Scheduling of Pole Line Inspections

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(Manuscript received June 21, 1962)

This paper is concerned with the scheduling of pole line inspections. The schedules are based on the physical lifetime distribution of pressure-treated southern pine poles, which constitute some eighty per cent of the current telephone pole plant. Results of studies described herein indicate that for scheduling purposes the physical lifetime distribution of such poles is adequately described by the lognormal density function. Supporting evidence includes the observation that sound older poles seem no more prone to failure than younger poles. As a consequence, there appears to be no need to decrease the intervals between inspections as poles age. Quality of treatment — particularly the amount of preservative retained — appears to be of primary importance in determining the physical lifetime of poles. The relative influences of environmental factors such as temperature, humidity, rainfall, soil conditions, length of growing season, etc., have not been adequately evaluated; however, for a given quality of treatment, poles tend to last longer in the North than in the South. Consequently, for pole lines in the South, inspections are scheduled earlier in the life of a pole and at shorter intervals thereafter than for similar pole lines in the North.

I. INTRODUCTION

In 1920 only ten per cent of the 14 million poles in line owned wholly or in part by the Bell System were treated full-length with preservatives. Of this ten per cent, most were creosoted southern pine poles. In 1960 about eighty per cent of the 23 million Bell System poles were pressure-treated southern pine poles; the majority of the others were Douglas fir and other western or Rocky Mountain species. Early pressure treatments used creosote; later, pentachlorophenol-petroleum solutions were also in common use. Today a creosote-penta mixture is specified for southern pine.

Early untreated poles, notably cedar and chestnut, had a much greater natural resistance to decay than untreated southern pine poles. They had relatively thin layers of sapwood surrounding the highly decayresistant heartwood, whereas today's southern pine poles consist largely of sapwood. Untreated southern pine poles might be expected to give less than five years service in the deep South, and but little more in the North. Treatment with preservatives toxic to decay fungi and insects prolongs the lifetime of poles with thick sapwood for many decades. The effectiveness of such treatment is reflected in the average physical lifetime, which is taken to mean the average time from placement until failure due to decay (or insect attack). *Physical life* is to be contrasted with *service life*. Service life, which averages about 25 years, is defined as the time from placement until replacement, regardless of whether replacement is for reasons of decay or for obsolescence, line relocation, fire, lightning, collisions, tornados, wind accompanying sleet, etc.

Periodic inspections serve to classify poles with respect to decay as: (1) sound, (2) decayed but serviceable to the next inspection, or (3) failed. With this classification there is for each pole a time interval t_d from placement to the first appearance of decay, and a time interval t_f from placement to failure. The difference, $t_f - t_d$, represents the time from the first appearance of decay until the decay has progressed to such an extent that the pole should be classed as failed. The time t_f represents the physical lifetime of the pole.

For purposes of scheduling pole line inspections the distribution functions of t_d, t_f, and $t_f - t_d$ would provide useful information. For the type of schedule discussed in the present paper, information concerning the general nature of distribution function of t_f is sufficient.

Based on experience and on experimental data presented in this paper, the lognormal density function provides a useful model for the distribution of t_d and of t_f. Experience indicates that adequately treated poles remain relatively immune to decay even at advanced ages. Lognormal density functions are shown to provide reasonably accurate descriptions of the experimental data concerning the time to decay t_d. Since some of the inspected poles were decayed but not failed, there is relatively less information concerning t_f than t_d. One reason for not presenting available data concerning t_f is that the definition of a failed pole varies in accordance with the application — in particular, in the test plot experiments a pole is classed as failed only when the decay has advanced to such an extent that the pole is of no further value in the experiment. However, based on available information it appears that lognormal density functions are useful in describing the distribution of t_f as well as t_d.

Relatively little data are available concerning $t_f - t_d$, but considerable variability is evident. In some cases decay spreads rapidly, while in others it makes very little progress between consecutive inspections. Such variations are not inconsistent with the concept that both t_d and t_f have lognormal distributions. As will become apparent, lack of specific information concerning the distribution of $t_f - t_d$ is of little consequence for the type of inspection plan considered here, nor is the fact that only very rough approximations to the distributions of t_d and t_f can be provided.

From 1945 through 1961 the American Telephone and Telegraph Company recommended that full-length treated southern pine poles be inspected at eighteen years from placement and at six-year intervals thereafter. These recommendations were revised in November, 1961, based partly on results reported in the present paper, which (1) supports the concept of constant intervals between inspections following an initial period of no inspections (due to indications of relatively constant failure rates), and (2) provides some information concerning the differences between the average physical lifetimes of poles in the North and the South.

The main shortcoming of the previous schedule was that it did not take into consideration the fact of earlier decay in the South than in the North. The revision has separate schedules for the North and the South.

As in the past, adherence to recommended schedules is expected to vary from Company to Company in response to their particular appraisals of the need for inspections, based on previous inspection results in their areas. The recommended inspection intervals are meant to serve as guides. If in particular applications consistently too many or too few failures, relative to a chosen economic level, are found, it might be well to adjust the frequency of inspection.

The primary purpose of this paper is to present background information concerning the physical lifetime of treated southern pine poles. This information may prove useful in adjusting the recommended schedules, should that be desirable. A model schedule, employing three-way classifications for geographical locations and for economic classes of poles, is presented in Table I of Section II. The use of three classes, rather than two, provides a buffer between extremes.

Section III discusses briefly the nature and causes of decay and of treatment to prevent decay. Section IV presents results of some of the pertinent field tests conducted as a part of a continuing program of the Outside Plant Laboratory of the Bell Telephone Laboratories for evaluating the effectiveness of various preservative treatments. An analysis of these results is contained in Section V. One conclusion is that the lognormal density function describes the physical lifetime distribution of pressure-treated southern pine poles more realistically than the normal density function. The normal density function, which is used to advantage in many applications as a first approximation to lifetime distributions, fails to account for the many long-lived individual poles. For example, if, as has been assumed in some applications, the physical lifetime of a pole has a normal distribution with an average of 35 years and a standard deviation of 6-10 years, then a 60-year old pole would have a high probability of failing within the next six years, say. However, experience indicates that failure of such a pole in this 6-year interval is very unlikely — i.e., the 6-year failure rate at age 60 years is small. It is in this connection that the lognormal density function proves useful, for it is characterized by a failure rate function that increases to a maximum and then gradually decreases with age. This is to be contrasted with the ever-increasing failure rate function characterizing the normal density function.

