



## **A Class of Efficient Row-Column Designs for Type III Diallel Cross Experiments with Specific Combining Abilities**

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### **SUMMARY**

In this paper, a methodology has been discussed for estimating gca effects free from sca effects under a row-column set-up for Type III complete diallel mating designs. A class of Mating-Environmental Row-Column (MERC) designs has been obtained which is variance balanced for estimating the contrasts pertaining to gca effects free from sca effects. A macro has been developed using PROC IML of SAS software for generating randomized layout of the MERC designs so constructed.

*Keywords:* Diallel cross, GCA, SCA, Row-column design, Type III CDC, SAS macro.

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### **1. INTRODUCTION**

The theory and analysis of diallel crosses were developed by Hayman (1954a, 1954b and 1958 and 1960), Griffing (1956a and 1956b) and Kempthorne (1956). There are four main types of diallel mating designs viz., Type I [ $F_1$ 's, reciprocal crosses and selfings], Type II [ $F_1$ 's and reciprocal crosses], Type III [ $F_1$ 's and parents] and Type IV [Only  $F_1$ 's] as suggested by Griffing (1956b). For more details on diallel cross experiments and analysis one may refer to (Kempthorne 1969 and Narain 1990). Experimental design issues in the context of diallel cross experiments has received considerable attention in the literature; see for reference, Curnow (1963), Gupta *et al.* (1994), Das and Ghosh (1999) and Hinkelmann and Kempthorne (2005).

Most of the work on designs for diallel cross experiments are done by taking only  $F_1$ 's into consideration (i.e., Type IV). For an experimenter, the interest may not lie only in comparing the  $F_1$ 's but in comparing  $F_1$ 's along with its parents. Furthermore, most of the work on diallel/ partial diallel cross experiments has been done under the assumption that the specific combining ability

(sca) is negligible. Apart from inferring on general combining abilities (gca), often an experimenter is also interested in inference on gca effects free from “cross effects” or, “sca effects”. This is possible when sca effect is included in the model. Chai and Mukerjee (1999) studied the optimality aspect of diallel cross experiments when “sca effects” are also included in the model. Choi *et al.* (2002), Das and Dey (2004) and Dey (2010) investigated optimality of orthogonally blocked complete diallel crosses (CDC) for estimating gca's when the model also includes sca's.

Heterogeneity in the experimental material is the most important problem to be reckoned with designing of scientific experiments. When heterogeneity is present in the experimental material in two directions, row-column (two-way blocking) designs will be useful. Varghese *et al.* (2015) proposed some classes of Mating-Environmental Row-Column designs which ensures balanced estimation of contrasts pertaining to gca effects free from sca effects. Varghese and Varghese (2016) investigated the problem of comparing t test lines with a control line under a row-column set up in complete diallel

cross experiments when *sca* effect is included in the model.

In this paper, a methodology has been developed for estimating *gca* effects free from *sca* effects under a row-column set up for Type III complete diallel mating designs. A class of Mating-Environmental Row-Column (MERC) designs has been constructed that is variance balanced for estimating the contrasts pertaining to *gca* effects free from *sca* effects.

## 2. EXPERIMENTAL SETUP AND METHODOLOGY

Consider a row-column setup with  $p$  rows and  $q$  columns. Let  $t$  be the number of inbred lines resulting in  $v' = v + t = [t(t + 1)/2]$  crosses, where  $[v = t(t - 1)/2]$  ( $F_1$ 's) are of the form  $i \times j$ ,  $i < j = 1, 2, \dots, t$  and  $t$  parents (Griffing's Type III mating design). The row-column fixed effects model for mating experiments can be expressed in the form

$$y_{kl(m)} = \mu + \tau_{ij(m)} + \alpha_k + \beta_l + e_{kl(m)} \quad (1)$$

$(1 \leq i, j \leq t)$

where  $y_{kl(m)}$  is the response from  $m^{\text{th}}$  cross ( $m = 1, 2, \dots, v'$ ) in the  $(kl)^{\text{th}}$  cell,  $\mu$  is the grand mean,  $\tau_{ij(m)}$  is the effect of  $m^{\text{th}}$  cross of the form  $i \times j$ ,  $\alpha_k$  is the  $k^{\text{th}}$  row effect ( $k = 1, 2, \dots, p$ ),  $\beta_l$  is the  $l^{\text{th}}$  column effect ( $l = 1, 2, \dots, q$ ) and  $e_{kl(m)}$  is random error assumed to be iid  $N(0, \sigma^2)$ .

