

CONFIRMED
OCTOBER 1985

Guide to

Statistical interpretation of data —

**Part 4: Techniques of estimation and
tests relating to means and variances**

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- Electronic Components Board
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- Institution of Production Engineers
- Ministry of Defence*
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- Post Office
- Royal Statistical Society*
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- University of Essex

The Government department and scientific and industrial organizations marked with an asterisk in the above list were directly represented on the committee entrusted with the preparation of this British Standard.

This British Standard, having been prepared under the direction of the Advisory Committee on Statistical Methods was published under the authority of the Executive Board on 31 August 1976

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The following BSI references relate to the work on this standard:
Committee reference OC/8/2
draft for approval ISO/DIS 2854

ISBN 0 580 09176 7

Amendments issued since publication

Amd. No.	Date of issue	Comments

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Foreword

The correct interpretation and presentation of test results have been assuming increasing importance in the analysis of data obtained from manufacturing processes based on sample determinations and prototype evaluations in industry, commerce and educational institutions. It was for this reason that Subcommittee 2 of Technical Committee 69, “Applications of Statistical Methods”, of the International Organization for Standardization (ISO), was charged with the task of preparing a guide to statistical methods for the interpretation of test results. International agreement has already been reached on the specification of several techniques and it was agreed in the UK to publish these as additional parts to the revision of BS 2846:1957 “The reduction and presentation of experimental results” as follows:

Statistical interpretation of data

- *Part 1: Routine analysis of quantitative data;*
- *Part 2: Estimation of the mean – confidence interval [ISO 2602];*
- *Part 3: Determination of a statistical tolerance interval [ISO 3207];*
- *Part 4: Techniques of estimation and tests relating to means and variances [ISO 2854];*
- *Part 5: Efficiency of tests relating to means and variances [ISO 3494]¹⁾;*
- *Part 6: Comparison of two means in the case of paired observations [ISO 3301].*

Much of the experimentation and testing is concerned with providing test results, which will give some idea of the value of a characteristic under investigation, or lend themselves to testing some theory concerning the characteristic. For example, it may be of interest to estimate the nitrogen content in a batch of some chemical compound, and further to test whether this content differs significantly from a required level. This Part of the standard is concerned with providing techniques which will answer these and similar questions. However, some caution is necessary in the application of the techniques and in this respect the General remarks should be read carefully and the validity of the assumptions checked.

This Part of this British Standard is identical with ISO 2854 “Statistical interpretation of data — Techniques of estimation and tests relating to means and variances”. The UK made a significant contribution during the later stages in the development of this international standard, Professor E.S. Pearson CBE FRS being primarily responsible for the Explanatory notes and examples in Section 2.

For the purposes of this British Standard the text of ISO 2854 given in this publication should be modified as follows:

Terminology. The words “British Standard” should replace “International Standard” wherever they appear.

The decimal point should replace the decimal comma wherever it appears.

Cross-reference. The references to other International Standards should be replaced by references to British Standards as follows.

Reference to ISO Standard	Appropriate British Standard
ISO 3534 ^a Statistics — Vocabulary	BS.... ^a
ISO 2602 Statistical interpretation of test results — Estimation of the mean — Confidence interval	BS 2846 Guide to statistical interpretation of data Part 2 Estimation of the mean — confidence interval
ISO 3207 Statistical interpretation of data — Determination of a statistical tolerance interval	BS 2846-3 Determination of a statistical tolerance interval

¹⁾ In course of preparation.

Reference to ISO Standard**Appropriate British Standard**

NOTE See “General remark no. 11” under “Additional information”.

ISO 3301 Statistical interpretation of data — Comparison of two means in the case of paired observations
BS 2846-6 Comparison of two means in the case of paired observations

^a In course of preparation.

Additional information

General remark no. 4. In line 16 the expression “exp (mean log x)” should be interpreted as the “antilogarithm, to the base e , of the arithmetic average of the logarithms, to the base e , of the observations x ”.

