

ALOG: A spreadsheet-based program for generating artificial logs

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Abstract

Log sawing simulation computer programs can be valuable tools for training sawyers as well as for testing different sawing patterns. Most available simulation programs rely on databases from which to draw logs and can be very costly and time-consuming to develop. ALOG (Artificial LOG Generator) is a Microsoft Excel®-based computer program that was developed to accurately generate random, artificial log data and to serve as an alternative to using a log database. Information obtained from the analysis of actual red oak (*Quercus rubra*, L.) logs was incorporated into the program to ensure the validity of the generated log data. Generated log feature information includes length, small and large inside-bark diameters, amount of sweep or crook, and defects. External defect attributes include type, location, length, width, and height. Internal defect information, including depth, volume, and angle, is also given for the most common defect types that exhibited a significant linear relationship between external and internal defect attributes within the sample data. The user has the option of specifying the grade of the log as well as the position of the log in the tree, or having the features drawn randomly from known distributions. Finally, a grading algorithm is incorporated into the program to check the grade of the generated log.

Researchers in the Department of Industrial and Manufacturing Systems Engineering at the University of Missouri-Columbia, in collaboration with the Southern Research Station of the USDA Forest Service, recently developed a hardwood log sawing simulator for use by the hardwood sawmill industry. LogCast (Log Computer Aided Sawyer Trainer) was designed to be used as a training tool for sawyers in primary hardwood processing mills (Occeña et al. 2000). The program provides a nondestructive method for sawyers to experiment with different log grades, orientations, and sawing patterns and presents the user with yield and value information

resulting from sawing decisions. A major advantage of the program is that it incorporates both external and internal defect information.

One limitation of the program, however, is the small number of logs in the database. Currently, there are only 18 logs available. The external characteristics of the sample logs including the surface defects were determined from ac-

tual red oak logs. The size and shape of internal defects were artificially generated using defect information obtained from physically sawn logs. The placement and orientation of the internal defects was hypothetically done around the pith and outwards in a random radial pattern following the upward direction of tree growth or where suggested by surface defects. Although many studies have attempted to model internal defects (Pnevmaticos et al. 1974, Richards et al. 1979, Samson 1993, Chen and Occeña 1996), none have successfully correlated internal and external defect attributes. Since log grading rules are based on a known correspondence between external indicators and the presence of internal defects, the program could be greatly improved by incorporating any significant correlation.

This paper describes software developed to generate realistic digital red oak logs with external and internal log defects, where the internal defects are based on external defect characteristics. Creating a computer-generated log is much faster, easier, and less costly than physically describing a real log. Another advantage of using computer-generated random logs is the assurance that every log will be unique. Unlike a database,

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which is finite, the chance of generating the same log twice is infinitesimal. This would also make the training program more closely related to real-world situations where every log a sawyer encounters is different.

Program overview

ALOG is a spreadsheet-based program that generates simulated log data in accordance with user-specified log features. The program allows the user to specify input parameters of log position in tree and grade or have them drawn at random from known distributions. Log positions include *butt* and *upper* and log grades include *F1*, *F2*, and *F3*, which are the standard grades for hardwood factory lumber logs based on the USDA Forest Service grading rules (Rast et al. 1973). Once the input parameters have been specified, the user can click a button to generate the artificial log attributes. Macros are used within the spreadsheet to perform calculations and display results. Log parameters included in the output are position in tree, grade, length, inside-bark end diameters, sweep depth and orientation, and crook length, depth, and orientation. External defect attributes include type, length, width, height, distance from large end of log, and radial orientation. A link to a defect key that contains descriptions of the various defect types is located in the bottom right-hand corner of the screen. Internal defect information is included for defect types that exhibited a significant linear relationship between external and internal defect attributes within the sample data. Internal information consists of the minimum depth of the defect from the cambium, volume, and the defect angle relative to the pith. There is no assumption made as to the shape of the internal defect.

