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An American National Standard

Standard Practice for Dealing With Outlying Observations[1]

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1. Scope

1.1 This practice covers outlying observations in samples and how to test the statistical significance of them. An outlying observation, or "outlier," is one that appears to deviate markedly from other members of the sample in which it occurs. In this connection, the following two alternatives are of interest:

1.1.1 An outlying observation may be merely an extreme manifestation of the random variability inherent in the data. If this is true, the value should be retained and processed in the same manner as the other observations in the sample.

1.1.2 On the other hand, an outlying observation may be the result of gross deviation from prescribed experimental procedure or an error in calculating or recording the numerical value. In such cases, it may be desirable to institute an investigation to ascertain the reason for the aberrant value. The observation may even actually be rejected as a result of the investigation, though not necessarily so. At any rate, in subsequent data analysis the outlier or outliers will be recognized as probably being from a different population than that of the other sample values.

1.2 It is our purpose here to provide statistical rules that will lead the experimenter almost unerringly to look for causes of outliers when they really exist, and hence to decide whether alternative 1.1.1 above, is not the more plausible hypothesis to accept, as compared to alternative 1.1.2, in order that the most appropriate action in further data analysis may be taken. The procedures covered herein apply primarily to the simplest kind of experimental data, that is, replicate measurements of some property of a given material, or observations in a supposedly single random sample. Nevertheless, the tests suggested do cover a wide enough range of cases in practice to have broad utility.

2. Referenced Documents

2.1 *ASTM Standards:*[2]

E 456 Terminology Relating to Quality and Statistics

3. Terminology

3.1 *Definitions:* The terminology defined in Terminology E 456 applies to this standard unless modified herein.

3.1.1 *outlier*—see **outlying observation**.

3.1.2 *outlying observation*, *n*—an observation that appears to deviate markedly in value from other members of the sample in which it appears.

4. Significance and Use

4.1 When the experimenter is clearly aware that a gross deviation from prescribed experimental procedure has taken place, the resultant observation should be discarded, whether or not it agrees with the rest of the data and without recourse to statistical tests for outliers. If a reliable correction procedure, for example, for temperature, is available, the observation may sometimes be corrected and retained.

4.2 In many cases evidence for deviation from prescribed procedure will consist primarily of the discordant value itself. In such cases it is advisable to adopt a cautious attitude. Use of one of the criteria discussed below will sometimes permit a clear-cut decision to be made. In doubtful cases the experimenter's judgment will have considerable influence. When the experimenter cannot identify abnormal conditions, he should at least report the discordant values and indicate to what extent they have been used in the analysis of the data.

4.3 Thus, for purposes of orientation relative to the over-all problem of experimentation, our position on the matter of screening samples for outlying observations is precisely the following:

4.3.1 *Physical Reason Known or Discovered for Outlier(s):*

4.3.1.1 Reject observation(s).

4.3.1.2 Correct observation(s) on physical grounds.

4.3.1.3 Reject it (them) and possibly take additional observation(s).

4.3.2 *Physical Reason Unknown—Use Statistical Test*:

4.3.2.1 Reject observation(s).

4.3.2.2 Correct observation(s) statistically.

4.3.2.3 Reject it (them) and possibly take additional observation(s).

4.3.2.4 Employ truncated-sample theory for censored observations.

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[1] This practice is under the jurisdiction of ASTM Committee E11 on Quality and Statistics and is the direct responsibility of Subcommittee E11.10 on Sampling / Statistics.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

4.4 The statistical test may always be used to support a judgment that a physical reason does actually exist for an outlier, or the statistical criterion may be used routinely as a basis to initiate action to find a physical cause.

5. Basis of Statistical Criteria for Outliers

5.1 There are a number of criteria for testing outliers. In all of these, the doubtful observation is included in the calculation of the numerical value of a sample criterion (or statistic), which is then compared with a critical value based on the theory of random sampling to determine whether the doubtful observation is to be retained or rejected. The critical value is that value of the sample criterion which would be exceeded by chance with some specified (small) probability on the assumption that all the observations did indeed constitute a random sample from a common system of causes, a single parent population, distribution or universe. The specified small probability is called the "significance level" or "percentage point" and can be thought of as the risk of erroneously rejecting a good observation. It becomes clear, therefore, that if there exists a real shift or change in the value of an observation that arises from nonrandom causes (human error, loss of calibration of instrument, change of measuring instrument, or even change of time of measurements, etc.), then the observed value of the sample criterion used would exceed the "critical value" based on random-sampling theory. Tables of critical values are usually given for several different significance levels, for example, 5 %, 1 %. For statistical tests of outlying observations, it is generally recommended that a low significance level, such as 1 %, be used and that significance levels greater than 5 % should not be common practice.