One consequence of the assumption that the physical lifetime of pressure-treated southern pine poles has a lognormal, rather than normal, distribution function is that there is no need to increase the frequency of inspection of such poles as they age. Another consequence concerns estimates of the average physical lifetime. If early failures would indicate an average lifetime of 35 years, assuming a normal distribution function, these same failures might indicate an average lifetime of 100 years, assuming a lognormal distribution function. This sharp increase in estimated average lifetime reflects the fact that some of the individuals may be expected to have extremely long physical lifetimes. As noted in Section VI, estimates of average physical lifetime based on the assumption that a particular distribution function applies should be viewed with restraint appropriate to the application. It would be well to temper such estimates with supplementary information. For example, under certain conditions (i.e., when failed poles are soon replaced, and when there are an insignificant number of replacements for reasons other than decay) the inverse of the proportion of poles that fail annually provides a rough estimate of the average physical lifetime — e.g., an average physical lifetime of fifty years is indicated if over the period of several years an average of two per cent per year of poles in line fail due to decay.

Comparisons of average physical lifetimes can be misleading, for in most applications the distribution of early failures is of primary importance. Potential long-lived poles may be replaced early for reasons other than decay, since the average service life is about 25 years. The proportion of poles expected to fail within 25 years, or some other selected value, might serve better than average physical lifetime as a measure of the effectiveness of treatment. Alternatively, the expected time until a selected proportion of poles can be expected to have failed might prove useful for comparisons. For example, the median might be used.

II. INSPECTION SCHEDULES FOR SOUTHERN PINE POLES

A model for inspection schedules for southern pine poles is shown in Table I. The zones referred to are delineated on the map that forms Fig. 1. The zones serve to separate the inspection results into three classes: Zone 3 represents areas where environmental conditions are relatively favorable to decay; Zone 1 represents areas of relatively little decay; and Zone 2 serves as a buffer between the two extremes. The zone boundaries are rather arbitrary. The area west of the eastern boundary of the Mountain States Telephone and Telegraph Company has not been included because southern pine poles, with which this paper is primarily concerned, are not generally used in the West, and therefore no inspection results were obtained. For a given quality of treatment, poles definitely have longer life expectancies in Zone 1 than in Zone 3. However, there is no sharp demarcation between adjacent zones. Quality of treatment, particularly the amount of preservative retained after treatment, appears to be of first importance in determining the lifetime of a pole. Poorly treated poles placed in the North may be expected to fail sooner than well treated poles placed in the South.

The classification of pole lines according to economic value is in recognition of the fact that the inspection of poles is largely an economic matter, though safety is also an important factor. The classification in Table I is primarily for illustrative purposes. It may prove helpful to

TABLE I

Economic Class of Line	Zone 1		Zone 2		Zone 3	
	x	y	x	y	x	y
1. (Toll)	8	18	7	15	6	12
2. (Exchange)	10	21	8	18	7	15
3. (Rural)	12	24	10	21	8	18

Inspect pole line every x years. On new line, first inspection should be made at age y years. For replacement poles, omit first regular inspection only.

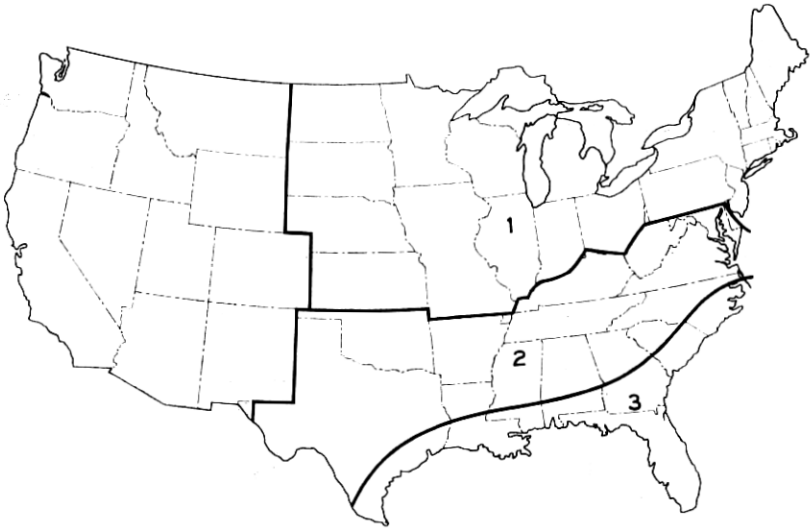
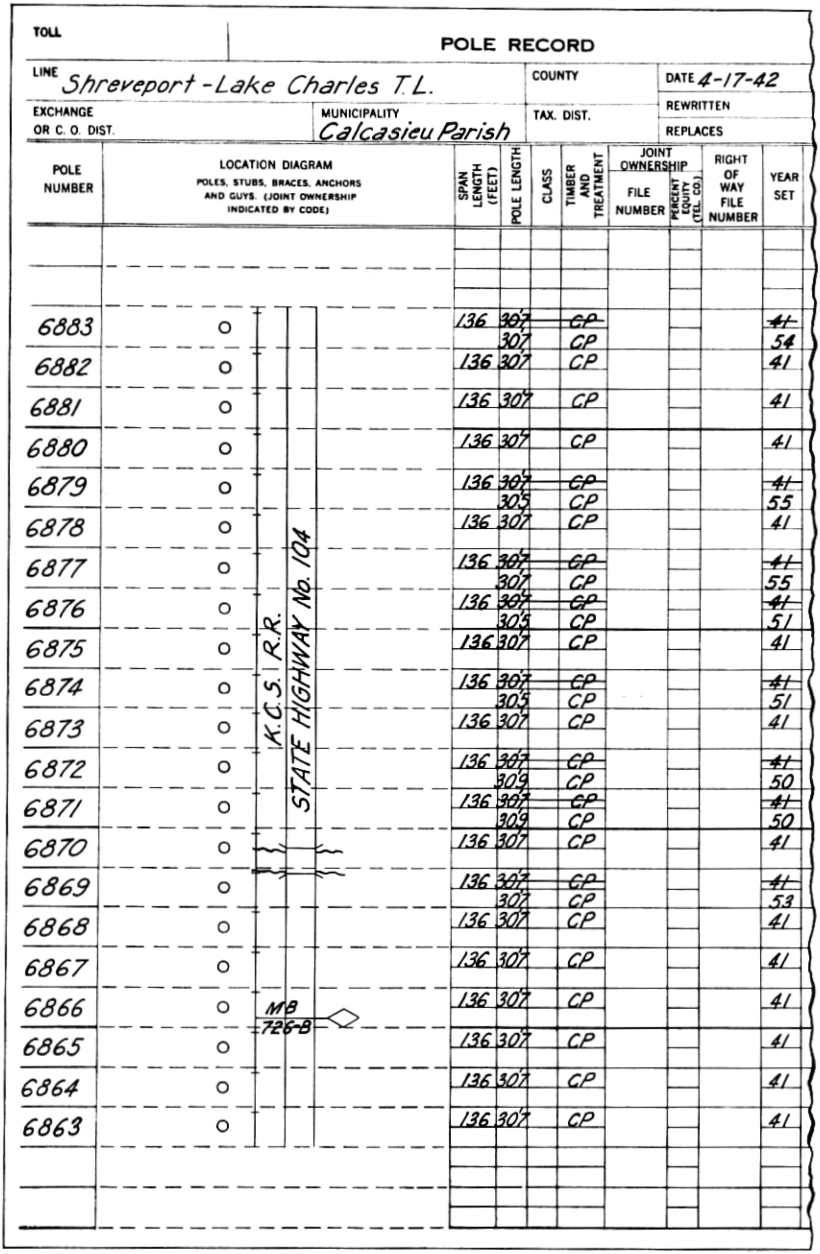