In the final line “characteristic s^2 ” is the estimated standard deviation, calculated by dividing the sum of squares by “ $n - 1$ ”, where n is the sample size.

General remark no. 8. In line 6 “value of the maximum value of the error of the first kind” should strictly read “value of the maximum value of the probability of committing the error of the first kind”.

General remark no. 11. The reference to ISO 3207 is incorrect and reference should be made to ISO/DIS 3725²⁾ “Statistics — Symbols”.

The following British Standards also provide practical guidance on the application of statistical methods.

BS 600, *Application of statistical methods to industrial standardization and quality control.*

BS 1313, *Fraction-defective charts for quality control.*

BS 2564, *Control chart technique when manufacturing to a specification, with special reference to articles machined to dimensional tolerances.*

BS 6000, *Guide to the use of BS 6001. Sampling procedures and tables for inspection by attributes.*

BS 6001, *Sampling procedures and tables for inspection by attributes.*

BS 6002, *Sampling procedures and charts for inspection by variables for percent defective²⁾.*

BS...., *Determination and statistical analysis of precision data for a standard test method²⁾.*

A British Standard does not purport to include all the necessary provisions of a contract. Users of British Standards are responsible for their correct application.

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Summary of pages

This document comprises a front cover, an inside front cover, pages i to iv, pages 1 to 49 and a back cover.

This standard has been updated (see copyright date) and may have had amendments incorporated. This will be indicated in the amendment table on the inside front cover.

²⁾ In course of preparation.

Section 1. Presentation of calculations

General remarks

- 1) This International Standard specifies the techniques required:
 - a) to estimate the mean or the variance of populations;
 - b) to examine certain hypotheses concerning the value of those parameters, from samples.
- 2) The techniques used are valid only if, in each of the populations under consideration, the sample elements are drawn at random and are independent. In the case of a finite population, elements drawn at random may be considered as independent when the population size is sufficiently large or when the sampling fraction is sufficiently small (for instance smaller than 1/10).
- 3) The distribution of the observed variable is assumed to be normal in each population. However, if the distribution does not deviate very much from the normal, the techniques described remain approximately valid to an extent sufficient for most practical applications, provided the sample size is not too small. For Table A, Table B, Table C and Table D, the sample size should be of the order of 5 to 10 at least; for all the other tables, it should be not less than about 20³⁾
- 4) A certain number of techniques exist which permit the verification of the hypothesis of normality. This subject is dealt with briefly in the examples in section 2 and will also be dealt with in a further document (yet to be prepared). Nevertheless, this hypothesis may be admitted on the basis of information other than that provided by the sample itself. In the case where the hypothesis of normality should be rejected, the obvious method to follow is to resort to non-parametric tests or to use suitable transformations for obtaining normally distributed populations, for example $1/x$, $\log(x + a)$, $\sqrt{x + a}$, but the conclusions reached by applying these procedures described in this International Standard are only directly valid for the transformed variate; caution should be used in the translation to the original variate. For example **exp (mean log x)** is equal to the **geometric mean** of x not the arithmetic mean.
 If what is really needed is an estimate of the mean or standard deviation of the variate X itself then, whether the population distribution is normal or not, an unbiased estimation of the mean m and the population variance σ^2 is produced by the sample mean $\bar{x}$ and characteristic s^2 .
- 5) It is desirable to accompany each statistical operation with all the particulars relevant to the source or to the method of obtaining the observations which may clarify this statistical analysis, and in particular to give the unit or the smallest unit of measurement having practical meaning.
- 6) It is not permissible to discard any observations or to apply any corrections to apparently doubtful observations without a justification based on experimental, technical or other evident grounds which should be clearly given. In any case the discarded or corrected values and the reason for discarding or correcting them must be mentioned.
- 7) In problems of estimation, the confidence level $1 - \alpha$ is the probability that the confidence interval covers the true value of the estimated parameter. Its most usual values are 0,95 and 0,99, or $\alpha = 0,05$ and $\alpha = 0,01$.
- 8) In problems of testing a hypothesis, the significance level is, in the two-sided cases, the probability of rejecting the null hypothesis (or tested hypothesis) if it is true (error of the first kind); in the one-sided cases, the significance level is the maximum value of this probability (maximum value of the error of the first kind). Values of $\alpha = 0,05$ (1 in 20 chance) or 0,01 (1 in 100 chance) are very commonly employed according to the risk which the user is prepared to take. Since a hypothesis may be rejected using $\alpha = 0,05$, but not when using 0,01, it is often appropriate to use the phrase: "the hypothesis is rejected at the 5 % level" or, if this is the case, "at the 1 % level". Attention is drawn to the existence of an error of the second kind. This error is committed if the null hypothesis is accepted when it is false. Terms concerning statistical tests are defined in clause 2 of ISO 3534, Statistics — Vocabulary⁴⁾.
- 9) The calculations can often be greatly reduced by making a change of origin and/or unit on the data. In the case of data classified into groups, reference may be made to the formulae in ISO 2602, "Statistical interpretation of test results — Estimation of the mean — Confidence interval".

