illustrates the effect of ½-inch width and 1-foot length differences (for 32-foot logs) on conversion factors for three diameters. Again, the discrepancy is magnified at smaller diameters.

Effect of defect deduction conventions. Defects can be classified as sound (shake, ring splits, checks, excessive knots, crook, break, butt flare) and unsound (rot, decay, scar). Although sound defects affect lumber yields, they tend not to reduce fiber yield for pulp. Accordingly, cubic rules often allow fewer deductions for sound wood defects than board foot log rules. Forest Service studies conducted on the basis of cubic scaling practices in the early 1980s found increased gross-to-net conversion factor ratios of less than 1 percent for small-diameter logs to more than 10 percent for large-diameter logs, where defects are more prevalent (Cahill 1984).

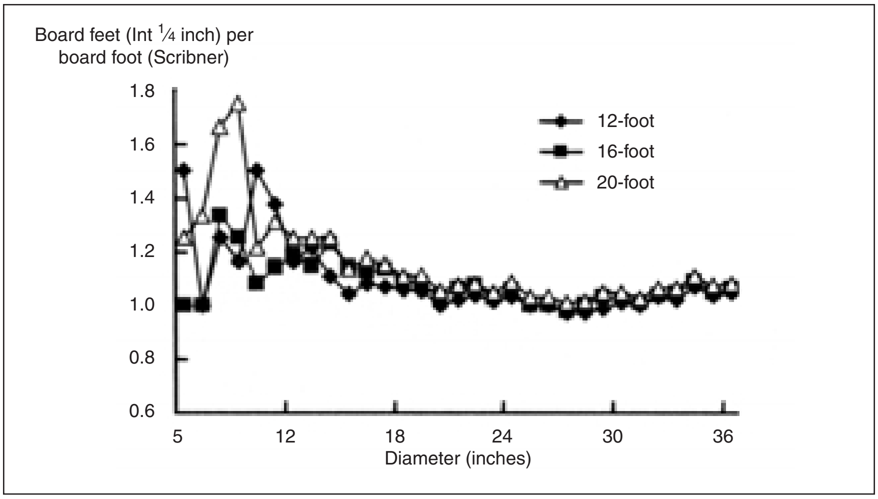

Figure 4. **Effect of changing log diameter and length on International 1/4-inch board foot to Scribner board foot conversion (no defects, taper 0.125 inch/foot).**

Board Foot versus Board Foot

Board foot scales take partial account of taper only when logs exceed specified lengths and then only in a stepwise manner. This omits varying amounts of potential product. They also assume different losses for slabs, kerf, and shrinkage. Thus, comparing board foot volumes measured by different rules is also problematic and varies with log diameter, length, and measurement conventions. The Doyle rule predominates in the US South, while the International ¼ inch finds use in the North. In the West, the Scribner rule is used, but with differences in regional measurement practices, including permitted lengths twice as long on the coast as in the interior. Many of the same factors that affect cubic–board foot volume relationships also influence board foot to board foot equivalents, which can be summarized as follows:

At small diameters, all rules produce the greatest undercounts, with the Doyle being worst, followed by Scribner and then the International. Consequently, the highest ratios of Scribner or International to Doyle occur there. As deductions for waste in Doyle are constant, their importance wanes with increasing diameter, and Doyle estimates surpass the others at varying points. Knowledgeable sellers thus have an incentive to scale sales in terms of International or Scribner at smaller tree diameters and in Doyle for larger ones. Scribner generally gives lower estimates than the International, although they tend to converge as diameters rise.

Except at small diameters, the Doyle to Scribner ratio is not much affected by log length. The ratio of Doyle to International, however, tends to be inversely related to length. The Scribner to International is similarly affected, but the stepwise increases in Scribner Decimal C values often confound that tendency at smaller diameters.

The differences among the scales become relatively minor at larger diameters. But large percentage differences occur at small diameters—the kind of sawlogs increasingly used by many contemporary softwood dimension and stud mills.

Figure 4 illustrates the ratios between International ¼ inch and Scribner volumes for three log lengths.

Conversion Factors

For trade and price reporting, policy assessments, or general statistical presentations, organizations need to convert between various US measures and metric equivalents. *Table 1* contrasts two types of published conversion factors: standard or general factors, applied to log populations at large without specific reference to size, and particular factors, in which the population diameter attribute is specified.