The model (1) can be rewritten as

$$\mathbf{Y} = \mu \mathbf{1} + \Delta' \boldsymbol{\tau} + \mathbf{D}'_1 \boldsymbol{\alpha} + \mathbf{D}'_2 \boldsymbol{\beta} + \mathbf{e}, \quad (2)$$

where  $\mathbf{Y}$  is a  $n \times 1$  vector of observations,  $\mathbf{1}$  is a  $n \times 1$  vector of ones,  $\Delta$  is a  $n \times v'$  matrix of observations versus crosses,  $\boldsymbol{\tau}$  is a  $v' \times 1$  vector of cross effects,  $\mathbf{D}'_1$  is a  $n \times p$  matrix of observations versus rows,  $\boldsymbol{\alpha}$  is a  $p \times 1$  vector of row effects,  $\mathbf{D}'_2$  is a  $n \times q$  matrix of observations versus columns,  $\boldsymbol{\beta}$  is a  $q \times 1$  vector of column effects and  $\mathbf{e}$  is a  $n \times 1$  vector of errors. Now, the design matrix  $\mathbf{X}_{n \times (v'+p+q+1)}$  with  $n > v' + p + q + 1$  can be partitioned into parameters of interest ( $\mathbf{X}_1$ ) and nuisance parameters ( $\mathbf{X}_2$ ).

$$\mathbf{X}_1 = [\Delta'], \quad \mathbf{X}_2 = [\mathbf{1} \quad \mathbf{D}'_1 \quad \mathbf{D}'_2].$$

The information matrix for estimating  $\boldsymbol{\tau}$  (parents + cross effects) can be obtained as

$$\mathbf{C}_\tau = \mathbf{X}'_1 \mathbf{X}_1 - \mathbf{X}'_1 \mathbf{X}_2 (\mathbf{X}'_2 \mathbf{X}_2)^{-1} \mathbf{X}'_2 \mathbf{X}_1 = \begin{bmatrix} \mathbf{C}_{11} & \mathbf{C}_{12} \\ \mathbf{C}'_{12} & \mathbf{C}_{22} \end{bmatrix},$$

where  $v \times v$  matrix  $\mathbf{C}$  is symmetric, non-negative definite with zero row and column sums. Further, the information matrix for estimating the elementary contrasts pertaining to cross effects can be obtained as

$$\mathbf{C}_{\text{cross}} = \mathbf{C}_{22} - \mathbf{C}_{21} \mathbf{C}_{11}^{-1} \mathbf{C}_{12}$$

Now, the cross effect  $\tau_{ij}$  can be expressed as

$$\bar{\tau}_{ij} = \bar{\tau} + g_i + g_j + s_{ij} \quad (1 \leq i, j \leq t) \quad (3)$$

where  $\bar{\tau}$  is the mean effect of crosses,  $\{g_i\}$  denotes the *gca* effects and  $\{s_{ij}\}$  denotes the *sca* effects such that

$$\sum_{i=1}^t g_i = 0 \quad (4)$$

$$\sum_{i < j=1}^t s_{ij} = 0, \quad (1 \leq i \leq t) \quad (5)$$

We arrange the crosses in the order (1,2), (1,3), ..., (1, t), (2, 3), ..., (2, t), ..., (t-1, t). Let  $\mathbf{g} = (g_1, g_2, \dots, g_t)'$  and let  $t$  and  $s$  be  $v \times 1$  vectors with elements  $\{\tau_{ij}\}$  and  $\{s_{ij}\}$  respectively. We follow Chai and Mukerjee (1999) and Das and Dey (2004) to express the general and specific combining abilities, i.e.,  $\mathbf{g}$  and  $\mathbf{s}$  in terms of  $\boldsymbol{\tau}$ . We define  $\mathbf{Q}$  to be a  $t \times v$  matrix with rows indexed by 1, 2, ...,  $t$  and columns by the pairs  $(i, j)$ ,  $(1 \leq i, j \leq t)$ , such that the  $\{u, (i, j)\}^{\text{th}}$  entry of  $\mathbf{Q}$  is 1 if  $u \in (i, j)$  and zero, otherwise. We then have,