NOTE A change of origin may be essential to obtain sufficient accuracy when calculating a variance using the stated formulae with a low precision calculator or computer.

³⁾ Studies about normal distributions are in progress in TC 69/SC 2.

⁴⁾ At present at the stage of draft.

10) The methods shown in Table C and Table C' deal with the comparison of two means. They assume that the corresponding samples are independent. For the study of certain problems, it may be interesting to pair the observations (for instance in the comparison of two methods or the comparison of two instruments). The statistical treatment of paired observations is the subject of ISO 3301, *Statistical interpretation of data — Comparison of two means in the case of paired observations*, but in Annex A an example of treatment of paired observations is given. It uses formally the data of Table A'.

11) The symbols and their definitions used in this International Standard are in conformity with ISO 3207, *Statistical interpretation of data — Determination of a statistical tolerance interval*.

Table A — Comparison of a mean with a given value (variance known)

Technical characteristics of the population studied (5)	
Technical characteristics of the sample items (5)	
Discarded observations (6)	
Statistical data Sample size : $n =$ Sum of the observed values : $\Sigma x =$ Given value : $m_0 =$ Known value of the population variance : $\sigma^2 =$ Or standard deviation : $\sigma =$ Significance level chosen (8) : $\alpha =$	Calculations $\bar{x} = \frac{\Sigma x}{n} =$ $[u_{1-\alpha}/\sqrt{n}] \sigma =$ $[u_{1-\alpha/2}/\sqrt{n}] \sigma =$
Results Comparison of the population mean with the given value m_0 : Two-sided case : The hypothesis of the equality of the population mean to the given value (null hypothesis) is rejected if : $ \bar{x} - m_0 > [u_{1-\alpha/2}/\sqrt{n}] \sigma$ One-sided cases : a) The hypothesis that the population mean is not smaller than m_0 (null hypothesis) is rejected if : $\bar{x} < m_0 - [u_{1-\alpha}/\sqrt{n}] \sigma$ b) The hypothesis that the population mean is not greater than m_0 (null hypothesis) is rejected if : $\bar{x} > m_0 + [u_{1-\alpha}/\sqrt{n}] \sigma$	

NOTE The numbers (5), (6) and (8) refer to the corresponding paragraphs of the "General remarks".

Comments

1) The significance level α (see § 8 of the “General remarks”) is the probability of rejecting the null hypothesis when this hypothesis is true.

