

NAG Library Routine Document

G04DBF

Note: before using this routine, please read the Users' Note for your implementation to check the interpretation of **bold italicised** terms and other implementation-dependent details.

1 Purpose

G04DBF computes simultaneous confidence intervals for the differences between means. It is intended for use after G04BBF or G04BCF.

2 Specification

```

SUBROUTINE G04DBF(TYP, NT, TMEAN, RDF, C, LDC, CLEVEL, CIL, CIU, ISIG,
1                      IFAIL)
    INTEGER          NT, LDC, ISIG(NT*(NT-1)/2), IFAIL
    double precision TMEAN(NT), RDF, C(LDC,NT), CLEVEL, CIL(NT*(NT-1)/2),
1                      CIU(NT*(NT-1)/2)
    CHARACTER*1      TYP

```

3 Description

In the computation of analysis of a designed experiment the first stage is to compute the basic analysis of variance table, the estimate of the error variance (the residual or error mean square), $\hat{\sigma}^2$, the residual degrees of freedom, ν , and the (variance ratio) F -statistic for the t treatments. The second stage of the analysis is to compare the treatment means. If the treatments have no structure, for example the treatments are different varieties, rather than being structured, for example a set of different temperatures, then a multiple comparison procedure can be used.

A multiple comparison procedure looks at all possible pairs of means and either computes confidence intervals for the difference in means or performs a suitable test on the difference. If there are t treatments then there are $t(t-1)/2$ comparisons to be considered. In tests the type 1 error or significance level is the probability that the result is considered to be significant when there is no difference in the means. If the usual t -test is used with, say, a 6% significance level then the type 1 error for all $k = t(t-1)/2$ tests will be much higher. If the tests were independent then if each test is carried out at the 100α percent level then the overall type 1 error would be $\alpha^* = 1 - (1 - \alpha)^k \simeq k\alpha$. In order to provide an overall protection the individual tests, or confidence intervals, would have to be carried out at a value of α such that α^* is the required significance level, e.g., five percent.

The $100(1 - \alpha)$ percent confidence interval for the difference in two treatment means, $\hat{\tau}_i$ and $\hat{\tau}_j$ is given by

$$(\hat{\tau}_i - \hat{\tau}_j) \pm T_{(\alpha, \nu, t)}^* se(\hat{\tau}_i - \hat{\tau}_j),$$

where $se()$ denotes the standard error of the difference in means and $T_{(\alpha, \nu, t)}^*$ is an appropriate percentage point from a distribution. There are several possible choices for $T_{(\alpha, \nu, t)}^*$. These are:

- (a) $\frac{1}{2}q_{(1-\alpha, \nu, t)}$, the studentized range statistic, see G01FMF. It is the appropriate statistic to compare the largest mean with the smallest mean. This is known as Tukey–Kramer method.
- (b) $t_{(\alpha/k, \nu)}$, this is the Bonferroni method.
- (c) $t_{(\alpha_0, \nu)}$, where $\alpha_0 = 1 - (1 - \alpha)^{1/k}$, this is known as the Dunn–Sidak method.

- (d) $t_{(\alpha,\nu)}$, this is known as Fisher's LSD (least significant difference) method. It should only be used if the overall F -test is significant, the number of treatment comparisons is small and were planned before the analysis.
- (e) $\sqrt{(k-1)F_{1-\alpha,k-1,\nu}}$ where $F_{1-\alpha,k-1,\nu}$ is the deviate corresponding to a lower tail probability of $1 - \alpha$ from an F -distribution with $k - 1$ and ν degrees of freedom. This is Scheffe's method.

In cases (b), (c) and (d), $t_{(\alpha,\nu)}$ denotes the α two tail significance level for the Student's t -distribution with ν degrees of freedom, see G01FBF.

The Scheffe method is the most conservative, followed closely by the Dunn–Sidak and Tukey–Kramer methods.

To compute a test for the difference between two means the statistic,

$$\frac{\hat{\tau}_i - \hat{\tau}_j}{se(\hat{\tau}_i - \hat{\tau}_j)}$$

is compared with the appropriate value of $T_{(\alpha,\nu,t)}^*$.

4 References

Kotz S and Johnson N L (ed.) (1985a) Multiple range and associated test procedures *Encyclopedia of Statistical Sciences* **5** Wiley, New York

Kotz S and Johnson N L (ed.) (1985b) Multiple comparison *Encyclopedia of Statistical Sciences* **5** Wiley, New York

Winer B J (1970) *Statistical Principles in Experimental Design* McGraw–Hill

5 Parameters

- 1: TYP – CHARACTER*1 Input
On entry: indicates which method is to be used.
 TYP = 'T'
 The Tukey–Kramer method is used.
 TYP = 'B'
 The Bonferroni method is used.
 TYP = 'D'
 The Dunn–Sidak method is used.
 TYP = 'L'
 The Fisher LSD method is used.
 TYP = 'S'
 The Scheffe's method is used.
Constraint: TYP = 'T', 'B', 'D', 'L' or 'S'.
- 2: NT – INTEGER Input
On entry: t , the number of treatment means.
Constraint: $NT \geq 2$.
- 3: TMEAN(NT) – **double precision** array Input
On entry: the treatment means, $\hat{\tau}_i$, for $i = 1, 2, \dots, t$.