Fig. 1 — Zones used for study of decay in poles.

imagine that the inspection intervals of Table I were selected so that the per cent of failures expected in the three economic classes would be in the ratio of 6:7:8, as might be the case in Zone 3. It has been noted that as the interval between inspections is increased, so is the tendency of inspectors to classify serviceable decayed poles as failures.

Another feature of Table I is that it presumes that complete lines of poles are inspected, omitting young replacements. To illustrate the procedure that might be used, consider the typical pole record, an E-297 form, shown as Fig. 2. Poles on this particular line, which is a toll line in Zone 3, would first be inspected at age 12, in 1953. The replacement poles set in 1950 and 1951 would first be inspected in the inspection of 1959.

Presumably, 100 per cent of the eligible poles in a line will be inspected. Questions may arise as to the feasibility of employing a sampling plan so that inspections may be halted on a line when few failures are encountered in a random sample of poles. Under certain conditions, such as when a line is to be inspected for the first time, a sampling plan might prove useful. However, the appropriate conditions are not often encountered when routine inspections are made. Furthermore, the results of previous inspections in the same area may prove as useful in evaluating the conditions to be expected on a typical line as inspection results from a sample of poles from that line. If the proportion of failures



TOLL

POLE RECORD

LINE *Shreveport - Lake Charles T.L.* | COUNTY | DATE *4-17-42*

EXCHANGE OR C. O. DIST. | MUNICIPALITY *Calcasieu Parish* | TAX. DIST. | REWRITTEN | REPLACES

POLE NUMBER	LOCATION DIAGRAM POLES, STUBS, BRACES, ANCHORS AND GUYS. (JOINT OWNERSHIP INDICATED BY CODE)	SPAN LENGTH (FEET)	POLE LENGTH	CLASS	TIMBER AND TREATMENT	JOINT OWNERSHIP FILE NUMBER	JOINT OWNERSHIP PERCENT EQUITY (TEL. CO.)	RIGHT OF WAY FILE NUMBER	YEAR SET
6883	o	136	~~30^7~~ 30^7		~~CP~~ CP				~~41~~ 54
6882	o	136	30^7		CP				41
6881	o	136	30^7		CP				41
6880	o	136	30^7		CP				41
6879	o	136	~~30^7~~ 30^5		~~CP~~ CP				~~41~~ 55
6878	o	136	30^7		CP				41
6877	o	136	~~30^7~~ 30^7		~~CP~~ CP				~~41~~ 55
6876	o	136	~~30^7~~ 30^5		~~CP~~ CP				~~41~~ 51
6875	o	136	30^7		CP				41
6874	o	136	~~30^7~~ 30^5		~~CP~~ CP				~~41~~ 51
6873	o	136	30^7		CP				41
6872	o	136	~~30^7~~ 30^9		~~CP~~ CP				~~41~~ 50
6871	o	136	~~30^7~~ 30^9		~~CP~~ CP				~~41~~ 50
6870	o	136	30^7		CP				41
6869	o	136	~~30^7~~ 30^7		~~CP~~ CP				~~41~~ 53
6868	o	136	30^7		CP				41
6867	o	136	30^7		CP				41
6866	o	136	30^7		CP				41
6865	o	136	30^7		CP				41
6864	o	136	30^7		CP				41
6863	o	136	30^7		CP				41

Fig. 2 — Typical pole record.

found on routine inspections in a general area over a long period of time is not consistent with a predetermined economic level, it may be well to adjust the interval between inspections in that general area.

Thoroughness of inspections may vary with the application. The procedures followed on routine inspections are somewhat different from those followed in this study on the experimental poles. In the latter case the instructions were:

(a) Record information found at the brand ten feet from the butt (species, preservative, supplier, class and length, and year treated) and pertinent comments.

(b) Visually examine above the ground line for mechanical damage, woodpecker holes, split tops, etc. Record findings.

(c) Remove earth from around the pole to a depth of about one foot (deeper in the drier areas of the country) to allow a visual examination and prodding in the critical sector just below the ground line.

(d) Sound the pole with a hand axe from below the ground line to eight feet above the ground line or as high as can be reached conveniently.

(e) In cases of suspicion of internal decay, as determined by sounding, take an increment boring and examine the wood thus removed. Make the boring at right angles to the vertical axis of the pole. Be sure to plug the hole with a locust heartwood or treated plug. Record findings.

(f) Rate the pole as (1) sound, (2) decayed but serviceable, or (3) failed.

At the test plot inspections, the sections are jacked from the ground for a thorough examination. In this way, too, disturbance of the soil is kept at a practicable minimum.

III. DECAY AND ITS PREVENTION

Decay of telephone poles is caused primarily by wood-destroying fungi. The survival and effectiveness of these plants are influenced by certain environmental conditions such as moisture content of the wood, an adequate oxygen supply, and a moderate (60–90°F) temperature. The wood of different species as well as the sapwood and heartwood of a given species varies in susceptibility to decay.