A standard factor of 4.53 m^3 for converting thousand board feet to cubic meters is found in many sources (e.g., FAO 1998). This factor was developed by a committee of experts organized by the UN Food and Agriculture Organization after World War II to harmonize reporting of international data. They determined that the factor was fairly representative of the size of saw and veneer logs typical for that time, and it has been used ever since to translate log flows to cubic (e.g., Howard 2001). However, this factor implies a large log diameter, as indicated by comparisons with conversion factors derived from both empirical and tabulated data *(table 1, columns 3, 4, and 5).* Such sizes are unlikely to be representative of logs today.

A focal reference for forest products conversion factors is the work of Binek (1973). The factors for logs in this source have been the cause of some confusion because the author attempted to replicate in cubic the intent of the board foot rules to define log volumes in terms of the small-end diameter-based cylinder only. However, he did not explicitly state this, and although the factors significantly understate the total cubic content of logs on which actual transactions are based, over the years they gained wide circulation (e.g., FAS 1990; Northeastern Loggers Association 2000).

Another source for conversion factors is the Random Lengths organization, publishers of widely read market reports (unpub. data by D. Bartel). Besides the standard factor, they have also circulated a set of factors for various-diameter logs of nominal 32-foot length. Especially at the low end of the diameter range, these estimates undershoot both empirical factors derived from field measurements and theoretical factors from published tables.

Conversion factors derived from raw tabulated values have no built-in allowances for defects. But defect deductions are lower in cubic than in board scaling, as evidenced by two sets of empirical equations, one gross and the other net of defects *(table 1, columns 3 and 4),* derived from a population of dual-scaled logs (Cahill 1984). The equations relate conversion factors to diameter and provide one basis for calculating contemporary conversion factors if the average diameter of a log population can be deter-

Table 1. Theoretical and empirical board foot to cubic volume conversion factors compared with some published estimates.

	Conversion factor (m^3/thousand board feet)				
	Binek (1973)	Random lengths[a]	Empirical gross[b]	Empirical net[c]	Theoretical gross[d]
Scribner					
Standard	4.53	4.53	—	—	—
Log diameter:					
8 inches	—	—	8.30	8.44	7.34
12 inches	—	5.6	6.27	6.51	6.18
16 inches	—	4.7	5.24	5.51	5.07
20 inches	—	4.3	4.70	4.99	4.31
24 inches	—	4.1	4.39	4.70	4.15
15 inches	3.90[e]	—	4.66[f]	4.99[f]	4.54[g]
International ¼ inch					
Log diameter:					
15 inches	3.48[e]	—	—	—	3.97[g]

[a] Unpublished data (obtainable from the author); except for standard, log length 33 feet, taper 0.125 inch/foot.
[b] Cahill (1984); based on westside Scribner rule with log lengths up to 40 feet, no defects.
[c] Cahill (1984); same as empirical gross except allowances taken for defects.
[d] No defects or allowance for trim, average taper 0.125 inch/foot, log length 32 feet.
[e] Based on log length 16 feet and no taper.
[f] Based on eastside Scribner rule with log lengths up to 20 feet.
[g] Based on log length 16 feet.

Table 2. Published conversion factors for three US log scales.

Source	1 mbf Doyle =	1 mbf Doyle =	1 mbf Scribner =
About, Inc. (2003)	1.39 mbf Scribner	1.59 mbf Int ¼ inch	1.14 mbf Int ¼ inch
University of Georgia (2002)	1.33 mbf Scribner	1.60 mbf Int ¼ inch	1.20 mbf Int ¼ inch
Texas Forest Service (2003)	1.28 mbf Scribner	1.35 mbf Int ¼ inch	1.05 mbf Int ¼ inch

mbf = thousand board feet

mined. Conversion accuracy can be improved by using more universal formulas that incorporate length and taper as additional variables (Verrill et al. 2004).

Conversions also need to be made between values and volumes denominated in US log scales. *Table 2* contains some published board foot to board foot conversion factors that are illustrative of the variability. These factors, like those for cubic, vary with log diameter and thus make different implicit assumptions about a log population's size that may or may not be accurate.

Contemporary Conversion Factors

With the change in US timber resource toward a smaller, second-growth resource, the traditional standard conversion factor to cubic appears to be outdated. One recent study for Washington State indicates the possible problem (Spelter 2002). Average log diameters from 1970 through 1998 were estimated from data on log characteristics. Inserting these diameters into the Cahill empirical equations (net form) yielded conversion factors over time *(table 3, p. 38)*. These indicated increases from around 4.7 m^3/thousand board feet in the 1970s to more than 6.7 (coast) and 5.9 (interior) m^3/thousand board feet by 1998.