Since random values are involved in the determination of defect size and location, surface defects will occasionally overlap. When two or more defects share the same surface area, the rows in the "Defect Attributes" table corresponding to the overlapping defects are highlighted. This is to alert the user that he/she needs to regenerate the log. Overlapping defects rarely occur on actual logs, and when they do, are usually limited to certain defect types.

Another side effect of using random variables is that the grade of the generated log may not correspond to the grade specified by the user. Therefore, a grad-

ing algorithm is incorporated into the ALOG program, allowing the user to verify the grade of the generated log. All logs are graded using USDA Forest Service grading rules for hardwood factory lumber logs (Rast et al. 1973) and the calculated grade is displayed to the user. Also available is a rudimentary, unrolled view of the log surface that shows all defects and the determined grading face of the log. Note that there may be several equivalent grading faces, but the program only displays the first one when moving from the top to the bottom of the image.

Data generation

A flowchart showing the steps involved in the log and defect data generation is shown in **Figure 1**. The majority of real log and external defect data used in the artificial log generator was extracted from a database compiled by the USDA Forest Service Northeastern Research Station during the early 1960s. The database consists of over 1,700 log samples encompassing 5 of the major hardwood species in the eastern United States. Only the red oak log data are currently incorporated into the program. Pertinent log attributes in the dataset include species, position in tree (butt or upper), length, sweep, crook, small and large end inside-bark diameter, and grade. Important external defect attributes include type, location, length, width, and height. After removing all logs that exhibited out of the ordinary characteristics or that appeared to contain errors, 110 red oak log samples remained. Database logs were then assigned to six respective log-grade/tree-position categories (three log grades Δ two log positions = six categories).

The other real log data used in the program were published by Goho and Wysor (1970) and include length, scaling diameter, and grade distributions for factory-grade hardwood logs delivered to Appalachian sawmills. The 958 logs included in the study were used independently of the previously mentioned dataset for generating log size attributes.

Log attributes

Nominal log lengths in 2-foot increments from 8 to 16 feet are calculated by random drawing from the length distribution published by Goho and Wysor (1970). A random trim allowance is then added to the nominal log length using the following formula:

$$T = \bar{t} + (s_t \times r) \quad [1]$$

where:

- T = trim allowance for the artificial log (in.)
- \bar{t} = mean trim allowance from USDA Forest Service log data for specified log type and grade (in.)
- s_t = standard deviation of trim allowance from USDA Forest Service log data for specified log type and grade (in.)
- r = random number from a standardized normal distribution.

Scaling diameter (small-end) is also derived from the distribution developed by Goho and Wysor (1970). The diameter distribution is subdivided by grade, so a random number is drawn from the distribution that corresponds to the grade specified in the program. The same method used in **Equation 1** is then used to generate a random log taper from the USDA Forest Service data. Large-end diameter is then calculated as:

$$D_{LE} = (P \times L) + D_{SE} \quad [2]$$

where:

- D_{LE} = large-end log diameter (in.)
- P = log taper (in./ft.)
- L = generated log length (ft.)
- D_{SE} = small-end log diameter (in.)

In order to assign sweep or crook to the generated logs, the percentage of logs containing these features is first calculated within each of the six data sets. Next, a random number is generated between 0 and 1. If the random number falls within the percentage of logs with sweep/crook, the generated log is given sweep/crook. The program is also configured to allow sweep *or* crook but not both. The method for determining the amount of sweep or crook to be assigned is explained in the following section on external defect generation.

External defect attributes

Now that the artificial log has been generated, the next step is to place external defects on the log. For all logs within each of the six datasets, the frequency of each defect type is first calculated. To account for the variations in log length, the resulting value is multiplied by eight and divided by the nominal log length to