2) U stands for the standardized normal variate: the value u_α is defined by:

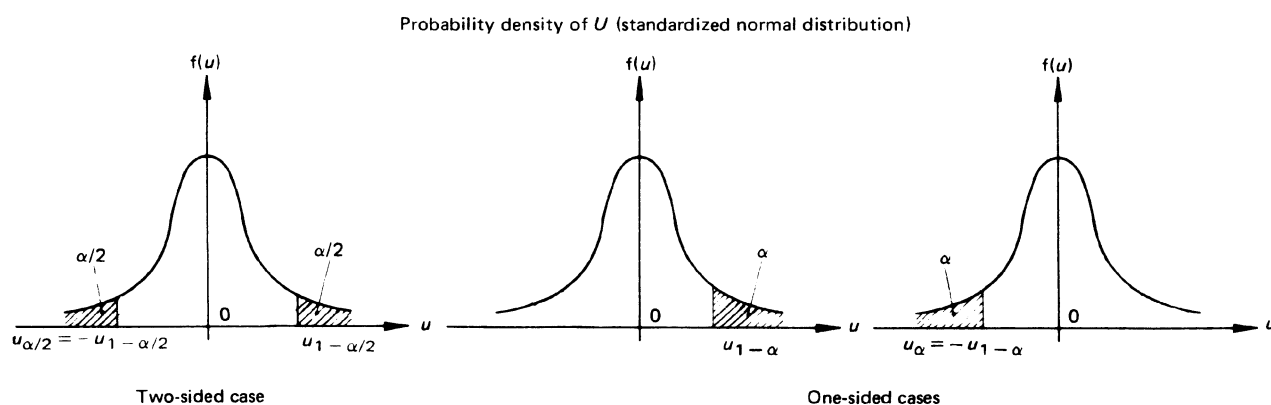
$$P[U < u_\alpha] = \alpha$$

Since the distribution of U is symmetrical around zero, $u_\alpha = -u_{1-\alpha}$

We therefore have:

$$P[U > u_\alpha] = 1 - \alpha$$

$$P[-u_{1-\alpha/2} < U < u_{1-\alpha/2}] = 1 - \alpha$$



3) $\sigma/\sqrt{n}$ is the standard deviation of the mean $\bar{x}$, in a sample of n observations.

4) For convenience in application, values of $u_{1-\alpha}/\sqrt{n}$ and $u_{1-\alpha/2}/\sqrt{n}$ are given in Table I of Annex B for $\alpha = 0,05$ and $\alpha = 0,01$.

EXAMPLE: see Section 2, “Explanatory notes and examples”.

Table A' — Comparison of a mean with a given value (variance unknown)

Technical characteristics of the population studied (5)	
Technical characteristics of the sample items (5)	
Discarded observations (6)	
Statistical data Sample size : $n =$ Sum of the observed values : $\Sigma x =$ Sum of the squares of the observed values : $\Sigma x^2 =$ Given value : $m_0 =$ Degrees of freedom : $\nu = n - 1$ Significance level chosen (8) . $\alpha =$	Calculations $\bar{x} = \frac{\Sigma x}{n} =$ $\frac{\Sigma (x - \bar{x})^2}{n - 1} = \frac{\Sigma x^2 - (\Sigma x)^2/n}{n - 1}$ $\sigma^* = s = \sqrt{\frac{\Sigma (x - \bar{x})^2}{n - 1}} =$ $[t_{1-\alpha}(\nu)/\sqrt{n}] s =$ $[t_{1-\alpha/2}(\nu)/\sqrt{n}] s =$
Results Comparison of the population mean with the given value m_0 : Two-sided case : The hypothesis of the equality of the population mean to the given value (null hypothesis) is rejected if : $ \bar{x} - m_0 > [t_{1-\alpha/2}(\nu)/\sqrt{n}] s$ One-sided cases : a) The hypothesis that the population mean is not smaller than m_0 (null hypothesis) is rejected if : $\bar{x} < m_0 - [t_{1-\alpha}(\nu)/\sqrt{n}] s$ b) The hypothesis that the population mean is not greater than m_0 (null hypothesis) is rejected if : $\bar{x} > m_0 + [t_{1-\alpha}(\nu)/\sqrt{n}] s$	

NOTE The numbers (5), (6) and (8) refer to the corresponding paragraphs of the "General remarks".

Comments

1) The significance level α (see § 8 of the “General remarks”) is the probability of rejecting the null hypothesis when this hypothesis is true.