Southern pine is particularly susceptible. To deter or prevent decay, poles of this species are treated with preservatives, of which creosote and pentachlorophenol or mixtures of the two are most common. Generally the preservatives are toxic not only to fungi but also to insects, whose activity constitutes a secondary cause of pole failure.

Economic considerations play a prominent role in the specification of the preservative treatment. The poles with which this paper is concerned were treated with creosote using the empty cell method of treatment. The specifications called for an average of eight pounds of creosote per cubic foot of wood (as measured by gauge). This is sufficient to penetrate most of the sapwood under the empty cell method, which replaced the full cell method in the early 1930's in Bell System specifications. The full cell method used more creosote — twelve pounds per cubic foot, on the average — but the penetration was not as deep or as uniform, in general. Poles treated under the 12-pound full cell method had more of a tendency to decay internally, and, in addition, were more subject to "bleeding" than poles treated under the 8-pound empty cell method. In fact, the problem of bleeding played an important role in specifying the amount of creosote to be used. More creosote would have resulted in longer-lasting poles, but bleeding would have been more prevalent.

Fig. 3 indicates how the actual amount of creosote absorbed varies from pole to pole within one treating lot.[1] Theoretically, decay is least likely and bleeding is most likely in those poles with the most creosote, though relative volume of sapwood, presence of defects, quality of treatment, and other factors enter the picture. Quality of treatment depends on such things as quality of creosote, conditioning of poles

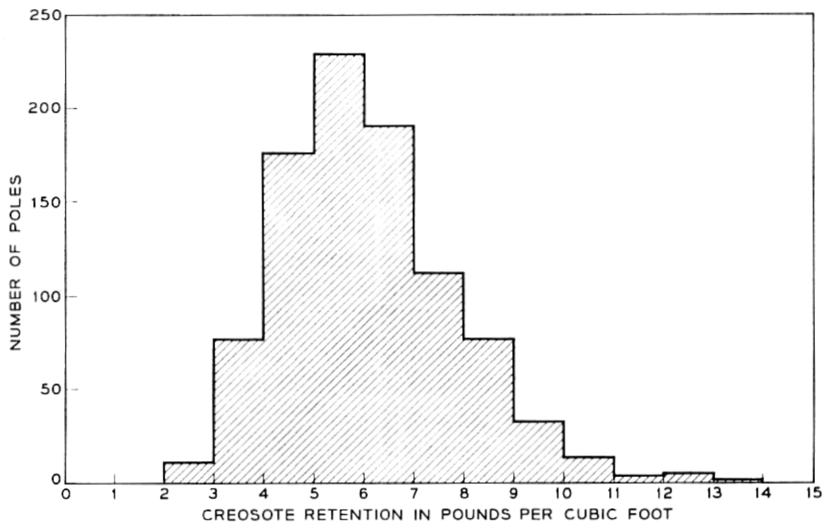


Fig. 3 — Creosote retention in individual poles as determined by gain in weight during treatment.

prior to creosoting, the treating cycle, the moisture content of the poles, and the uniformity and thoroughness of absorption.

IV. RESULTS OF FIELD TESTS

The description of lifetime distributions of items such as poles is often based on observations of lifetimes of a sample of similar items. The best description obtainable from the sample must await the failure of the longest-lived items in the sample. For example, the average cannot be estimated very well from only the early failures unless the nature of the distribution function is known. By the time the last failures occur, the then-current items may have properties that differ from the original items due to changes in design, production methods, or materials. Therefore a compromise between timeliness and accuracy is often necessary for practical reasons.

Commercial treatment for the Bell System of southern pine poles with preservatives using the empty cell method began in the early 1930's and continues today under essentially the same conditions, except that the preservative is now a fortified one containing both creosote and pentachlorophenol. In describing the lifetime distribution of these poles, we have the advantage of almost thirty years of experience. Foremost in usefulness are results of Laboratories field tests on sets of poles and ten-foot pole sections treated under controlled conditions in the 1930's and periodically inspected since that time.

4.1 *Test Plot Results*

Fig. 4 shows the results of inspections of groups of 10-foot pole sections that were treated in 1935 and 1936 and placed in 1936 and 1937 in test sites at Gulfport, Mississippi, and Chester, New Jersey. The sections were placed shortly after treatment. The sections represent either top, center, or bottom thirds of 30-foot poles.

There were 60 sections at each site in the 1935 series, and 55 in the 1936 series. Fig. 4 shows on lognormal probability paper the per cent of these poles classed as decayed (including those classed as failed) on the inspections, which were usually made biannually. Since there is no place on this lognormal paper to show zero per cent decayed, the early inspections at Chester are not represented. Because of the nature of the supporting data, the line through the Chester data was drawn parallel to the Gulfport line.

The advantage of using lognormal probability paper for Fig. 4 is that if the lognormal distribution describes the time to decay, t_d, then the points will, with allowances for sampling variability, fall roughly along a straight line. Also, the fact that the points representing the Gulfport data do fall roughly along a straight line provides some evidence of the applicability of the lognormal distribution in this case, and, by inference, in similar cases. The line drawn through the Gulfport data may be used for estimates such as the time when 80 per cent of the sections can be expected to have decayed. This estimate would be 90 years. A different estimate would be obtained if a different line were selected to represent the Gulfport data. Such estimates are of limited accuracy.

As illustrated by Fig. 3, the creosote content varies widely among poles of a given charge. An important result of the test plot study was the high correlation between time to decay and creosote content — that is, in general decay appeared earliest in those pole sections with the least initial creosote content. This fact was emphasized in earlier papers.[2,3]

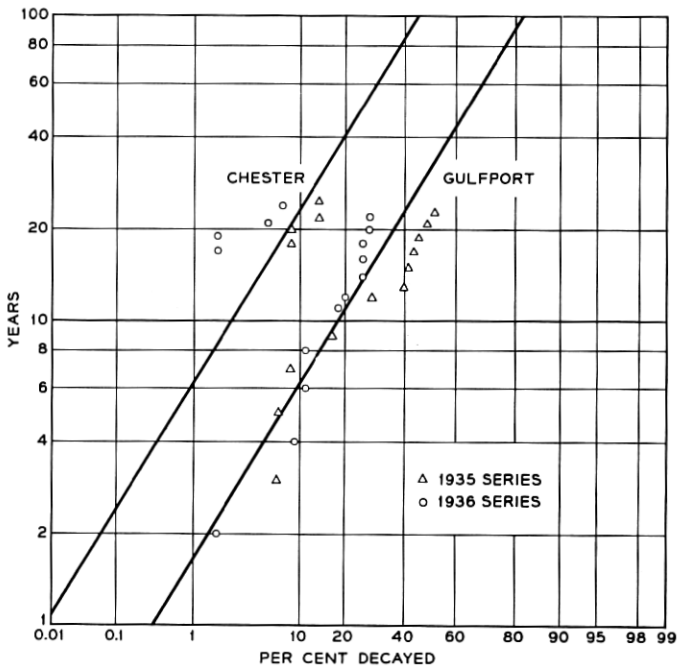


Fig. 4 — Distribution of time to decay, southern pine poles.

