A STATISTICAL APPROACH TO SELECTING GREEN DIMENSIONS FOR LUMBER TO BE DRIED

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Introduction

The need for relating rough green lumber dimensions to dry surfaced dimensions is readily apparent. Customarily, the actual relationship has been established by experience and judgement but this may not be the most efficient approach. Improving the method of selecting sawn sizes assumes increased importance as the cost of logs placed on the sawmill carriage increases and, at the same time, with improvement in performance of sawmill equipment, the feasibility of instituting closer control of surfacing allowance improves. The purpose of this paper is to describe how probabilities and statistics may be used to advantage in doing this, using the example of a firm that was changing its operation by adding a drying facility.

One of the certainties of the world is variation, variation in size, shape, color, and other characteristics. It is as true of lumber as it is of oranges and automobiles, axles and antelopes. We all recognize this when we describe something by its average or $\bar{X}$, such as weight or miles per gallon. The average does not tell us enough, however, when we are concerned with the control of a manufacturing process. We need some measure of the spread or range in values as well. The most useful measure of variation is a statistic called the standard deviation or s. For a sample from a normal population, the average $\pm$ 1s includes about two thirds of the individuals, $\pm$ 2s includes more than 95% and $\pm$ 3s includes 99.7%. If we measure the sizes of a randomly selected sample of lumber we can calculate both the average size and the standard deviation. The purpose of this paper is to show how information about the average and standard deviation can be used to set sawing limits so that maximum recovery is obtained for lumber that is to be dried.

The amount of variation in lumber sizes is determined by the basic accuracy of the mill equipment, the quality of its maintenance and use, as well as the material itself. The average size must be increased as variation increases. A number of workers (Bethel, et al., 1951; Jackson, et al., 1965; Laudenschlager, 1951) have emphasized the importance of variation in their work on statistical methods for lumber size quality control. They have shown that statistical quality control techniques, specifically the use of Shewhart control charts (Grant, 1952) are appropriate for lumber manufacturing processes. Such charts can indicate when a process is out of control even before this fact becomes readily apparent and, therefore, before serious losses have been incurred.

Sources of Variation

Knowledge of the variation in rough green size is all that is required in order to select an optimum target or average rough size for lumber to be surfaced green. Since boards vary in shrinkage rate, the variability added on by the drying process must be included with the rough green size variation when the boards are to be dried before surfacing. If we assume that there is no variation due to the planer, then the only other factor need is an estimate of surface roughness. This is generally called the planing allowance. The required average rough green size may then be computed in the following form:

$$\bar{X}_{\text{Rough green}} = \text{Surfaced size} + \text{planing allowance} + \text{shrinkage factor} + \text{variability factor} \quad (1)$$

The first two terms are easily obtained although at some future point in the refinement of such techniques the planing allowance might be subjected to some statistical study. The third and fourth terms are more difficult to obtain, and each is established by somewhat different means.

Surfaced size - This is given in some set of specifications, frequently the American Lumber Standards, but the buyer or some other party may specify another size according to intended use.

Planing allowance - General present practice is to include an estimate of the variability factor with the planing allowance. In this paper, however, planing allowance is limited to only that amount of material necessary to remove surface variations. The justification and importance of this distinction is that the operator should be aware of these factors as separate effects. For example, there are saws available which produce a surface that is smooth enough for most uses. Lumber produced with these saws probably would still require planing but only because of the variability in size resulting from the sawing and drying processes.

Shrinkage factor - Shrinkage data are readily available for most species. The values given, however, are determined from small specimens of defect-free material, carefully selected and machined so that the growth rings are parallel and perpendicular to the faces. They are carefully and slowly dried so that the drying stresses and creep which often accompany the shrinkage of boards are avoided. Thickness and width measurements made on small clear specimens will result in true species values for tangential and radial shrinkage. Unfortunately, the shrinkage data just described are of limited usefulness in lumber manufacture since lumber is not defect free, perfectly quarter - or flat-sawn and dried in a stress-free condition. In addition, information on variation in shrinkage generally is not provided.

