QUALITY CHARACTERISTICS OF APPALACHIAN RED OAK LUMBER

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ABSTRACT

Red oak lumber defect information derived from a well-constructed board databank was analyzed. The potential utility of No. 1 Common and No. 2A Common lumber is indicated by the finding that 23 percent of the No. 1 Common boards and 35 percent of the No. 2A Common boards in the databank contain clear-face cutting percentages that meet the minimum requirement for the next higher grade. The mean surface measure of the FAS, Selects, No. 1 Common, and No. 2A Common lumber was 9.1, 7.5, 6.3, and 6.2, respectively. The mean defect areas for each grade were: FAS - 1.2 percent, Selects -2.3 percent, No. 1 Common- 6.8 percent, and No. 2A Common -9.8 percent. Approximately 89 percent of the total defect area in these boards consisted of unsound defects. Wane, unsound knots, and bark pockets are the three major defects found in red oak lumber. Between grades, there are significant differences in the occurrence of these defects. Pith is relatively uncommon in Common-grade lumber, occurring in 9 percent of the No. 1 Common boards and 19 percent of the No. 2A Common boards. Twenty-five percent of the No. 1 Common and No. 2A Common boards contained crook of 1/2 inch or more.

How much of each board in each lumber grade is defective? Which defects occur most often? How well do the various grades predict utility? How readily might the grade rules be adapted to automated grading and processing systems? Answers to questions such as these are needed by researchers and manufacturers who want to improve automation and maximize productivity.

For grading purposes, the most important defect factors are the type, size, and location of defects in a board. For utilization purposes, the most important defect factor is the degree of difficulty a defect presents to the wood processor trying to obtain available rough dimension parts from aboard.

All hardwood lumber grades have minimum requirements for board size and number and size of cuttings. In addition, the higher quality grades restict the maximum allowable size of individual defects and the maximum allowable amounts of accumulated wane, pith, and end splits. To a secondary hardwood processor, these grading requirements may have little importance when aboard is converted to rough dimension parts; however, they may place a board in a lower grade, even though the board otherwise qualifies for a higher grade. For example, a grading cutting might be too short or narrow, or a defect might be a little too large.

When converting lumber to rough dimension parts through automated vision systems, what is the hierarchy of importance of various types and sizes of defects in each lumber grade? For example, if the amount of pith in FAS lumber is non-existent or inconsequential, testing for pith is a waste of time. On the other hand, testing for bark and unsound knots is very important for FAS. If we cannot consider all factors in real time, what is the importance of each factor in turn?

In this report, we discuss the wide range of quality possible within each grade and analyze the most important red oak lumber quality characteristics by grade.

MATERIALS AND METHODS

Defects in the 1,578 boards contained in a new red oak data bank (5) were analyzed. The defects had previously been mapped out using a large-scale digitizer (1). Fifteen defect types were specified during board mapping **(Table 1).** Board grades were established using the computerized grading program ReGS (4). We verified or made corrections to these grades using to-scale plots of the lumber.

The data bank is not intended to be a statistically representative sample of Appalachian red oak lumber (5). It is a full complement of boards from which samples can be drawn for analysis. During data bank development, wider boards were relatively scarce. Almost all

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TABLE 1. — Board defects specified during board mapping.

Defect	Definition
Void	The space between the edge of the board and the smallest rectangle enclosing the board; caused by crook, taper, or differential shrinkage.
Pith	The small soft core occurring in the structural center of the log.[a]
Pith-related	Tear or split related to the pith.
Decay	Discolored wood that is rotten/soft.
Shake	Separation of the annual rings.
Wane	Scant wood thickness and bark.
Bark pocket	A bark-filled blemish in the board.[a]
Grub hole	Holes 1/4 inch and larger in diameter.
Shot worm hole	Holes greater than 1/16 inch, less than 1/4 inch.
Pin worm hole	Holes 1/16 inch in diameter, or smaller.
Unsound knot	A knot containing soft tissue or pits or open checks.
Sound knot	A knot containing only solid wood tissue and tight checks.
Incipient decay	Objectionable stain that will not surface out.
Bud trace	Objectionable bud traces containing bark.
Split	A lengthwise separation of the wood that penetrates more deeply than checks.