4.2 *Some Field Test Results*

Fig. 5 shows on lognormal probability paper the percentage of poles found decayed in several lines which were inspected three times. Most of these lines consist of poles treated under observation of Laboratories personnel in the early 1930's. In cases where the initial creosote content of the individual poles was measured, most of the early failures were poles that retained a relatively low amount of creosote.

4.3 *Other Results*

Because of (1) the limited sample sizes and environmental conditions, and (2) the possibility of bias due to close surveillance of the treatment in the tests whose results have been described thus far, it was decided to inspect representative lines throughout the country. Representative results of these inspections are shown in Figs. 6 through 8 for Zones 1 through 3 respectively. Most of the data for Figs. 6 and 8 were obtained in 1960; Fig. 7 is based on data collected in the early 1950's. The line drawn on Figs. 6–8 is for purposes of illustration. It is line 4 of Fig. 10, and it represents a lognormal distribution with a median of 80 years and a failure rate of roughly one per cent per year (more specifi-

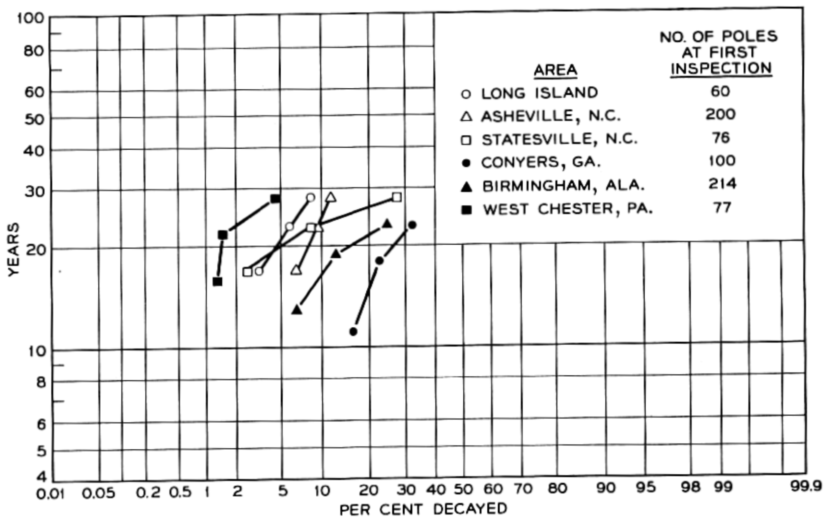


Fig. 5 — Distribution of time to decay, southern pine poles.

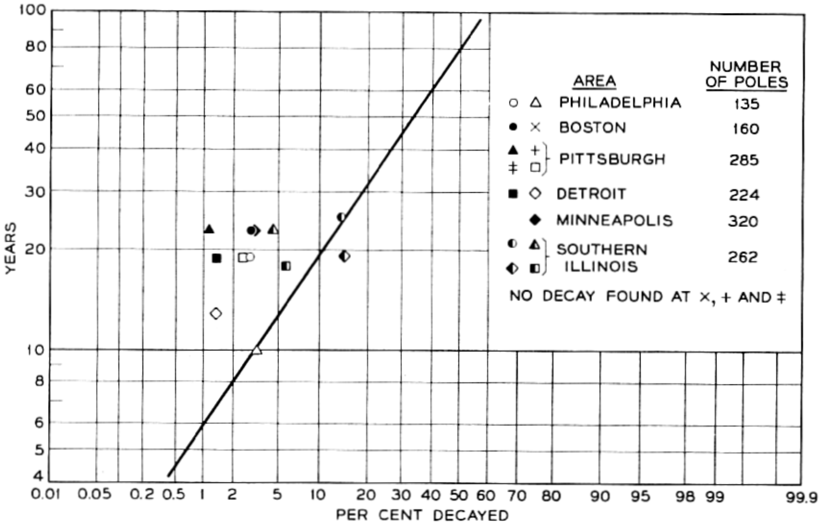


Fig. 6 — Inspection results, Zone 1.

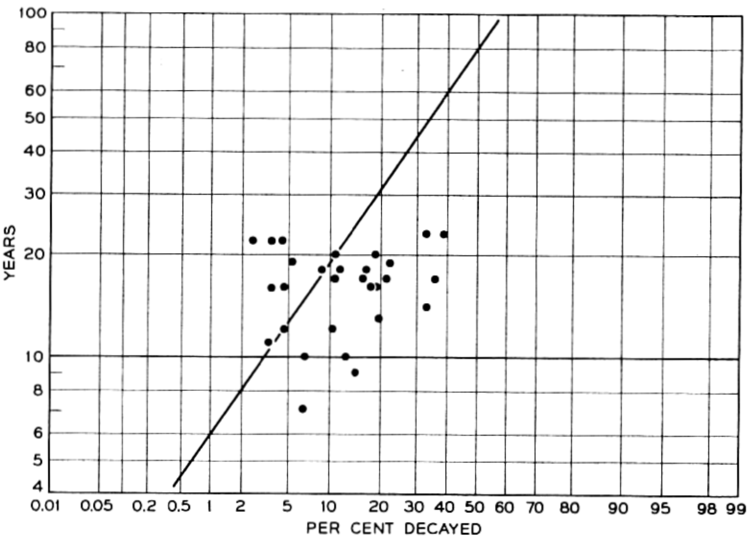


Fig. 7 — Inspection results, Zone 2.