2) $t(v)$ stands for Student's variate with $v = n - 1$ degrees of freedom: the value $t_\alpha(v)$ is defined by

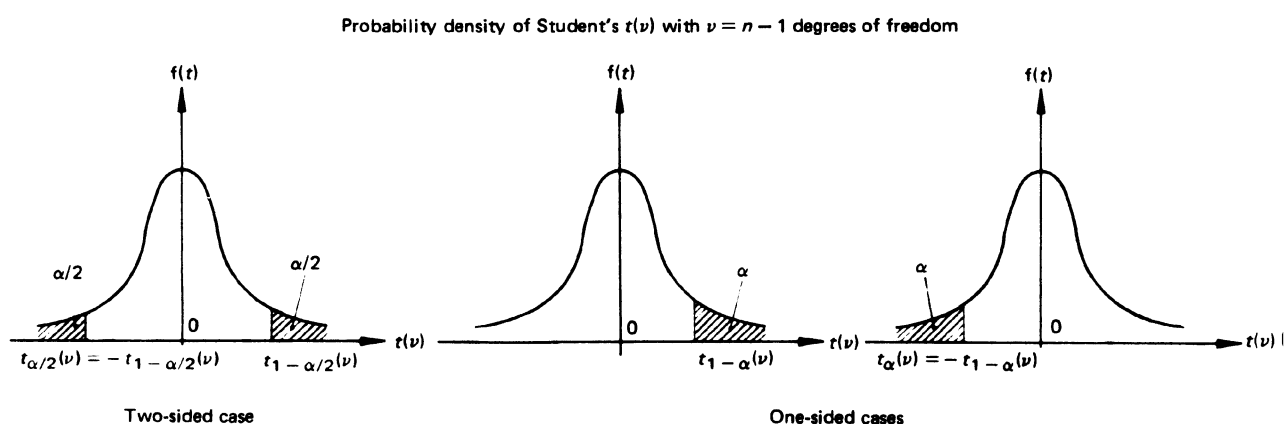
$$P[t(v) < t_\alpha(v)] = \alpha$$

Since the distribution of $t(v)$ is symmetrical around zero, $t_\alpha(v) = -t_{1-\alpha}(v)$.

We therefore have:

$$P[t(v) > t_\alpha(v)] = 1 - \alpha$$

$$P[-t_{1-\alpha/2}(v) < t(v) < t_{1-\alpha/2}(v)] = 1 - \alpha$$



3) $\sigma^*/\sqrt{n}$ is the estimated standard deviation of the mean $\bar{x}$, in a sample of n observations.

4) For convenience in application, values of $t_{1-\alpha/2}(v)/\sqrt{n}$ and $t_{1-\alpha}(v)/\sqrt{n}$ are given in Table IIb of Annex B for $\alpha = 0,05$ and $\alpha = 0,01$

EXAMPLE: see Section 2, “Explanatory notes and examples”.

Table B — Estimation of a mean (variance known)

Technical characteristics of the population studied (5)	
Technical characteristics of the sample items (5)	
Discarded observations (6)	
Statistical data Sample size : $n =$ Sum of the observed values : $\Sigma x =$ Known value of the population variance : $\sigma^2 =$ Or standard deviation : $\sigma =$ Confidence level chosen (7) : $1 - \alpha =$	Calculations $\bar{x} = \frac{\Sigma x}{n} =$ $[u_{1-\alpha}/\sqrt{n}] \sigma =$ $[u_{1-\alpha/2}/\sqrt{n}] \sigma =$
Results Estimation of the population mean m : $m^* = \bar{x} =$ Two-sided confidence interval : $\bar{x} - [u_{1-\alpha/2}/\sqrt{n}] \sigma < m < \bar{x} + [u_{1-\alpha/2}/\sqrt{n}] \sigma$ One-sided confidence intervals : $m < \bar{x} + [u_{1-\alpha}/\sqrt{n}] \sigma$ or $m > \bar{x} - [u_{1-\alpha}/\sqrt{n}] \sigma$	

NOTE The numbers (5), (6) and (7) refer to the corresponding paragraphs of the "General remarks".