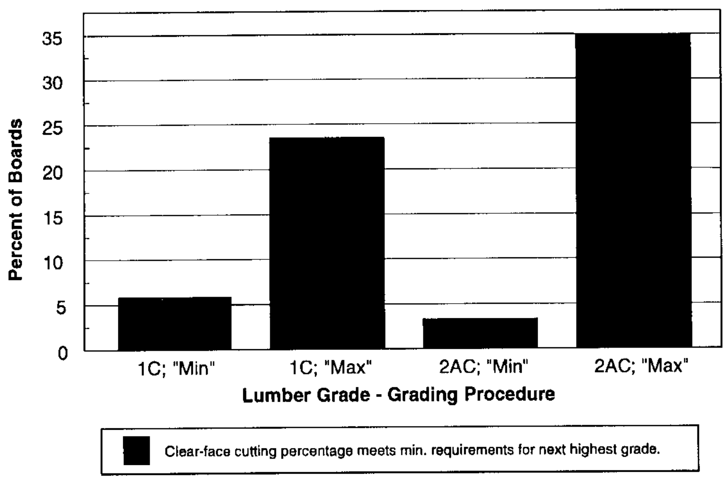

Figure 1. — Percentage of Common boards with total clear-face grading cutting surface areas greater than the minimum requirements of the next highest grade. "Min" units were determined by the ReGS grading program; "Max" units were determined visually using to-scale board plots.

boards that were 8 inches and wider were taken at three mills in two states. Only a small percentage of the available No. 1 Common and No. 2A Common boards available at these same three mills was included. Total sampling time was about 20 days.

To reveal the range of surface area values in the clear-face grading cuttings of No. 1 and No. 2A Common data bank boards, we graded the boards twice, staying within the National Hardwood Lumber Association (NHLA) rules (9). First, we used the computerized grading program ReGS (4). We called this the "minimum" method. Because ReGS terminates with the first combination of cuttings that meet or exceed the grade requirements, this method frequently underestimates the amount of grading cuttings surface area that could be found if optimization were used. However, ReGS closely simulates what a human grader does.

For the second grading, we manually graded the lumber from to-scale plots of each board. We used an iterative procedure to determine the largest surface area in as many grading cuttings as possible without exceeding the maximum number of cuttings allowed. We called this the "maximum" method. While the grade of lumber does not change, we feel the maximum grading surface area is a better predictor of utility for computer simulations.

Included in our defect analyses were calculations and between-grade comparisons of the: 1) area of each defect type per board foot as per Harding et al. (7); 2) percentage and area of sound versus unsound defects per board foot; and 3) frequency of occurrence of the different defect types in terms of the number and percentage of boards containing that defect type. We used analysis of variance procedures ($\alpha = 0.05$) to establish the statistical significance of between-grade differences and the Tukey test was used to compare means.

RESULTS AND DISCUSSION

WITHIN-GRADE RANGE OF QUALITY

Understanding the useful quality of a board in relation to its grade is not straightforward. Each lumber grade is a discrete description of a level of quality that is open-ended on the high side. NHLA procedures used in grading boards make it possible to have more than 100 percent of the board surface measure in grading cuttings. The human grader scans each board for the minimum requirements of the highest possible grade. Even though the human grader does not consider how well the board falls within the grade, it is assumed that over time this grading procedure will produce an equal distribution of all quality levels within a grade. However, our findings indicate that overall quality within a grade will be higher than the minimum requirements might suggest.

When a board has enough surface area in its grading cuttings to meet the minimum requirement of the next highest grade, other reasons often prevent its placement in that grade. Often, a board dimension (length or width) or a grading cutting is too small. Boards that might otherwise be FAS or Selects can be downgraded for first-foot violations, individual defects that are too large, or too much accumulated pith, wane, or end splits. A No. 1 Common board with more than one-half of its length containing pith must be graded no higher than No. 2A Common.

Based on the "maximum" method, 23 percent of the No. 1 Common boards **(Fig. 1)** contained clear-face cutting percentages of at least 83 percent for boards with surface measures ≥ 4 or 91 percent for surface measure 2 and 3 boards. These are the minimum requirement for FAS lumber. Thirty-five percent of the No. 2A Common boards **(Fig. 1)** have "maximum" clear face cutting percentages that exceed 66 percent, the minimum requirement for No. 1 Common lumber. Approximately 25 percent of these No. 1 and No. 2A Common "high-quality" boards met the next higher grade's standard for the maximum allowable number of cuttings used to obtain the requisite clear-face percentage.