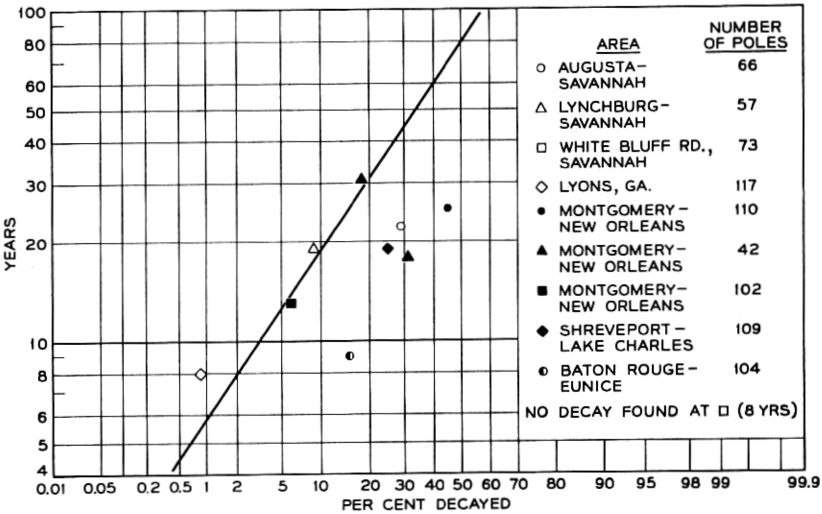


Fig. 8 — Inspection results, Zone 3.

cally, after fifteen years of age about one per cent of the poles that are sound at the beginning of a year will exhibit decay by the end of that year). Based on the data of Figs. 6–8, it appears that most of the pole lines in Zone 1 have failure rates of less than one per cent per year, and most of the pole lines in Zones 2 and 3 have failure rates greater than one per cent per year. Some of the discussion in Section V should prove helpful in interpreting the data.

4.4 *Sources of Variability of Results*

There are a number of sources of variability in the results presented. First of all, there are sampling errors. To illustrate the meaning of this term, consider a large number of poles treated under fixed conditions and subjected to the same environmental conditions. Let p_t be the probability that a pole selected at random will be decayed at time t. If N poles are inspected at time t, and x of these are classified as decayed, then x/N is an estimate of p_t, and $(x/N - p_t)$ is the sampling error. The absolute value of the sampling error may be expected to be reduced by increasing N. The abscissas of the points plotted on Figs. 4 through 8 are subject to sampling errors; the ordinates are also subject to error, because the age of the poles is given only to the nearest year.

Incidentally, the age shown is measured from time of placement until inspection; the time from treatment until placement is also of importance, but is seldom known.

There are also inspection errors. No two inspectors will consistently agree in their classification of the poles they inspect. As noted in Section II, our inspectors classified poles as (1) sound, (2) decayed but serviceable, or (3) failed. Cases of internal decay and incipient external decay may be noted by one inspector but not by another. It is also difficult to differentiate sharply between a badly decayed pole and a failed pole. How advanced should decay be before the pole is classed as failed? One can specify a proportion of the cross section that must be decayed before a pole is classed as failed, but measurements, particularly of internal decay, are crude. Errors due to differences between inspectors were minimized because most of inspections were by two Laboratories employees following the same general procedure.

In obtaining an estimate of the per cent p_t of poles decayed at age t, it is not adequate to select for inspection a set of N poles of age t at random from the field. The difficulty is that those poles of age t that had been previously removed because of decay would be missing from the sample. For example, suppose 50 per cent of poles of age 40 years have been removed for failure due to decay, and suppose we select at random 100 of the remaining poles for inspection and find ten of them decayed — the proper estimate of per cent decayed at age 40 years is not $\frac{10}{100} = 10$ per cent, but rather $\frac{110}{200} = 55$ per cent. Of course, in practice the per cent of poles of the selected age that have already been removed for decay is generally unknown. To minimize this difficulty, the poles inspected in 1960 in representative parts of the country were in lines of 100 or more poles that were treated and placed in a selected year. Every remaining original pole was inspected, and the estimated per cent of nonsound poles is taken as $(N_d + R_d)/(N_i + R_d)$ where R_d is the number of replacements due to decay in the section of line inspected, N_i is the total number of poles inspected, and N_d is the number of inspected poles classed as either decayed or failed. Because the number R_d had to be obtained (estimated in some cases) from pole records, the choice of lines was restricted to those where reasonably complete histories were available.

In some of the nonexperimental lines inspected prior to 1960 it was impossible to ascertain the number of poles in the inspection lot that had previously been removed for decay. For this reason, some of the estimates of per cent decayed shown in Fig. 7 may be too low.

V. DISTRIBUTION OF PHYSICAL LIFETIME OF CREOSOTED SOUTHERN PINE POLES

5.1 *Selection of Lognormal Distribution Function*

Section IV described results of inspections of selected groups of creosoted southern pine poles. From these results and other experience we would like to establish the nature of an appropriate lifetime distribution function. Then we can estimate parameters — generally average and standard deviation — that determine the particular equation to be used for a specific application. The parameters must reflect the influences of the factors, such as climate, that affect the physical lifetime distribution of the poles under consideration.

Three common types of distribution functions that may prove of practical value in describing the physical lifetime distribution of creosoted southern pine poles within the broad ranges of accuracy needed for setting up inspection schedules are: (1) normal, (2) lognormal, and (3) gamma (the exponential distribution is a special case of the gamma distribution). Fig. 9 illustrates the nature of these types of distribution functions, assuming an average lifetime of 40 years in each case. The top row of figures shows the density functions, which are

$$\begin{aligned} f(x) &= \left\{\exp -\frac{(x-\mu)^2}{2\sigma^2}\right\} \Big/ \sqrt{2\pi}\,\sigma, \\ &= \left\{\exp -\frac{(\log x-\mu)^2}{2\sigma}\right\} \Big/ \sqrt{2\pi}\,x\sigma, \quad \text{and} \\ &= \{\exp - \lambda x\}\,\lambda^{k+1}\,x^k/k!, \end{aligned}$$

respectively, for normal, lognormal, and gamma; μ, σ, λ and k are parameters that are to be chosen to suit the application. The normal curve is symmetrical about its average value, μ. The probability that a pole will fail within x years is represented by the fraction of the total area under the curve that falls to the left of abscissa x. The second row of curves shows the fraction surviving,

$$S(x) = \int_x^\infty f(x)\,dx.$$

That is, it shows at abscissa x the probability that a pole will survive beyond x years. The third row of curves shows the instantaneous failure rate, $f(x)/S(x)$. This is the limit, as Δx approaches zero, of the probability that a pole that has survived to x years will fail within the