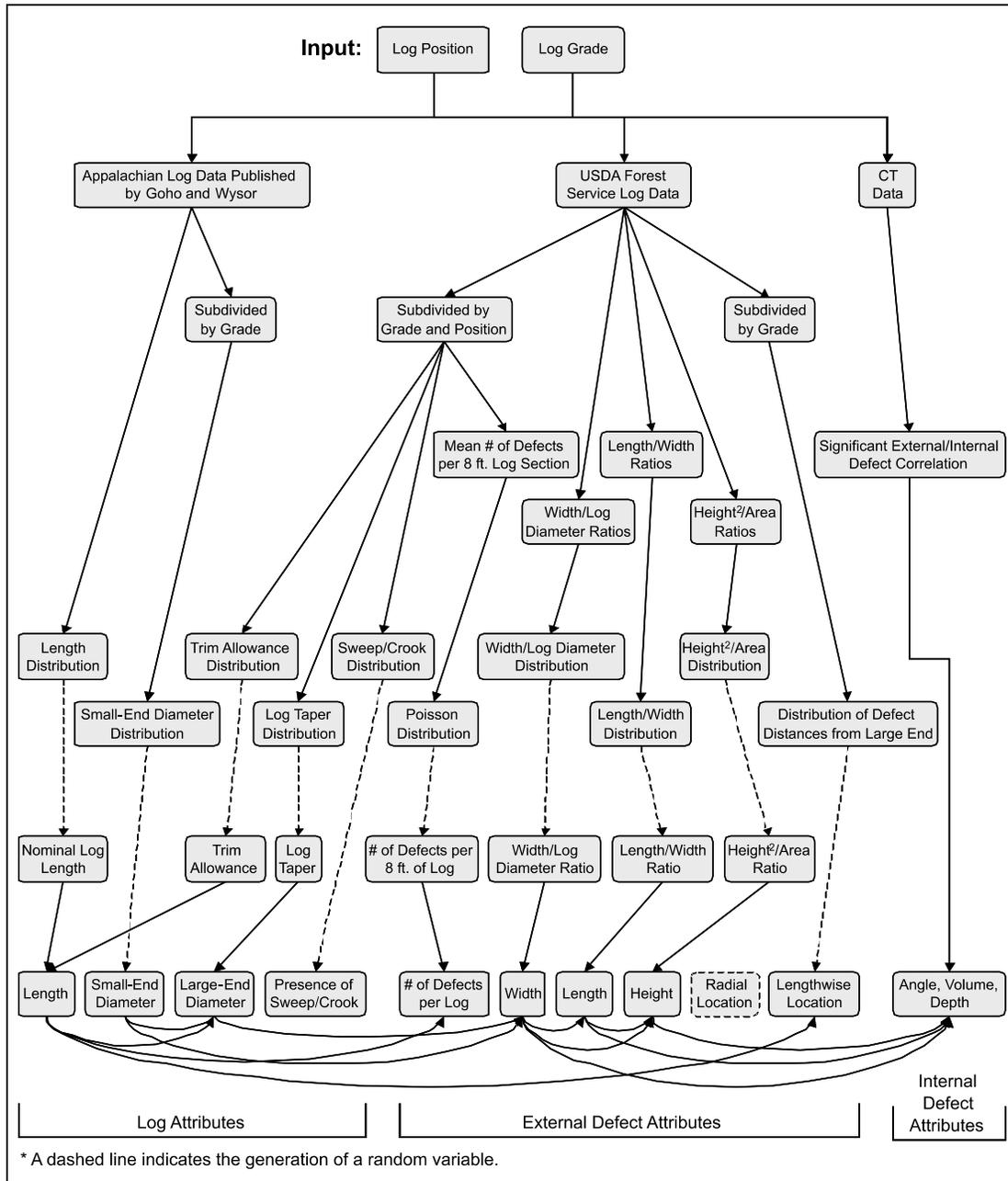


Figure 1. — Diagram showing the steps involved in the log and defect data generation in ALOG.

give the number of defects per 8-foot log section. For each dataset, the mean number of defects of each type per 8-foot log section is calculated. A random number is then generated from a Poisson distribution with the frequency mean as the input parameter. A Poisson distribution is ideal for count data since it will always return an integer greater than or equal to zero. Finally, the number of defects per 8-foot log is weighted so that it corresponds to the log length. This is done by multiplying the random number by the ratio of generated log length to eight and rounding to the nearest whole

number. The values from the dataset corresponding to the artificial log grade and type represent the number of defects of each type placed on the generated log.