If the grading surface area of these boards is high enough for the board to qualify for the next higher grade, why aren't the boards in that grade? Twenty-four percent of our high-quality No. 1 Common data-bank boards were either too short or too narrow to meet the Selects grade. An additional 28 percent of our high-quality No. 1 Common boards contained grading cuttings that were smaller than the minimum size allowed in the FAS or Selects grade. Many of our No. 1 Common boards could not be upgraded because they contained. an oversize defect (35%), first-foot rule violations (4%), and/or too much pith (0%), wane (4%), or end splits (5%). For most high-quality No. 2A Common boards, the rule that pertains to the minimum allowable size of the grading cuttings limits upgrading.

BETWEEN-GRADE DIFFERENCES IN BOARD SURFACE MEASURE

The mean surface measure for the 198 FAS boards in the databank was 9.1 **(Fig. 2).** For the 209 Selects boards, the mean surface measure was 7.5. For the 591 No. 1 Common boards and 580 No. 2A Common boards, the mean surface measures were 6.3 and 6.2, respectively.

What proportion of the surface measure difference can be attributed to minimum board width and length limitations in the FAS and Selects grades? Of the 591 No. 1 Common boards, 214 were too short and/or too narrow to make the FAS grade. When these boards are removed from the sample, the surface measure of the remaining boards is 7.2, which is still significantly lower than the average surface measure of the FAS boards. After accounting for board size differences imposed by the NHLA grade rules, FAS and Selects grade lumber is still wider and longer than the Common grade lumber.

Lumber size should be an important consideration for both secondary hardwood processors and researchers. For secondary processors, lumber size affects the efficiency and costs associated with various manufacturing operations. Researchers involved in developing scanning and optimization technologies should consider the possible effects of lumber size on the field-of-view of vision systems and computer memory requirements.

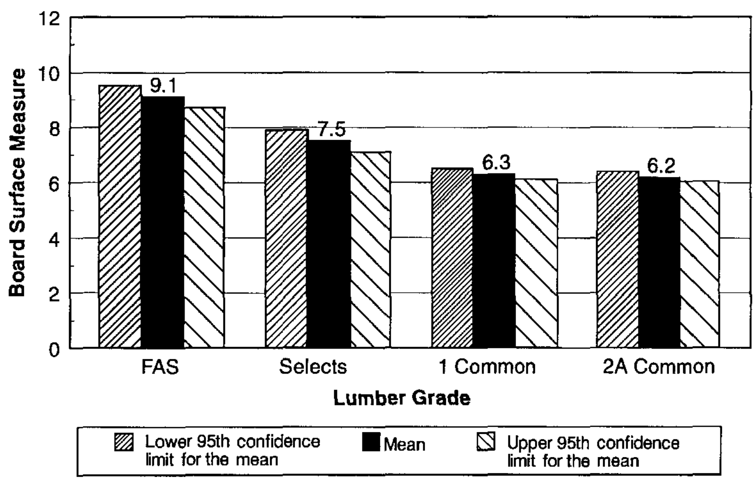

Figure 2. — Mean board National Hardwood Lumber Association surface measure by grade for 414 Appalachian red oak.

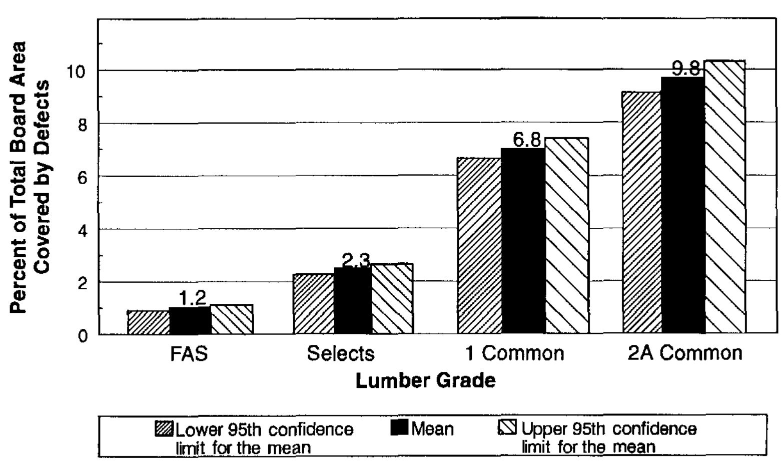

Figure 3. — Mean board defect area as a percentage of total board surface area by grade for 4/4 Appalachian red oak.