The shrinkage of both small specimens and boards for all practical purposes is directly related to moisture content and when shrinkage is plotted against moisture content a reasonably straight line graph is obtained. If moisture content were the only factor affecting shrinkage one would develop an equation which would appear as:

$$\text{shrinkage} = a + b\ (\text{moisture content}) \qquad (2)$$

where: a and b are experimentally determined constants

Since other factors also affect shrinkage, they must be included in the equation. In the study which we will use as an example in this paper, such an equation became:

$$\begin{aligned}\text{shrinkage} = a &+ b\ (\text{moisture content}) + c\ (\text{percent sapwood}) \qquad (3)\\ &+ d\ (\text{ring angle}) + e\ (\text{specific gravity}) + f\ (\text{growth rate})\\ &+ g\ (\text{ring radius}).\end{aligned}$$

where: a, b, c, etc., are again experimentally determined constants. This equation states that the effects of the other variables on shrinkage are combined with the effect of moisture content in a simple additive fashion. Such information is not readily available in the literature and thus one must determine it experimentally for most species at present.

Variability factor - the last term in our simplified equation for required average green size (Eq. 1) includes the variation from all sources. The most important of these are variations in rough green size, shrinkage and in final moisture content. Other factors could be included, such as that due to possible differences in drying conditions, but they are usually of less importance. One factor that might easily be overlooked but which has recently been shown to be quite important is drying temperature (Espenas, 1971). The standard deviations for each of these variations can be combined in a straight forward fashion as follows:

$$s_{\text{Rough dry}} = \sqrt{s^2_{\text{Rough green}} + s^2_{\text{Drying}}} \qquad (4)$$

Additional factors - With this information available, several decisions must be made before it is possible to make the necessary calculation of an appropriate green size. The first is whether or not any undersized material is to be tolerated and if so, how much. Sawing so that there is none is not likely to be the most economic practice. The cost of accepting a limited percent of undersized material is usually less than sawing so that all production is full sized. Figure 1 illustrates the average dry size needed if five percent of the material of a sample could acceptably be less than 3.500 inches in width. The size that a given percentage of the material must exceed is called the lower tolerance limit. The amount of scant material which is acceptable depends upon the loss in value in the scant boards and the value saved by permitting some undersizing.

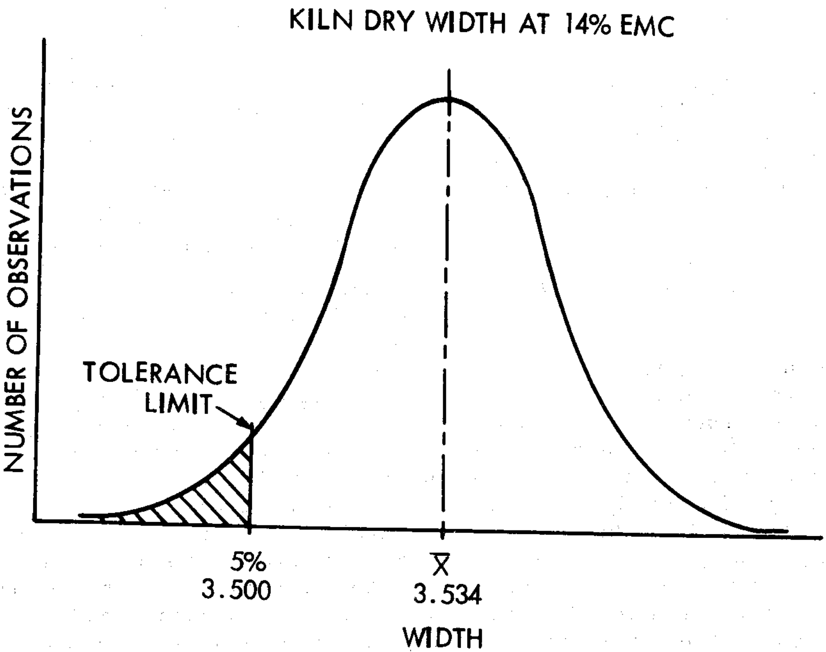

Figure 1. Relation between average rough dry size and surfaced dry size in the study used as an example. Planing allowance has not yet been included.