- 4: RDF – **double precision** *Input*
On entry: ν , the residual degrees of freedom.
Constraint: $\text{RDF} \geq 1.0$.
- 5: C(LDC,NT) – **double precision** array *Input*
On entry: the strictly lower triangular part of C must contain the standard errors of the differences between the means as returned by G04BBF and G04BCF. That is $C(i, j)$, $i > j$, contains the standard error of the difference between the i th and j th mean in TMEAN.
Constraint: $C(i, j) > 0.0$, for $i = 2, 3, \dots, t$ and $j = 1, 2, \dots, i - 1$.
- 6: LDC – INTEGER *Input*
On entry: the first dimension of the array C as declared in the (sub)program from which G04DBF is called.
Constraint: $\text{LDC} \geq \text{NT}$.
- 7: CLEVEL – **double precision** *Input*
On entry: the required confidence level for the computed intervals, $(1 - \alpha)$.
Constraint: $0.0 < \text{CLEVEL} < 1.0$.
- 8: CIL($\text{NT} \times (\text{NT} - 1)/2$) – **double precision** array *Output*
On exit: the $((i - 1)(i - 2)/2 + j)$ th element contains the lower limit to the confidence interval for the difference between i th and j th means in TMEAN, for $i = 2, 3, \dots, t$ and $j = 1, 2, \dots, i - 1$.
- 9: CIU($\text{NT} \times (\text{NT} - 1)/2$) – **double precision** array *Output*
On exit: the $((i - 1)(i - 2)/2 + j)$ th element contains the upper limit to the confidence interval for the difference between i th and j th means in TMEAN, for $i = 2, 3, \dots, t$ and $j = 1, 2, \dots, i - 1$.
- 10: ISIG($\text{NT} \times (\text{NT} - 1)/2$) – INTEGER array *Output*
On exit: the $((i - 1)(i - 2)/2 + j)$ th element indicates if the difference between i th and j th means in TMEAN is significant, for $i = 2, 3, \dots, t$ and $j = 1, 2, \dots, i - 1$. If the difference is significant then the returned value is 1; otherwise the returned value is 0.
- 11: IFAIL – INTEGER *Input/Output*
On entry: IFAIL must be set to 0, -1 or 1. If you are unfamiliar with this parameter you should refer to Section 3.3 in the Essential Introduction for details.
On exit: $\text{IFAIL} = 0$ unless the routine detects an error (see Section 6).
 For environments where it might be inappropriate to halt program execution when an error is detected, the value -1 or 1 is recommended. If the output of error messages is undesirable, then the value 1 is recommended. Otherwise, if you are not familiar with this parameter, the recommended value is 0. **When the value -1 or 1 is used it is essential to test the value of IFAIL on exit.**

6 Error Indicators and Warnings

If on entry $IFAIL = 0$ or -1 , explanatory error messages are output on the current error message unit (as defined by X04AAF).

Errors or warnings detected by the routine:

$IFAIL = 1$

On entry, $NT < 2$,
 or $LDC < NT$,
 or $RDF < 1.0$,
 or $CLEVEL \leq 0.0$,
 or $CLEVEL \geq 1.0$,
 or $TYP \neq 'T', 'B', 'D', 'L' \text{ or } 'S'$.

$IFAIL = 2$

On entry, $C(i, j) \leq 0.0$ for some i, j , $i = 2, 3, \dots, t$ and $j = 1, 2, \dots, i - 1$.

$IFAIL = 3$

There has been a failure in the computation of the studentized range statistic. This is an unlikely error. Try using a small value of CLEVEL.

7 Accuracy

For the accuracy of the percentage point statistics see G01FBF and G01FMF.

8 Further Comments

If the treatments have a structure then the use of linear contrasts as computed by G04DAF may be more appropriate.

An alternative approach to one used in G04DBF is the sequential testing of the Student–Newman–Keuls procedure. This, in effect, uses the Tukey–Kramer method but first ordering the treatment means and examining only subsets of the treatment means in which the largest and smallest are significantly different. At each stage the third parameter of the Studentised range statistic is the number of means in the subset rather than the total number of means.

9 Example

In the example taken from Winer (1970) a completely randomized design with unequal treatment replication is analysed using G04BBF and then confidence intervals are computed by G04DBF using the Tukey–Kramer method.