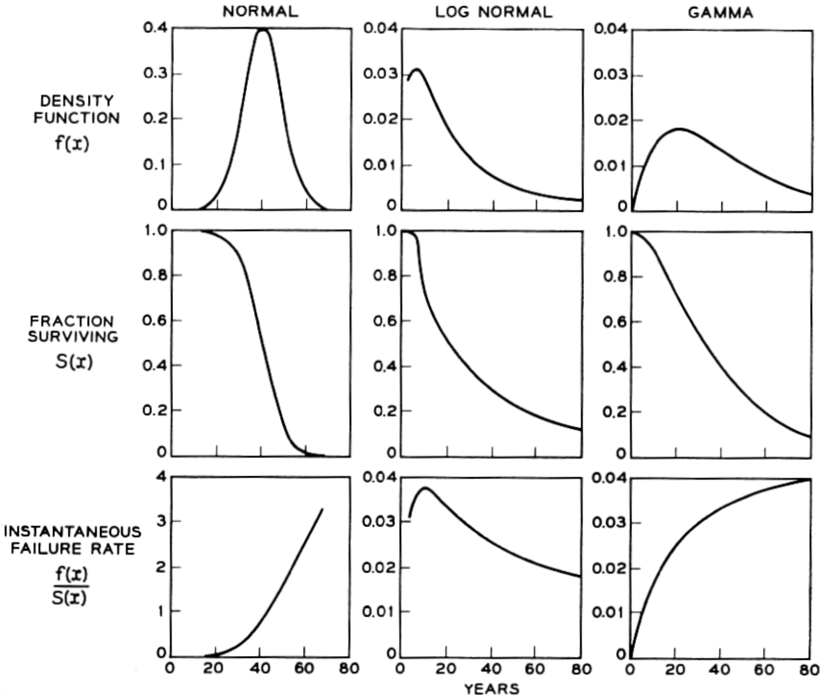


Fig. 9— Comparison of normal, lognormal, and gamma density functions.

interval between x and $x + \Delta x$. Later we shall be concerned with the six-year failure rate, which involves Δx of six years. The three types of distribution functions have different types of failure rate functions. The failure rate for the normal distribution increases monotonically and that for the gamma distribution approaches a constant, while the failure rate for the lognormal distribution increases to a maximum and then gradually decreases. Experience indicates that the failure rate functions of the gamma and lognormal distributions are considerably more realistic than that of the normal distribution. The normal distribution fails to account for the many long-lived poles observed in the field. If the failure rate of poles increased with age as indicated by the normal distribution, special attention should be given to poles as their ages passed beyond their expected values.

While for purposes of choosing inspection intervals, either the lognormal or gamma distribution would prove suitable, there are reasons to believe the lognormal distribution provides a more realistic description of failure rates of older poles. To explain why failure rates may decrease with age, we shall describe briefly some of the present thinking on the effectiveness of preservatives.

When poles are treated, there is variation in effectiveness of treatment even among poles in a single treatment charge. As illustrated by Fig. 3, some poles absorb and retain more than others; also, the uniformity of absorption may vary significantly around the circumference and along the length of a given pole. Let us assume for purposes of illustration that the amount of preservative retained in a selected cubic section near the surface of a pole is a good measure of the effectiveness of the treatment in deterring decay. Previous studies of the effectiveness of preservatives indicate that the expected life of a pole under fixed environmental conditions increases with increasing preservative content. Of course, there is an upper limit to the amount of preservative that wood can absorb. Further, depending on type of (1) wood, (2) preservative, (3) fungus, and (4) environment, there is a critical value of preservative content above which the wood is protected from that fungus. If, after the evaporation and migration that occurs with aging, the preservative content remains above the highest critical value (often referred to as the "threshold retention") for any fungus likely to be encountered, presumably the wood will never decay. Thus there is the possibility of a pole lasting indefinitely unless some new decay organism appears. It is primarily due to the existence of such poles that the lognormal distribution function appears to present a better description of pole lifetimes than either the normal or the gamma functions. Future results may indicate improvements over the lognormal distribution function in accounting for such poles. A recent book[4] discusses the lognormal distribution and the nature of many of its applications.

5.2 *Family of Lognormal Distribution Functions*

Once the lognormal distribution has been chosen to represent physical lifetime distributions, there remains the problem of selecting the appropriate parameters to use for a particular pole line. Two parameters are to be selected, and these may be thought of as determining the slope and an intercept of a straight line on lognormal probability paper. When two or more points are plotted on such paper to represent the per cent of failed poles found on two separate inspections of a given lot of poles, a straight line can be drawn through or near such points to represent the physical lifetime distribution. A single point will not suffice, and little confidence can be placed on a line drawn through a pair of points. Considerably more confidence could be placed in the straight line if we knew its approximate slope, for example, or if experience indicated that it was likely to belong to a particular family of straight lines. In these cases a single point would be of use.

Fig. 10 shows on lognormal probability paper a family of parallel straight lines having slopes roughly the same as that of the line of Fig. 4 through the Gulfport test plot data. These lines, which will be called Curves 1 through 6, are for purposes of illustration. If they represented physical lifetime distributions of poles in six different poles lines, they would indicate that these poles had median lifetimes of 10, 20, 40, 80, 160, and 320 years, respectively. The averages are 1.87 times the median in each case.

Fig. 11 shows the 6-year failure rate functions for the Curves 1 through 6 of Fig. 10. Notice that the failures rates are slow to change.

To illustrate the application of Figs. 10 and 11, consider the pole line from Asheville, N.C., represented on Fig. 5. Assume that the distribution of t_f rather than t_d is represented in Fig. 5. This pole line would have characteristics somewhere between those represented by Curves 4 and 5. Looking at Fig. 11, we would be led to expect about 4 or 5 per cent of the poles surviving at 30 years to fail within the next six years. The median lifetime of these poles might be expected to be roughly 100 years, and, correspondingly, an average lifetime of 187 years is indicated, based on the assumptions used.