The second decision pertains to the level of certainty. No prediction of future events can be made with 100 percent assurance but, with statistical techniques, it is at least possible to establish the odds. A 95 percent probability, or a 1-in-20 chance of error, is a commonly chosen level.

Calculation of average green dimension - The average rough dry size that is necessary for a given limit of scant material can be calculated as follows:

Average rough dry size = $\overline{X}_{\text{Rough dry}}$ = lower tolerance limit + Ks + planing allowance (5)

where K = constant which changes for differing percentages of scant material and sample size. For example, when sample size is 300:

K = 1.800 for 5 percent scant

K = 2.133 for 2.5 percent scant[1]

s = standard deviation of rough dry sizes at some given final moisture content (Eq. 4)

The average green dimension can now be finally calculated by adjusting the average rough dry size for the loss of dimension occurring from shrinkage during drying:

Example - A study we recently made at the University of California Forest Products Laboratory illustrates how this can work. We measured initial moisture content, ring angle, percent sapwood, growth rate, specific gravity, and estimated distance to the pith for a 300-board sample of young redwood 2-inch by 4-inch lumber. We measured size when green and at 14 percent and 10 percent moisture contents. From this data we obtained the following two equations for shrinkage, one for width and one for thickness:

Percent thickness shrinkage = 3.842 - 0.1233 (moisture content) + 0.0060 (%sapwood) - 0.0509 (radius) - 0.0079 (90° - ring angle) (7)

Percent width shrinkage* = 4.114 - 0.1481 (moisture content) + 0.0050 (% sapwood) - 0.0092 (ring angle) (8)

* Radius non-significant in the width shrinkage equation.

These equations have correlation coefficients (R^2) of about 0.6 and 0.8, respectively. The correlation coefficient is a measure of how accurately the equation describes the raw data. With a correlation coefficient of 1.0, there is no variation and each and every experimental point would lie exactly on the line described by the equation.

Not all of the above mentioned variables were found to significantly affect shrinkage, and thus only those found to have a statistically significant, or real effect, on shrinkage have been included. Where no sorting before drying is anticipated, only size and moisture content need to be measured. The above equations, however, permit one to calculate either width or thickness shrinkage for any value of moisture content, percent sapwood, ring angle, etc. The fact that the correlation coefficient for each equation is less than 1.0 indicates that there are other variables affecting shrinkage. Considering the variability of the material studied, these coefficients are fairly high. We also obtained information on the variation in shrinkage (or s), from the same data as well as how this standard deviation is affected by selecting different sorts of lumber for drying. Knowing both the average and standard deviation of the shrinkage one is able to describe the performance of the material.

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[1] See Owen (1962) for K values at other sample sizes and percentages of scant material.

One-sixteenth inch was arbitrarily set as the planing allowance and this added to the American Lumber Standards surfaced dry size set the lower tolerance limit for the final product . . . in this particular example, 3.5" for a 4" nominal dimension. The average and standard deviation of the width of green boards, or the performance of the sawmill was determined by measuring a random sample of boards and with this, all of the necessary data was available. In this case, a 95 percent confidence level was established and it was decided that if 2-1/2 percent of the boards showed planer skip, this would be acceptable. We will assume that all boards would be dried to 14 percent moisture content to simplify the example. The average rough dry size required is calculated as follows, using equation (5):

$$\overline{X}_{\text{Rough dry}} = 3.500'' + 0.0625'' - 2.133\ (0.0601) = 3.691''$$

and finally the necessary green size using equations 8 and 6:

$$\overline{X}_{\text{Rough green}} = \frac{3.691''}{1 - \frac{1.69}{100}} = 3.754''$$

This then is the answer we were looking for to begin with. It is the lowest average rough green size which will not result in more scant lumber than is acceptable by this particular mill. It is not, however, fixed for all time. It is only correct as long as all parts of the process remain the same as during the study. Changes in variation in rough green size due to changes in mill performance will occur, and new standard deviations would have to be obtained routinely. Changes in other conditions are always possible also.

This technique does, however, permit selecting rough green sizes on an optimal basis. It is only a short additional step to put dollar values into the system so that the savings in wood due to careful selection of size can be balanced against losses due to rejects and thus maximum recovery is achieved.

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