$$\mathbf{Q}\mathbf{Q}' = (t-2) \mathbf{I}_t + \mathbf{J}_{tt} \quad (6)$$

$$(\mathbf{Q}\mathbf{Q}')^{-1} = (t-2)^{-1} \{ \mathbf{I}_t - [2(t-1)]^{-1} \mathbf{J}_{tt} \}$$

$$\mathbf{Q}\mathbf{1}_v = (t-1)\mathbf{1}, \text{ and } \mathbf{Q}'\mathbf{1}_t = 2\mathbf{1}_v \quad (7)$$

where for positive integers  $c$  and  $d$ ,  $\mathbf{1}_c$  is the  $c^{\text{th}}$  order identity matrix,  $\mathbf{1}_c$  is the  $c \times 1$  vector of all ones and  $\mathbf{J}_{cd} = \mathbf{1}_c \mathbf{1}'_d$ . Therefore (3) can be represented in matrix notation as

$$\boldsymbol{\tau} = \bar{\tau} \mathbf{1}_v + \mathbf{Q}' \mathbf{g} + \mathbf{s}, \tag{8}$$

where from (4) and (5), we have

$$\mathbf{1}_v \mathbf{g} = \mathbf{0} \text{ and } \mathbf{Q} \mathbf{s} = \mathbf{0} \tag{9}$$

Pre-multiplying (8) by  $\mathbf{Q}$  and using (4), (5) and (9), one has

$$\mathbf{g} = \mathbf{H}_1 \boldsymbol{\tau} \text{ and } \mathbf{s} = \boldsymbol{\tau} - \bar{\tau} \mathbf{1}_v - \mathbf{Q}' \mathbf{g} = \mathbf{H}_2 \boldsymbol{\tau}, \tag{10}$$

where

$$\begin{aligned} \mathbf{H}_1 &= (\mathbf{Q}\mathbf{Q}')^{-1} \mathbf{Q} - (2v)^{-1} (2v)^{-4} \mathbf{J}_{v} \\ &= (t-2)^{-1} (\mathbf{Q} - 2t^{-1} \mathbf{J}_{v}), \end{aligned} \tag{11}$$

and

$$\begin{aligned} \mathbf{H}_2 &= \mathbf{I}_v - \mathbf{Q}' (\mathbf{Q}\mathbf{Q}')^{-1} \mathbf{Q} \\ &= \mathbf{I}_v - (t-2)^{-1} (\mathbf{Q}' \mathbf{Q} - 2(t-1)^{-1} \mathbf{J}_{vv}). \end{aligned} \tag{12}$$

Here,  $\mathbf{H}_1 \mathbf{1}_v = \mathbf{0}$ ,  $\mathbf{H}_2 \mathbf{1}_v = \mathbf{0}$ ,  $\mathbf{H}_1 \mathbf{H}'_2 = \mathbf{0}$ ,

Rank  $(\mathbf{H}_1) = t - 1$  and

$$\text{Rank}(\mathbf{H}_2) = t(t-1)/2 - t \tag{13}$$

It is clear from (13) that  $\mathbf{g}$  and  $\mathbf{s}$  represent  $t - 1$  and  $t(t - 1)/2 - t$  linearly independent treatment contrasts respectively. But for  $t = 3$ ,  $\mathbf{s} = \mathbf{0}$  and hence  $t$  should be greater than 3.

Now, under (2), the joint information matrix

for  $\begin{pmatrix} \mathbf{H}_1 \\ \mathbf{H}_2 \end{pmatrix} \boldsymbol{\tau}$  is given by

$$\mathbf{C} = \begin{bmatrix} \mathbf{H}_1 \mathbf{C}_{\text{cross}} \mathbf{H}'_1 & \mathbf{H}_1 \mathbf{C}_{\text{cross}} \mathbf{H}'_2 \\ \mathbf{H}_2 \mathbf{C}_{\text{cross}} \mathbf{H}'_1 & \mathbf{H}_2 \mathbf{C}_{\text{cross}} \mathbf{H}'_2 \end{bmatrix} \text{ with } \mathbf{H}_1 \mathbf{C}_{\text{cross}} \mathbf{H}'_2 = \mathbf{0}.$$

Thus, the contrasts representing  $\mathbf{g}$  are orthogonal to those representing  $\mathbf{s}$ .