Considering the existence of sampling errors, the results shown on

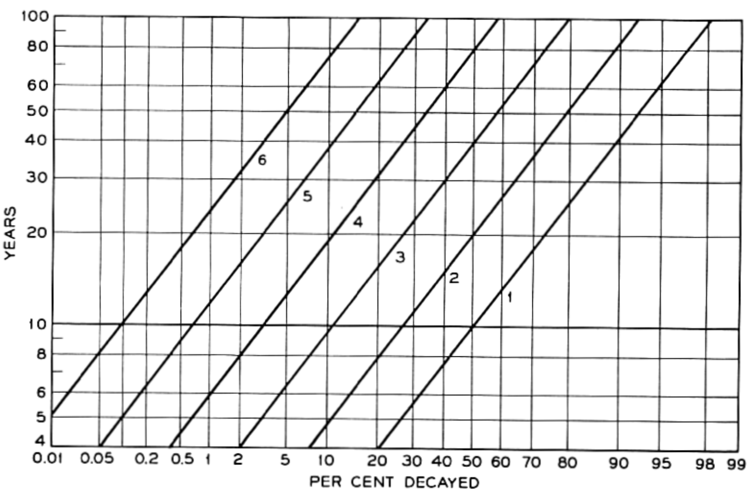


Fig. 10 — A family of lognormal density functions.

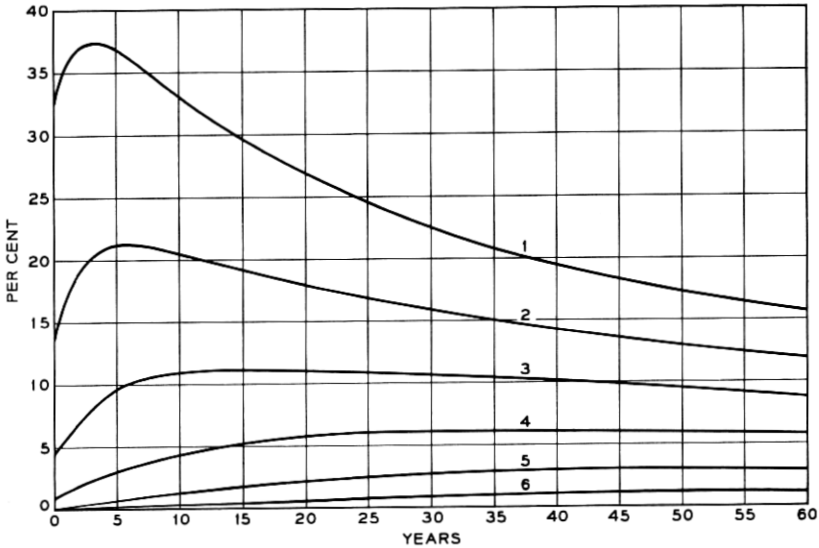


Fig. 11 — Six-year failure rates for curves of Fig. 10.

Fig. 5 are remarkably consistent among themselves, and they provide some support for the use of a family of distributions such as represented in Figs. 10 and 11. Of course, allowances must be made for the differences between time t_d to the first appearance of decay and the time t_f of failure. As a first approximation we might estimate that $t_f - t_d$ averages 6 years in the South and 10 years in the North. A comparison of the results shown in Figs. 5 through 8 with Figs. 10 and 11 leads to the conclusion that median pole lines (half of the pole lines will be better, half worse) in Zones 1, 2, and 3, respectively, will have failure rates in the order of 0.5, 1.3, and 1.5, per cent per year, respectively. This conclusion played a prominent role in the design of the inspection schedule of Table I.

VI. SUMMARY

An analysis of results of inspections of creosoted southern pine poles in test plots and in selected lines in the field indicates that their physical lifetime distribution appears to be adequately described by the lognormal distribution function. There is no evidence that the failure rate of these poles increases as they survive beyond their life expectancy;

indeed, there is reason to suspect that the failure rate may decrease, thereby supporting the contention that the lognormal distribution is suitable.

If the lognormal distribution is appropriate, the average physical lifetime of these poles is considerably greater than commonly believed. One explanation of this is that some of the poles may "never fail." Because of lack of evidence concerning these poles as they reach an advanced age, extrapolation of results from the first thirty years of pole life must necessarily be made with restraint. For this reason, estimates of average physical life should allow considerable latitude for accuracy. Under this circumstance, a rule-of-thumb for such estimates that may prove useful is as follows: (1) Estimate the average annual failure rate of poles in the 30–50 year age bracket. (2) The reciprocal is an estimate of the life expectancy of these poles. For example, suppose in a given area 10,000 poles in this age bracket were inspected and declared serviceable in 1950, and of these, 600 were declared to have failed by 1956. Then the failure rate is roughly one per cent per year, and an estimate of the life expectancy of these poles is $(0.01)^{-1} = 100$ years. This rule-of-thumb will indicate in general that the life expectancy is well over 35 years.

The results also support the observation that poles last longer in the North than in the South. Evidently this is due to a better environment for growth (length of growing season, annual rainfall, and average temperature and humidity are considered to be of primary importance) of wood-destroying fungi in the South. This fact leads to the requirement of more frequent inspections in the South to maintain a given level of pole line quality.

VII. ACKNOWLEDGMENTS

This paper records results for which a number of people are responsible, particularly those who set up test plot experiments in the 1930's. These early experiments, as well as the content of this paper, benefited from contributions of G. Q. Lumsden and J. Leutritz, Jr. While with Bell Telephone Laboratories, A. H. Hearn of the American Telephone and Telegraph Company was responsible for some of the inspections whose results are reported; he also made arrangements for later inspections. The inspections of 1959–1960 were made by James A. Taylor, who also helped in the preparation of this paper while at Bell Laboratories. We are also grateful to many people in various associated companies, particularly Southern Bell, for their interest and cooperation.

REFERENCES

1. Lumsden, G. Q., Fortified Wood Preservatives, Forest Products Jour., **10,** 1960, pp. 456–462. Bell System Monograph 3718.
2. Colley, R. H., The Evaluation of Wood Preservatives, B.S.T.J., **32,** January and March, 1953, pp. 120–169, 425–505.
3. Lumsden, G. Q., A Quarter Century of Evaluating Pole Preservatives, Proc. of the Amer. Wood-Preservers' Association, **48,** 1952, pp. 27–47.
4. Aitchison, J., and Brown, J. A. C., *The Lognormal Distribution*, Cambridge University Press, 1957.