Comments

1) The confidence level $1 - \alpha$ (see § 7 of the “General remarks”) is the probability that the confidence interval covers the true value of the mean.

2) U stands for the standardized normal variate: the value u_α is defined by:

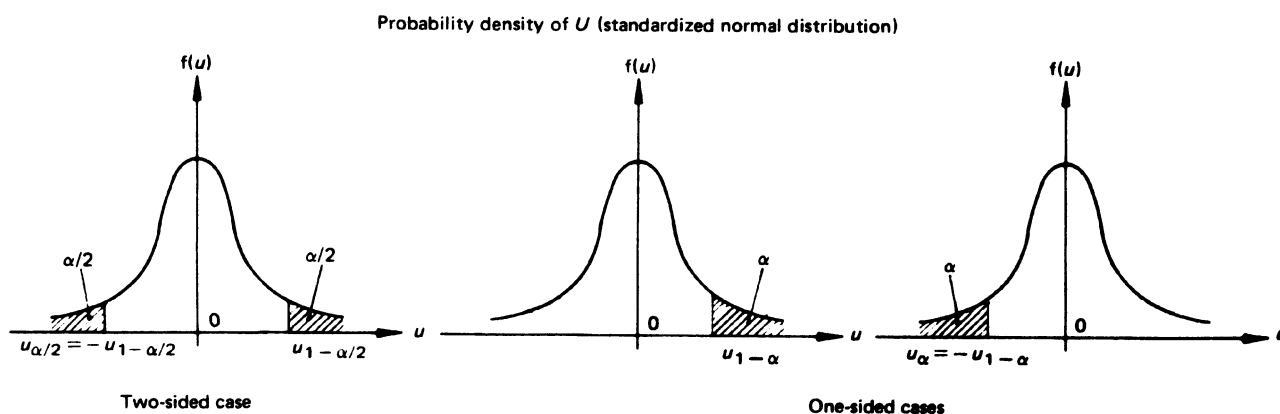
$$P[U < u_\alpha] = \alpha$$

Since the distribution of U is symmetrical around zero, $u_\alpha = -u_{1-\alpha}$

We therefore have:

$$P[U > u_\alpha] = 1 - \alpha$$

$$P[-u_{1-\alpha/2} < U < u_{1-\alpha/2}] = 1 - \alpha$$



3) $\sigma/\sqrt{n}$ is the standard deviation of the mean $\bar{x}$, in a sample of n observations.

4) For convenience in application, values of $u_{1-\alpha/2}/\sqrt{n}$ and $u_{1-\alpha}/\sqrt{n}$ are given in Table I of Annex B for $\alpha = 0,05$ and $\alpha = 0,01$.

EXAMPLE: see Section 2, “Explanatory notes and examples”.

Table B* — Estimation of a mean (variance unknown)

Technical characteristics of the population studied (5) Technical characteristics of the sample items (5) Discarded observations (6)	
Statistical data Sample size : $n =$ Sum of the observed values : $\Sigma x =$ Sum of the squares of the observed values : $\Sigma x^2 =$ Degrees of freedom : $\nu = n - 1 =$ Confidence level chosen (7) : $1 - \alpha =$	Calculations $\bar{x} = \frac{\Sigma x}{n} =$ $\frac{\Sigma (x - \bar{x})^2}{n - 1} = \frac{\Sigma x^2 - (\Sigma x)^2/n}{n - 1} =$ $\sigma^* = s = \sqrt{\frac{\Sigma (x - \bar{x})^2}{n - 1}} =$ $[t_{1-\alpha}(\nu)/\sqrt{n}] s =$ $[t_{1-\alpha/2}(\nu)/\sqrt{n}] s =$
Results Estimation of the population mean m : $m^* = \bar{x} =$ Two-sided confidence interval : $\bar{x} - [t_{1-\alpha/2}(\nu)/\sqrt{n}] s < m < \bar{x} + [t_{1-\alpha/2}(\nu)/\sqrt{n}] s$ One-sided confidence intervals : $m < \bar{x} + [t_{1-\alpha}(\nu)/\sqrt{n}] s$ or $m > \bar{x} - [t_{1-\alpha}(\nu)/\sqrt{n}] s$	

NOTE The numbers (5), (6) and (7) refer to the corresponding paragraphs of the "General remarks".