NOTE 1—In this practice, we will usually illustrate the use of the 5 % significance level. Proper choice of level in probability depends on the particular problem and just what may be involved, along with the risk that one is willing to take in rejecting a good observation, that is, if the null-hypothesis stating "all observations in the sample come from the same normal population" may be assumed correct.

5.2 It should be pointed out that almost all criteria for outliers are based on an assumed underlying normal (Gaussian) population or distribution. When the data are not normally or approximately normally distributed, the probabilities associated with these tests will be different. Until such time as criteria not sensitive to the normality assumption are developed, the experimenter is cautioned against interpreting the probabilities too literally.

5.3 Although our primary interest here is that of detecting outlying observations, we remark that some of the statistical criteria presented may also be used to test the hypothesis of normality or that the random sample taken did come from a normal or Gaussian population. The end result is for all practical purposes the same, that is, we really wish to know whether we ought to proceed as if we have in hand a sample of homogeneous normal observations.

6. Recommended Criteria for Single Samples

6.1 Let the sample of n observations be denoted in order of increasing magnitude by $x_1 \leq x_2 \leq x_3 \leq ... \leq x_n$. Let x_n be the doubtful value, that is the largest value. The test criterion, T_n, recommended here for a single outlier is as follows:

$$T_n = (x_n - \bar{x})/s \tag{1}$$

where:

$\bar{x}$ = arithmetic average of all n values, and
s = estimate of the population standard deviation based on the sample data, calculated as follows:

$$s = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{n-1}} = \sqrt{\frac{\sum_{i=1}^{n} x_i^2 - n \cdot \bar{x}^2}{n-1}} = \sqrt{\frac{\sum_{i=1}^{n} x_i^2 - (\sum_{i=1}^{n} x_i)^2 / n}{n-1}}$$

If x_1 rather than x_n is the doubtful value, the criterion is as follows:

$$T_1 = (\bar{x} - x_1)/s \tag{2}$$

The critical values for either case, for the 1 and 5 % levels of significance, are given in Table 1. Table 1 and the following tables give the "one-sided" significance levels. In the previous tentative recommended practice (1961), the tables listed values of significance levels double those in the present practice, since it was considered that the experimenter would test either the lowest or the highest observation (or both) for statistical significance. However, to be consistent with actual practice and in an attempt to avoid further misunderstanding, single-sided significance levels are tabulated here so that both viewpoints can be represented.

6.2 The hypothesis that we are testing in every case is that all observations in the sample come from the same normal population. Let us adopt, for example, a significance level of 0.05. If we are interested *only* in outliers that occur on the *high side*, we should always use the statistic $T_n = (x_n - \bar{x})/s$ and take as critical value the 0.05 point of Table 1. On the other hand, if we are interested *only* in outliers occurring on the *low side*, we would always use the statistic $T_1 = (\bar{x} - x_1)/s$ and again take as a critical value the 0.05 point of Table 1. Suppose, however, that we are interested in outliers occurring on *either side*, but do not believe that outliers can occur on both sides simultaneously. We might, for example, believe that at some time during the experiment something possibly happened to cause an extraneous variation on the high side or on the low side, but that it was very unlikely that two or more such events could have occurred, one being an extraneous variation on the high side *and* the other an extraneous variation on the low side. With this point of view we should use the statistic $T_n = (x_n - \bar{x})/s$ or the statistic $T_1 = (\bar{x} - x_1)/s$ whichever is larger. If in this instance we use the 0.05 point of Table 1 as our critical value, the true significance level would be twice 0.05 or 0.10. If we wish a significance level of 0.05 and not 0.10, we must in this case use as a critical value the 0.025 point of Table 1. Similar considerations apply to the other tests given below.