Once the quantity of each defect type has been determined, it is necessary to generate the external defect parameters of length, width, and height. Since the values are based on the distributions of the sample defects, there must be enough samples to generate a reasonable distribution. Therefore, due to the scarcity of defects of the same type within an individual dataset, all datasets are combined for this analysis.

For each defect in the sample data, ratios are first calculated for defect width to log diameter, defect length to width, and defect height squared to defect basal area. Using ratios allows correlation information among defect parameters to be maintained. Frequency histograms for the defects' size attributes are then developed for each defect type, omitting any defects in the array that contained extreme outliers (more than three times the inter-quartile range). Next, a random integer is generated for each defect type between one and the total number of defect occurrences. That number is then

Table 1. — Significance test results, r^2 values, and models for the regression of the independent variables of internal defect size, depth, and orientation on the dependent external defect size variables.

Defect type	Dependent variable	Significant variation explained? ^a	r^2	p -value	Regression model ^b
Adventitious knot	Angle	--	--	--	--
	Volume	Yes	0.39	<0.0001	$0.20365 + 0.0855(\ln(L)) + .92617(H^2)$
	Depth	No	0.10	0.0739	$0.31676 - 0.72956(H) - 0.00447(\ln(LW))$
Bark distortion	Angle	No	0.11	0.1148	$-70.89624 + 44.28222(H) + 44.17451((\ln(D)))$
	Volume	Yes	0.51	<0.0001	$2.98786 - 13.93413(H) - 0.02412(D^2) + 1.26960(LW)$
	Depth	No	0.04	0.3732	$0.88362 - 2.21764(H) - 0.02512(LW)$
Overgrown knot	Angle	No	0.09	0.1057	$-87.95512 - 6.14030(H^2) + 53.21951(\ln(D))$
	Volume	Yes	0.60	<0.0001	$-0.83092 + 0.01521(D^2) + 0.8677(LW)$
	Depth	Yes	0.27	0.0004	$0.06214 + 0.01217(W^2) - 0.14899(H)$
Sound knot	Angle	Yes	0.32	0.0361	$21.30083 - 44.68715(\ln(L)) + 58.77868(\ln(W))$
	Volume	Yes	0.93	<0.0001	$-15.35176 + 9.65642(L) + 9.00918(H)$
	Depth	--	--	--	--
Unsound knot	Angle	No	0.13	0.1703	$40.82826 - 17.28493(\ln(L)) + 14.67098(\ln(W)) + 0.64885((H^2))$
	Volume	Yes	0.79	<0.0001	$-24.39964 + 13.32873(L) + 8.92737(\ln(D))$
	Depth	--	--	--	--

^aSignificance was determined at the 5 percent significance level.

^b D represents log diameter; L , W , H , and LW represent external indicator length, width, height, and the length-width product, respectively.

compared to the cumulative frequency distribution to determine an attributes range. Finally, a random real number is drawn from the selected attributes range. Based on this computed attributes range, the defect parameters are calculated as follows:

$$\text{Width} = \frac{\text{Width/Diameter Ratio} \Delta}{\text{Log Diameter}}$$

$$\text{Length} = \frac{\text{Length/Width Ratio} \Delta}{\text{Width}}$$

$$\text{Height} = \sqrt{\frac{\text{Height}^2}{\text{Area Ratio}} \times \text{Area}}$$

Following the previously described steps of log periphery (length, diameter, taper) generation, external defect type and number determination, we next proceed to external defect placement. Each defect is arranged radially around the log from a specified point by generating a random degree between 0 and 360. Position along the length of the log is given as a percentage of log length from the large end and is calculated in the same manner as the defect size attributes. The only difference is that the distribution will be derived from *all* defects within a grade. This is mainly for grading purposes since defect location is an important grading factor but defect type is not.