Comments

1) The confidence level $1 - \alpha$ (see § 7 of the “General remarks”) is the probability that the confidence interval covers the true value of the mean.

2) $t(v)$ stands for Student's variate with v degrees of freedom; the value $t_\alpha(v)$ is defined by

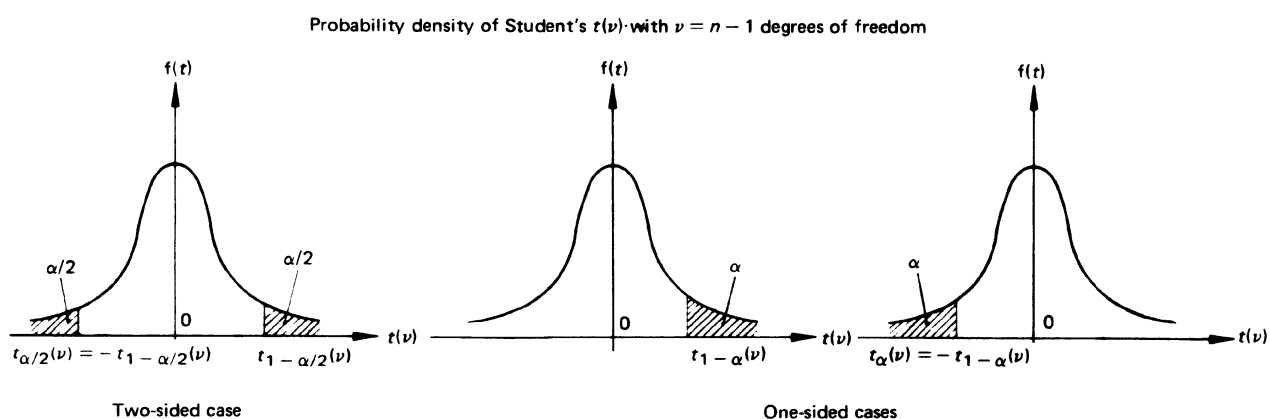
$$P[t(v) < t_\alpha(v)] = \alpha$$

Since the distribution of $t(v)$ is symmetrical around zero, $t_\alpha(v) = -t_{1-\alpha}(v)$.

We therefore have:

$$P[t(v) > t_\alpha(v)] = 1 - \alpha$$

$$P[-t_{1-\alpha/2}(v) < t(v) < t_{1-\alpha/2}(v)] = 1 - \alpha$$



3) $\sigma^*/\sqrt{n}$ is the estimated standard deviation of the mean $\bar{x}$, in a sample of n observations.

4) For convenience in application, values of $t_{1-\alpha/2}(v)/\sqrt{n}$ and $t_{1-\alpha}(v)/\sqrt{n}$ are given in Table IIb of Annex B for $\alpha = 0,05$ and $\alpha = 0,01$.

EXAMPLE: see Section 2, “Explanatory notes and examples”.

Table C — Comparison of two means (variances known)