BETWEEN-GRADE DIFFERENCES IN DEFECT AREA AND DEFECT OCCURRENCE

Only a small fraction of the total surface area of a board is covered by defects. For the FAS lumber in our data bank, only 1.2 percent of the surface area of all boards was covered by defects **(Fig. 3).** For the Selects lumber in our data bank, an average of 2.3 percent of the board surface area was covered by defects. The defect area percentages for these two grades were not statistically different. For the No. 1 Common and No. 2A Common grades, 6.8 and 9.8 percent of the board surface area, respectively, were covered by defects. The defect area percentages for these two grades were statistically different from each other and from the FAS and Selects boards. For a secondary hardwood processor cutting relatively short and relatively narrow clear two-face parts, the total defect area of the board may have some significance.

However, for most secondary hardwood processors, defect area information alone is insufficient. A dimension manufacturer who cuts a lot of clear one-face and sound parts can use information on the relative occurrence of sound versus unsound defects. Details about the distribution patterns of the different types of defects can also be important when considering lumber grade mix changes. For instance, waney lumber is less of a problem operationally in a gang-rip-first operation than in a crosscut-first operation. Because fewer sawing operations are required to remove wane, costs are lower. This also is true for other linearly oriented defects such as splits, checks, stain (incipient decay), and pith. Conversely, defects such as knots, bark pockets, decay, and crook are often removed more cost effectively in a crosscut-first rough mill operation.

Unsound defects make up a substantial percentage of the total defect area in each lumber grade. On average, 85 percent of the total defect area for the FAS boards in our data bank consisted of unsound defects. Likewise, 90 percent of the total defect area of Selects boards consisted of unsound defects. Unsound defects made up, on average, 88 and 87 percent of the total defect area for our No. 1 Common and No. 2A Common data-bank boards, respectively. The percentage of total defect area comprised of unsound defects was not statistically different for these four grades.

In **Fig. 4,** the distribution of the seven most important defects in our databank is shown by grade. In the upper grades (FAS and Selects), the incidence of most defect types is so low that relative values are unimportant.

Because the process used to grade Selects boards is so different, the Selects grade cannot be compared directly with the other grades in terms of clear-face cutting percentages. However, both the board size and defect data for the Selects grade seem to indicate that Selects lumber is more similar to FAS lumber than to No. 1 Common, a conclusion that also can be drawn from the data presented by Harding et al. (7).

Table 2 lists the analysis of variance test results and Tukey multiple comparison groupings for the variable "defect area per board foot" for these same seven defects. These results are similar to those of Harding et al. (7) with only slight variation in some of the multiple comparison groupings.

Wane area, unsound knot area, and bark pocket area per board foot vary the most between lumber grades. Differences in the occurrence of these defects in the different lumber grades are governed by both the grading rules and the position in the log from which the lumber is cut. One might expect that lower grade boards, which tend to be cut from the more interior portions of the log, should contain more knots and bark pockets than FAS and Selects boards because the interior of the log is knottier. On the other hand, FAS and Selects boards, usually cut from the periphery of the log, could be expected to contain more wane than the Common boards were it not for the wane restrictions within the NHLA grade rules (9). Secondary manufacturers who demand