For CDC experiments, we define

$$\mathbf{M} = \begin{bmatrix} 1 & 1 & 0 \\ 1 & 0 & 1 \\ 0 & 1 & 1 \end{bmatrix}, \text{ then } \mathbf{Q}_t = \begin{bmatrix} \mathbf{1}'_{t-1} & \mathbf{0}'_{v-t+1} \\ \mathbf{I}_{t-1} & \mathbf{Q}_{t-1} \end{bmatrix} \text{ where}$$

$$\mathbf{Q}_4 = \begin{bmatrix} \mathbf{1}'_3 & \mathbf{0}'_3 \\ \mathbf{I}_3 & \mathbf{M} \end{bmatrix} \text{ then } \mathbf{Q}\mathbf{Q}' = (t-2)\mathbf{I}_t + \mathbf{J}_{tt},$$

$$(\mathbf{Q}\mathbf{Q}')^{-1} = \frac{1}{(t-2)} \left[ \mathbf{I}_t - \frac{\mathbf{J}_{tt}}{2(t-1)} \right]$$

$$\text{Hence, } \{(\mathbf{Q}\mathbf{Q}')^{-1} \mathbf{Q}\}_{ij} = \begin{cases} \frac{1}{t-1}, & \text{if } \mathbf{Q}_{ij} = 1 \\ -\frac{1}{(t-1)(t-2)}, & \text{if } \mathbf{Q}_{ij} = 0 \end{cases}$$

$i = 1, 2, \dots, t$  and  $j = 1, 2, \dots, t$ .

$$\text{Therefore, } \{\mathbf{H}_1\}_{ij} = \begin{cases} \frac{1}{t}, & \text{if } \mathbf{Q}_{ij} = 1 \\ -\frac{2}{t(t-2)}, & \text{if } \mathbf{Q}_{ij} = 0 \end{cases}$$

### 3. METHOD OF CONSTRUCTION

Construct a standard Latin square of size  $t$  ( $t$  must be odd). Develop another array of size  $t$  by adding values  $0, 1, \dots, t - 1$  to each row of the standard Latin square consecutively and by taking modulo  $t$ . Now, superimpose the generated array on the standard Latin square and form crosses between the corresponding elements of the array. This arrangement leads to a MERC design with

parameters  $v = \frac{t(t+1)}{2}$ ,  $p = q = t$ ,  $r_1$  (replication of

selfings) = 1 and  $r_2$  (replication of  $F_1$ 's) = 2.

For this class of MERC designs, the crosses are partially balanced following a two associate class triangular association scheme. The information matrix for estimating the contrasts pertaining to

gca is  $\mathbf{C}_{gca} = \frac{2t(t-3)}{(t-2)^2(t-1)} \left[ \mathbf{I} - \frac{\mathbf{J}}{t} \right]$ . The variance of

elementary treatment contrasts pertaining to gca effects is given by

$$V(\hat{g}_i - \hat{g}_j) = \frac{(t-2)^2(t-1)}{t(t-3)} \sigma^2; i \times j = 1, 2, \dots, t.$$

**Example 1:** For  $t = 5$ , the MERC design (including selfings) with parameters  $v = 15$ ,  $p = q = 5$ ,  $r_1 = 1$  and  $r_2 = 2$  is obtained as follows:

Standard Latin square of order 5

0	1	2	3	4
1	2	3	4	0
2	3	4	0	1
3	4	0	1	2
4	0	1	2	3

Array developed by adding 0, 1 ..., 4 (mod 5) to the rows of the standard Latin square

0	1	2	3	4
2	3	4	0	1
4	0	1	2	3
1	2	3	4	0
3	4	0	1	2

MERC design

0 × 0	1 × 1	2 × 2	3 × 3	4 × 4
1 × 2	2 × 3	3 × 4	4 × 0	0 × 1
2 × 4	3 × 0	4 × 1	0 × 2	1 × 3
3 × 1	4 × 2	0 × 3	1 × 4	2 × 0
4 × 3	0 × 4	1 × 0	2 × 1	3 × 2

The variance of elementary treatment contrasts pertaining to gca effects is given by

$$V(\hat{g}_i - \hat{g}_j) = 3.6\sigma^2 ; i \neq j = 1, 2, \dots, 5.$$

**Note:** It may be noted here that superimposing any two orthogonal Latin squares (if the same exist for a given  $t$ ) and forming crosses with the corresponding elements of each of the array results in a MERC design with parameters  $v = \frac{t(t+1)}{2}$ ,  $p = q = t$ ,  $r_1$  (replication of selfings) = 1 and  $r_2$  (replication of  $F_1$ 's) = 2. Hence, MERC designs for even  $t$  can also be obtained as a special case.