The 1998 data points in *table 3* can be checked by comparing the derived diameters with survey data (Larsen 2002). Direct validation is impossible because the survey data were aggregated into broad size categories *(table 4, p. 38)*. However, calculating the possible range in the survey data can allow an indirect comparison. By taking the extreme value of each cell and calculating the highest and lowest possible values for the population, we see that the 1998 estimates fell within these ranges and very close to the medians for both regions.

Discussion

Three points that emerge from this review of log scale relationships are that log scaling, as traditionally practiced in the United States, is imprecise, inconsistent, and biased. As an expression of log value, the board foot scales, founded on archaic assumptions about how a log is processed into lumber, offer a poor approximation of reality. Inconsistencies show up in a multitude of conflicting conversion factors based on the assumption of processing old-growth timber. And if the goal of a measurement system is to create a level playing field between buyers and sellers, the board foot scales fail in varying degrees, in most instances favoring the buyer.

Table 3. Estimated sawlog sizes and conversion factors from Spelter (2002).

Year	Diameter[a] (inches)		Conversion factor[b] (m^3/thousand board feet)	
	Coast	Interior	Coast	Interior
1970	22.1	16.2	4.81	4.84
1972	22.6	18.1	4.78	4.64
1974	21.8	18.0	4.83	4.66
1976	21.5	17.3	4.86	4.73
1978	20.2	17.8	4.97	4.67
1980	21.2	16.9	4.88	4.77
1982	18.1	15.3	5.20	4.96
1984	17.8	15.9	5.23	4.88
1986	17.9	16.0	5.22	4.86
1988	17.6	16.0	5.26	4.87
1990	15.6	12.6	5.58	5.35
1992	14.2	13.2	5.87	5.25
1996	11.8	11.1	6.60	5.64
1998	11.4	10.0	6.74	5.93

[a] *See Spelter (2002) for derivation of log diameters.*
[b] *Conversion factors obtained by inserting diameters into net-based formulas derived by Cahill (1984).*
NOTE: Survey was not conducted in 1994, hence no data are available for that year.

Table 4. Sawlog distribution by diameter class from Larsen (2002).

	Sawlogs (million board feet)				Sawlog diameter (inches)*		
	<5 in.	5–10 in.	11–20 in.	>20 in.	High	Low	Median
Coastal	124	909	812	137	14.1	8.4	11.2
Interior	22	200	173	39	13.7	6.9	10.3

** High and low values were made by taking the extreme value of each cell (3, 5, 11, and 21 for the lows; 4, 10, 20, and 29 for the highs), converting board feet to cubic volume using the Cahill (1984) conversion factor for that diameter, and weighting diameter values by those volumes.*

At a fundamental level, the issues raised here go beyond the intricacies of conversion factors to the basis of the measurement system itself. The inadequacies of traditional log scaling were recognized by a previous generation of foresters whose recommended solution was a change to less variable cubic scaling (Rapraeger 1950; Orchard 1953). Momentum toward conversion to cubic gathered in the 1970s, but that drive stalled and is indeed regressing, as attested to by recent moves to have western Forest Service timber sales revert to Scribner.

Although cubic scaling based on the metric system is almost universally practiced in forestry, a switch to cubic in the United States would not guarantee harmony. Many versions of cubic scales exist, some of which are as inscrutable as the most opaque board foot scale. However, a transition to cubic would place the United States on the same theoretical footing and serve as a basis for further harmonization. At the least, such a step would improve domestic log market transparency by reducing the worst inequities of board foot scales and making regional comparisons easier.

If conversion to cubic is too ambitious, then other means to achieve better scaling might be worth considering. Adoption of a national board foot scale, such as the International ¼ inch instead of the current three systems, would achieve consistency among regions. The International ¼ inch would be the most accurate rule to adopt. Alternatively, redefining the diameter in rules such as the Scribner or Doyle to some average of both ends would reduce biases stemming from omission of taper. A third level of improvement might be to eliminate the Decimal C convention in favor of using actual values and to update board foot yield estimates based on current parameters for kerf, waste, and lumber sizes (e.g., nominal 2-inch dimension instead of full 1-inch boards).

However, as long as residual use of board foot measures continues, there remains a need for conversion factors. In any conversion exercise, factors should be tailored to the board foot rule(s) involved. Ideally, scale data on relative diameters, lengths, tapers, and defects should be the basis for conversions, but such data are seldom reported and not easily obtained. In their absence, sampling should be used to narrow the probable ranges of these variables, the most important of which is diameter. Then, further adjustments should be made for any differences in measurement conventions. The analytical rigor of conversion attempts should be evaluated by the degree to which they meet the above criteria.

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