Technical characteristics (5)	{ of population 1 of population 2	
Technical characteristics of the sample items taken (5)	{ in population 1 in population 2	
Discarded observations (6)	{ in sample 1 in sample 2	
Statistical data		Calculations
	First sample	Second sample
Size	$n_1 =$	$n_2 =$
Sum of the observed values	$\Sigma x_1 =$	$\Sigma x_2 =$
Known values of the variances of the populations	$\sigma_1^2 =$	$\sigma_2^2 =$
Significance level chosen (8) :		
$\alpha =$		
		$\bar{x}_1 = \frac{\Sigma x_1}{n_1} =$ $\bar{x}_2 = \frac{\Sigma x_2}{n_2} =$ $\sigma_d = \sqrt{\frac{\sigma_1^2}{n_1} + \frac{\sigma_2^2}{n_2}} =$ $u_{1-\alpha} \sigma_d =$ $u_{1-\alpha/2} \sigma_d =$
Results		
Comparison of the two population means :		
Two-sided case :		
The hypothesis of the equality of the means (null hypothesis) is rejected if :		
$ \bar{x}_1 - \bar{x}_2 > u_{1-\alpha/2} \sigma_d$		
One-sided cases :		
a) The hypothesis that the first mean is not smaller than the second (null hypothesis) is rejected if :		
$\bar{x}_1 < \bar{x}_2 - u_{1-\alpha} \sigma_d$		
b) The hypothesis that the first mean is not greater than the second (null hypothesis) is rejected if :		
$\bar{x}_1 > \bar{x}_2 + u_{1-\alpha} \sigma_d$		

NOTE The numbers (5), (6) and (8) refer to the corresponding paragraphs of the "General remarks".

Comments

1) The significance level α (see § 8 of the “General remarks”) is the probability of rejecting the null hypothesis when this hypothesis is true.

2) U stands for the standardized normal variate: the value u_α is defined by:

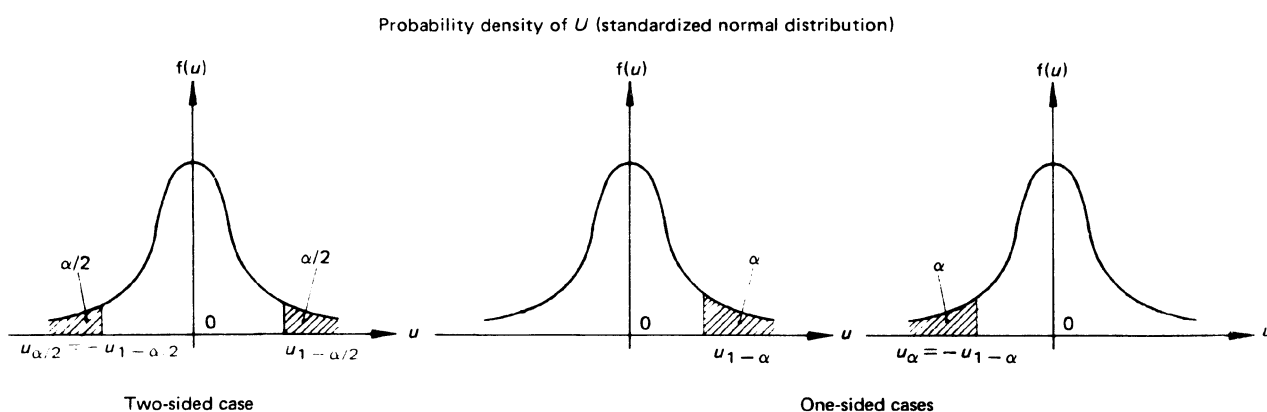
$$P[U < u_\alpha] = \alpha$$

Since the distribution of U is symmetrical around zero, $u_\alpha = -u_{1-\alpha}$.

We therefore have:

$$P[U > u_\alpha] = 1 - \alpha$$

$$P[-u_{1-\alpha/2} < U < u_{1-\alpha/2}] = 1 - \alpha$$



3) $\sigma_d = \sqrt{\frac{\sigma_1^2}{n_1} + \frac{\sigma_2^2}{n_2}}$ is the standard deviation of the difference $d = \bar{x}_1 - \bar{x}_2$ of the means of the two samples of n_1 and n_2 observations respectively.

4) The values $u_{1-\alpha/2}$ and $u_{1-\alpha}$ must be read for $\alpha = 0,05$ and $\alpha = 0,01$ on the line $n = 1$ of Table I of Annex B.

EXAMPLE: see Section 2, “Explanatory notes and examples”.