9.1 Program Text

```
*      G04DBF Example Program Text
*      Mark 17 Release. NAG Copyright 1995.
*      .. Parameters ..
      INTEGER          NIN, NOUT
      PARAMETER        (NIN=5,NOUT=6)
      INTEGER          NMAX, NTMAX, NBMAX, LDC
      PARAMETER        (NMAX=26,NTMAX=4,NBMAX=1,LDC=NTMAX)
*      .. Local Scalars ..
      DOUBLE PRECISION CLEVEL, GMEAN, RDF, TOL
      INTEGER          I, IFAIL, IJ, IRDF, J, N, NBLOCK, NT
      CHARACTER        TYP
*      .. Local Arrays ..
      DOUBLE PRECISION BMEAN(NBMAX), C(LDC,NTMAX),
+                     CIL(NTMAX*(NTMAX-1)/2), CIU(NTMAX*(NTMAX-1)/2),
+                     EF(NTMAX), R(NMAX), TABLE(4,5), TMEAN(NTMAX),
```

```

+          WK(NTMAX*NTMAX+NTMAX), Y(NMAX)
  INTEGER      IREP(NTMAX), ISIG(NTMAX*(NTMAX-1)/2), IT(NMAX)
  CHARACTER    STAR(2)
*   .. External Subroutines ..
  EXTERNAL     GO4BBF, GO4DBF
*   .. Executable Statements ..
  WRITE (NOUT,*) 'G04DBF Example Program Results'
*   Skip heading in data file
  READ (NIN,*)
  READ (NIN,*) N, NT
  IF (N.LE.NMAX .AND. NT.LE.NTMAX) THEN
    READ (NIN,*) (Y(I),I=1,N)
    READ (NIN,*) (IT(I),I=1,N)
    TOL = 0.000005D0
    IRDF = 0
    NBLOCK = 1
    IFAIL = -1
    CALL GO4BBF(N,Y,NBLOCK,NT,IT,GMEAN,BMEAN,TMEAN,TABLE,4,C,LDC,
+             IREP,R,EF,TOL,IRDF,WK,IFAIL)
    IF (IFAIL.LT.0) GO TO 60
    WRITE (NOUT,*)
    WRITE (NOUT,*) ' ANOVA table'
    WRITE (NOUT,*)
    WRITE (NOUT,*)
+   ' Source          df          SS          MS          F',
+   ' Prob'
    WRITE (NOUT,*)
    WRITE (NOUT,99998) ' Treatments', (TABLE(2,J),J=1,5)
    WRITE (NOUT,99998) ' Residual ', (TABLE(3,J),J=1,3)
    WRITE (NOUT,99998) ' Total      ', (TABLE(4,J),J=1,2)
    WRITE (NOUT,*)
    WRITE (NOUT,*) ' Treatment means'
    WRITE (NOUT,*)
    WRITE (NOUT,99999) (TMEAN(J),J=1,NT)
    WRITE (NOUT,*)
    WRITE (NOUT,*) ' Simultaneous Confidence Intervals'
    WRITE (NOUT,*)
    RDF = TABLE(3,1)
    READ (NIN,*) TYP, CLEVEL
*
    CALL GO4DBF(TYP,NT,TMEAN,RDF,C,LDC,CLEVEL,CIL,CIU,ISIG,IFAIL)
*
    STAR(2) = '*'
    STAR(1) = ' '
    IJ = 0
    DO 40 I = 1, NT
      DO 20 J = 1, I - 1
        IJ = IJ + 1
        WRITE (NOUT,99997) I, J, CIL(IJ), CIU(IJ),
+          STAR(ISIG(IJ)+1)
      20 CONTINUE
    40 CONTINUE
    END IF
    60 CONTINUE
*
99999 FORMAT (10F8.3)
99998 FORMAT (A,3X,F3.0,2X,2(F10.1,2X),F10.3,2X,F9.4)
99997 FORMAT (2X,2I2,3X,2(F10.3,3X),A)
  END

```

9.2 Program Data

G04DBF Example Program Data

```

26 4
 3 2 4 3 1 5
 7 8 4 10 6
 3 2 1 2 4 2 3 1
10 12 8 5 12 10 9

```

```

1 1 1 1 1 1
2 2 2 2 2
3 3 3 3 3 3 3
4 4 4 4 4 4 4
'T' .95

```

9.3 Program Results

G04DBF Example Program Results

ANOVA table

Source	df	SS	MS	F	Prob
Treatments	3.	239.9	80.0	24.029	0.0000
Residual	22.	73.2	3.3		
Total	25.	313.1			

Treatment means

```

3.000  7.000  2.250  9.429

```

Simultaneous Confidence Intervals

2 1	0.933	7.067	*
3 1	-3.486	1.986	
3 2	-7.638	-1.862	*
4 1	3.610	9.247	*
4 2	-0.538	5.395	
4 3	4.557	9.800	*