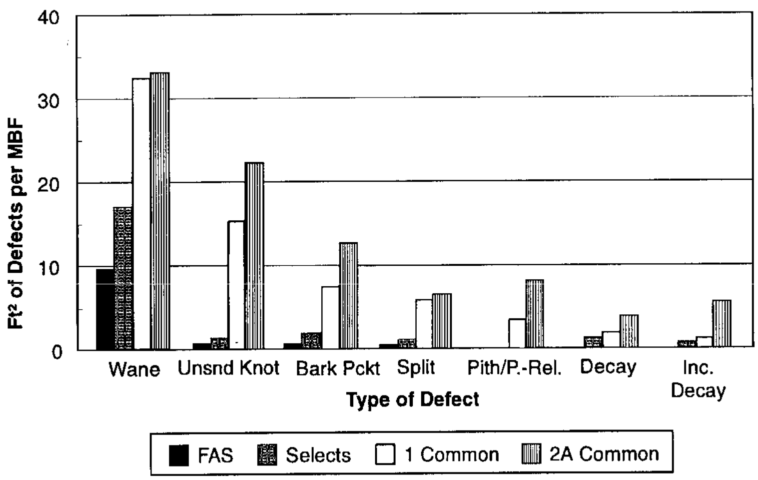

Figure 4. — Major defect types within each lumber grade for kiln-dried, 4/4 Appalachian red oak lumber.

TABLE 2. — Analysis of variance and Tukey multiple comparison test results for comparisons of the difference in the mean cumulative urea of various defects between lumber grades.[a,b,c]

	Wane	Unsound knot	Bark pocket	Split area	Pith/pith-related	Decay area	Incipient decay
	Mean	Mean	Mean	Mean	Mean	Mean	Mean
FAS	9.7 A[d]	0.7 A	0.7 A	0.7 A	0.0 A	0.0 A	0 A
Selects	16.7 A	1.4 A	2.1 A	1.4 A	0.0 A	1.4 A,B	0.7 A
1 Common	32.6 B	15.3 B	7.6 B	6.3 B	3.5 A	2.1 A,B	1.4 A
2A Common	33.3 B	22.9 C	13.2 C	6.9 B	8.3 B	4.2 B	5.6 B

[a]Analysis of variance test results indicated significant ($\alpha = 0.05$) differences between grade-based groups for each defect category.
[b]Other defects included in the data bank and this analysis were void, shake, sound knot, bud trace with bark, grub holes, shot worm boles, and pin worm holes. In addition, pith and pith-related tear or splits are aggregated in this analysis but were individually defined in the data bank.
[c]Cumulative defect areas are given in ft.^{2}/MBF.
[d]Within columns, means followed by the same capital letter do not differ significantly ($\alpha = 0.05$).

TABLE 3. — Frequency of occurence of 11 major defect types within the FAS, Selects, No. 1 Common, and No. 2A Common grades of red oak lumber.

	Percentage of boards with defects										
Grade	Wane	Unsound knot	Bark pocket	Split	Pith	Pith-related	Decay	Incipient decay	Shake	Sound knot	Grub worm hole
	(%)										
FAS	54	26	44	26	0	0	0	2	0	1	8
Selects	55	48	68	30	2	0	2	3	2	2	9
1 Common	68	72	69	43	9	6	7	6	4	2	12
2A Common	61	89	86	47	19	16	7	14	6	6	17

TABLE 4. — Number of boards containing pith.

Grade	Aggregated length of pith (ft.)							No. of boards with pith	Total no. of boards in sample
	<1	1	2	3	4	5	≥6		
FAS	0	0	0	0	0	0	0	0	198
Selects	4	0	0	0	0	0	0	4	209
1 Common	31	13	7	0	2	0	0	53	591
2A Common	53	26	10	7	7	2	3	108	580

TABLE 5. — Average crook deviation and percentage of boards with 1/2 inch or more of crook, by length and grade. [a]

Nominal length of board	No. 1 Common		No. 2A Common	
	Average crook deviation per board	Boards with ≥ 1/2 in. crook	Average crook deviation per board	Boards with ≥ 1/2 in. crook
(ft.)	(in.)	(%)	(in.)	(%)
4 to 5	0.08	3	0.10	0
6 to 7	0.18	8	0.18	5
8 to 9	0.26	12	0.25	15
10 to 11	0.30	21	0.30	18
12 to 13	0.38	30	0.37	27
14 to 15	0.51	48	0.40	34
16	0.55	44	0.64	46

[a] Analysis of variance test results indicated significant ($\alpha = .05$) differences in crook deviation between length-based groups.

relatively wane-free "uppers" (FAS and Selects) should be aware that the edging that is done in the sawmill to produce these wane-free boards can also remove a large amount of clear wood (8).