6.2.1 *Example 1*—As an illustration of the use of T_n and Table 1, consider the following ten observations on breaking strength (in pounds) of 0.104-in. hard-drawn copper wire: 568, 570, 570, 570, 572, 572, 572, 578, 584, 596. See Fig. 1. The doubtful observation is the high value, $x_{10} = 596$. Is the value

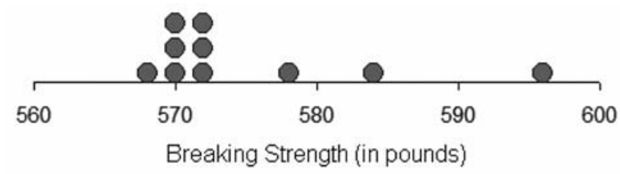

FIG. 1 Ten Observations of Breaking Strength from Example 1 in 6.2.1

of 596 significantly high? The mean is $\bar{x} = 575.2$ and the estimated standard deviation is $s = 8.70$. We compute

$$T_{10} = (596 - 575.2)/8.70 = 2.39 \quad (3)$$

From Table 1, for $n = 10$, note that a T_{10} as large as 2.39 would occur by chance with probability less than 0.05. In fact, so large a value would occur by chance not much more often than 1 % of the time. Thus, the weight of the evidence is against the doubtful value having come from the same population as the others (assuming the population is normally distributed). Investigation of the doubtful value is therefore indicated.

TABLE 1 Critical Values for *T* (One-Sided Test) When Standard Deviation is Calculated from the Same Sample[A]

Number of Observations, *n*	Upper 0.1 % Significance Level	Upper 0.5 % Significance Level	Upper 1 % Significance Level	Upper 2.5 % Significance Level	Upper 5 % Significance Level	Upper 10 % Significance Level
3	1.155	1.155	1.155	1.155	1.153	1.148
4	1.499	1.496	1.492	1.481	1.463	1.425
5	1.780	1.764	1.749	1.715	1.672	1.602
6	2.011	1.973	1.944	1.887	1.822	1.729
7	2.201	2.139	2.097	2.020	1.938	1.828
8	2.358	2.274	2.221	2.126	2.032	1.909
9	2.492	2.387	2.323	2.215	2.110	1.977
10	2.606	2.482	2.410	2.290	2.176	2.036
11	2.705	2.564	2.485	2.355	2.234	2.088
12	2.791	2.636	2.550	2.412	2.285	2.134
13	2.867	2.699	2.607	2.462	2.331	2.175
14	2.935	2.755	2.659	2.507	2.371	2.213
15	2.997	2.806	2.705	2.549	2.409	2.247
16	3.052	2.852	2.747	2.585	2.443	2.279
17	3.103	2.894	2.785	2.620	2.475	2.309
18	3.149	2.932	2.821	2.651	2.504	2.335
19	3.191	2.968	2.854	2.681	2.532	2.361
20	3.230	3.001	2.884	2.709	2.557	2.385
21	3.266	3.031	2.912	2.733	2.580	2.408
22	3.300	3.060	2.939	2.758	2.603	2.429
23	3.332	3.087	2.963	2.781	2.624	2.448
24	3.362	3.112	2.987	2.802	2.644	2.467
25	3.389	3.135	3.009	2.822	2.663	2.486
26	3.415	3.157	3.029	2.841	2.681	2.502
27	3.440	3.178	3.049	2.859	2.698	2.519
28	3.464	3.199	3.068	2.876	2.714	2.534
29	3.486	3.218	3.085	2.893	2.730	2.549
30	3.507	3.236	3.103	2.908	2.745	2.563
31	3.528	3.253	3.119	2.924	2.759	2.577
32	3.546	3.270	3.135	2.938	2.773	2.591
33	3.565	3.286	3.150	2.952	2.786	2.604
34	3.582	3.301	3.164	2.965	2.799	2.616
35	3.599	3.316	3.178	2.979	2.811	2.628
36	3.616	3.330	3.191	2.991	2.823	2.639
37	3.631	3.343	3.204	3.003	2.835	2.650
38	3.646	3.356	3.216	3.014	2.846	2.661
39	3.660	3.369	3.228	3.025	2.857	2.671
40	3.673	3.381	3.240	3.036	2.866	2.682
41	3.687	3.393	3.251	3.046	2.877	2.692
42	3.700	3.404	3.261	3.057	2.887	2.700
43	3.712	3.415	3.271	3.067	2.896	2.710
44	3.724	3.425	3.282	3.075	2.905	2.719
45	3.736	3.435	3.292	3.085	2.914	2.727
46	3.747	3.445	3.302	3.094	2.923	2.736
47	3.757	3.455	3.310	3.103	2.931	2.744
48	3.768	3.464	3.319	3.111	2.940	2.753
49	3.779	3.474	3.329	3.120	2.948	2.760