Internal defect attributes

Before including internal defect information into the program, it was necessary to determine the relationship (if any) between internal defect attributes (including size, depth, and orientation) and external defect size attributes for the various defect types. By describing this relationship, we can predict internal defect characteristics based solely on the characteristics of the external defect indicators. Due to cost constraints, it was decided to limit the initial investigation to the five most common defect types from the USDA Forest Service log data: Overgrown knots, adventitious knots, sound knots, unsound knots, and bark distortions. 115 red oak log sections containing 247 defects were collected from 8 trees in the Appalachian Mountains of Virginia. The log sections ranged from 11 to 30 inches in length and had a minimum small-end diameter of 8 inches. The goal was to collect manageable log sections that contained as many whole defects as possible.

First, the length, width, and height of all external defects were measured, as well as the log diameter at the defect. The log sections were then CT scanned to obtain internal defect information. Internal defect measurements were taken

on each CT slice in order to determine defect volume, the minimum distance from the defect to the cambium, and the angle of the defect with respect to the pith.

Multiple linear regression analysis was performed on the data in an attempt to find significant predictor variables for the three internal defect parameters of angle, volume, and depth. Predictor variables that were used include log diameter and external indicator length, width, height, and the length-width product. Two transformations of the predictor variables were also considered: the natural log and the square. Adventitious knot angle was omitted from any regression analysis since it usually only occurred in one or two CT slices, making the angle calculation unreliable. It should be noted, however, that adventitious knots generally grow perpendicular to the pith. Depth measurements for sound and unsound knots were also omitted since they always appear above the log surface. Tests were performed to determine if a significant amount of variation in the dependent variables was explained by the predictor variables. **Table 1** shows the results of the significance tests, r^2 values, p -values and regression equations for all dependent variables.

The volume variable was significant for all five defect types and has r^2 values ranging from 0.39 (adventitious knots) to 0.93 (sound knots). Overgrown knot depth and sound knot angle also were significant, with r^2 values of 0.27 and 0.32, respectively. There is insufficient evidence, however, to conclude that log diameter and external defect dimensions explain a significant amount of variation in adventitious knot depth, bark distortion depth, bark distortion angle, overgrown knot angle, and unsound knot angle.

In ALOG, if a defect type is generated that showed significance in the regression analysis, values are generated for the significant variable(s) using the corresponding regression equation. Of the five defect types sampled, the program will provide internal information for adventitious knot volume, bark distortion volume, overgrown knot volume and depth, sound knot angle and volume, and unsound knot volume. Since not all defect types were included in the regression analysis and only some of those that were showed significance, some of the generated defects will lack internal information.

Summary

Sawing simulation computer programs can be invaluable tools for training sawyers as well as for obtaining value-yield information for different sawing patterns. A major limitation of such programs, however, is that true log data (internal and external) can be difficult and costly to obtain. Also, most sawing simulation programs input log data via a database, which limits the number of logs that can be tested.

ALOG, an artificial log generation program, can be a valuable alternative to using log databases. This Microsoft® Excel spreadsheet program can quickly generate simulated log and defect data. Also, since the program relies on drawing random values from known log data distributions, the number of unique logs that can be generated is infinite. This relates more closely to what one might find in a sawmill or logyard, where every log is different. Since the generated data is based on real log data, the simulated logs should be representative of possible log and defect configurations.

The external data generated by the program should be consistent with the sample data, although this assumption has not yet been verified. Internal information, including defect volume, depth, and angle, was predicted using regression models based on external defect characteristics. Models that showed significance had relatively low r^2 values, indicating that the models did not explain a large amount of the variation. However, given the purposes for which the data will be used, this is probably not a critical matter. The accuracy of the internal defect information is not crucial to the effective use of the sawing simulator. It is better to have internal defect information that may lack accuracy than to have no internal information at all. One solution to the problem of the low r^2 values might be to test other predictor variables for significance and see if a considerably larger amount of variation is explained. If not, it may be more feasible to simply pull internal defect attributes from known distributions, as was done with the external defect characteristics.

Future work on the ALOG program will focus on improving the accuracy of the internal defect information, adding end defects, improving upon the generated log image, and adding additional log species. In addition to the red oak log information, the USDA Forest Service log data also include samples of white oak, maple, yellow-poplar, and cherry. Therefore, it would be reasonable to assume that these species can be added to the program without much difficulty.

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