Table 3 shows the frequency of occurrence of the 11 most important defect types in terms of the percentage of boards containing the defect. Of special interest is the very low incidence of pith and pith-related defects (e.g., checks) in the Common grades. The grading rules state that No. 1 Common boards may contain an aggregated length of pith up to one-half the length of the board (9). For No. 2A Common, there are no pith restrictions (except that pith cannot occur in the grading cuttings). In practice, however, pith occurs infrequently in both grades **(Tables 3** and **4)** as previously found by Harding et al. (7). The data in **Table 4** reveal that most boards containing pith contained less than 2 feet of pith in the aggregate.

INCIDENCE OF CROOK

Boards with crook exceeding 1/4 inch are not included in our data bank (5). We chose to omit these boards because current versions of the computerized grading and cut-up programs cannot accurately process boards with crook. However, we did collect and map approximately 350 No. 1 Common and No. 2A Common boards with crook. Overall, 25 percent of the boards in both the No. 1 Common and No. 2A Common samples had 1/2 inch or more of crook. In both grades, the degree of crook (average crook deviation per board) increased with increasing board length **(Table 5).** Approximately 66 percent of the crooked boards in both lumber grades contained between 1/2 and 3/4 inch of crook. Twenty-five percent of the crooked boards contained between 1 and 1-1/4 inches of crook. Nine percent of the boards were crooked in excess of 1 -1/4 inches.

We also surveyed the incidence of crook in an independent sample of over 900 FAS One Face and Better red oak boards that were manufactured and dried by a major hardwood lumber producer. In this sample, 35 percent of the boards were crooked at least 1/2 inch. In addition, the crooked boards in this sample were more severely crooked than were the boards in our red oak data bank; 26 percent of these boards were crooked in excess of 1-1/4 inches. This frequency of crook occurrence can significantly lower both primary part yield and total part yield in a gang-rip-first rough mill operation (2,3).

SIGNIFICANT FINDINGS AND CONCLUSIONS

To provide the type of information sought by industry members and researchers, we analyzed the defects in the FAS, Selects, No. 1 Common, and No. 2A Common grades described in our recent data-bank publications (5,6). Analysis of these data on well-manufactured, carefully mapped, and precision-graded Appalachian red oak lumber leads to significant findings. These findings and conclusions follow.

The potential utility of No. 1 Common and No. 2A Common lumber is indicated by the fact that 23 percent of the No. 1 Common boards and 35 percent of the No. 2A Common boards in our data bank contain clear-face cutting percentages that meet the minimum requirement for the next higher grade.

Between-grade differences in surface measure were revealed in the data bank. FAS-grade boards had the highest average surface measure while the Common-grade boards had the lowest average surface measure. This difference cannot be totally attributed to the minimum size restrictions associated with the FAS and Selects grades.

Both secondary hardwood processors and researchers should consider lumber size important to productivity and automation. In some manufacturing operations, lumber size affects efficiency and costs, while in research and development, lumber size may affect the field-of-view of the vision system and computer memory requirements.

The mean defect areas for the four grades were: FAS - 1.2 percent, Selects - 2.3 percent, No. 1 Common - 6.8 percent, and No. 2A Common - 9.8 percent. Approximately 89 percent of the total defect area of these boards consisted of unsound defects. Wane, unsound knots, and bark pockets are the three major defects found in red oak lumber. Occurrence of these defects differs significantly between the grades; each defect is less prevalent in the FAS and Selects grades than in the No. 1 Common and No. 2A Common grades.

Because FAS and Selects boards are usually cut from the periphery of the log, they should contain more wane than the Common boards. However, NHLA (9) restrictions reduce the occurrence of wane in the upper grades. Sawmill edging to produce wane-free "uppers" can also remove a large amount of clear wood.

Even though Selects-grade boards cannot be compared directly with other grades in terms of clear-face cutting percentages, data on Selects-grade board size and defects indicate that Selects lumber is more similar to FAS lumber than No. 1 Common lumber.

Pith is relatively uncommon in the No. 1 and No. 2A Common grades; 9 percent in No. 1 Common and 19 percent in No. 2A Common. These levels of occurrence do not approach those allowed under the NHLA grade rules (9).

Twenty-five percent of the No. 1 Common and No. 2A Common boards in our data bank contained 1/2 inch or more of crook. Yield studies have indicated that this level of crook can significantly lower both primary part yield and total part yield in gang-rip-first rough mill processing.

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