#### 4. OUTLINE OF ANALYSIS

Under the linear model (2) with  $p = q = t$ , sum of squares corresponding to the three sources of variability viz., rows, columns and entries ( $F_1$ 's + parents/selfings) can be obtained as  $Q'_\alpha C'_\alpha Q_\alpha$ ,  $Q'_\beta C'_\beta Q_\beta$  and  $Q'_\tau C'_\tau Q_\tau$  respectively where  $Q_\alpha$ ,  $Q_\beta$  and  $Q_\tau$  are the adjusted totals for rows, columns and entries  $C_\alpha$ ,  $C_\beta$  and  $C_\tau$  are the information matrices for estimating the contrasts pertaining to rows, columns and entries respectively. The sum of squares due to parents and crosses can be obtained by appropriately partitioning the information matrix for estimating the contrasts of entries. Sum of squares due to parents Vs crosses can be obtained by developing a suitable contrast. Now, sum of squares for gca and sca

can be obtained by  $Q'_{cross} (H_1 C_{cross} H'_1)^- Q_{cross}$  and  $Q'_{cross} (H_2 C_{cross} H'_2)^- Q_{cross}$  respectively, where  $Q_{cross}$  is the adjusted total for cross effects. The split-up degrees of freedom is as follows:

Source	DF
Row	$t - 1$
Column	$t - 1$
Entries	$\frac{t(t+1)}{2} - 1$
Parents	$t - 1$
Parents vs. Crosses	1
Crosses	$\frac{t(t-1)}{2} - 1$
gca	$t - 1$
sca	$\frac{t(t-3)}{2}$
Error	$(t - 1)^2 - \frac{t(t+1)}{2} + 1$
Total	$t^2 - 1$

**Remark:** The developed designs are minimal with respect to the number of experimental units. This may lead to non-estimability of some of the sca effects. This can be sorted out by either repeating the design or suitably repeating the crosses while doing the experimentation.

For the easy accessibility of these designs to the users, a Macro (given in the end) has been developed using PROC IML of SAS software which generates randomized layout of the designs.

#### 5. EFFICIENCY

Considering a row-column model, the per cross canonical efficiency of these designs as compared to an orthogonal design with same number of crosses has been studied by developing a SAS code in PROC IML and listed along with other parameters in Table 1.

**Table 1.** List of designs obtained

S.N.	t	v	p	q	r <sub>1</sub>	r <sub>2</sub>	V <sub>(i,i)</sub>	E <sub>canonical</sub>
1	5	15	5	5	1	2	3.60	0.7692
2	7	28	7	7	1	2	5.36	0.8077
3	9	45	9	9	1	2	7.26	0.8654
4	11	66	11	11	1	2	9.20	0.8594
5	13	91	13	13	1	2	11.17	0.8764
6	15	120	15	15	1	2	13.14	0.9023
7	17	153	17	17	1	2	15.13	0.9001
8	19	190	19	19	1	2	17.11	0.9096

Here,  $V_{(i,i)}$  = Variance of the estimated elementary contrasts pertaining to gca effects and  $E_{\text{canonical}}$  = Canonical efficiency factor, where  $E_{\text{canonical}}$  of the MERC design is computed relative to an orthogonal design with the same number of crosses by working out the harmonic mean of  $(1/r)$  times the non-zero eigen values of the information matrix pertaining to cross effects.  $r$  is the number of replications of the crosses and it is assumed that  $\sigma^2$  is the same for the developed MERC design and the orthogonal design to which it is compared. It can be seen that the efficiency is quite high for the class of designs obtained and it increases with increase in the number of lines involved in the crosses.

## 6. CONCLUSION

When the number crosses becomes large (it increases rapidly with the increase in number of lines), which leads to a large experimental area, and it may be more advantageous to use row-column (RC) setup to eliminate the effects of heterogeneity in the experimental material in two directions. RC designs always provide more precise comparison among combining ability effects as compared to any block design when heterogeneity is present in the experimental material in two directions. Here, an easy method to construct Mating-Environmental Row-Columns (MERC) design for Type III complete diallel mating designs in smaller number observations has been given, which facilitates a more precise

and variance balanced estimation of gca effects free from sca effects.

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### SAS MACRO FOR GENERATION AND RANDOMIZATION OF TYPE III MATING ENVIRONMENTAL ROW-COLUMN DESIGN

Macros provided here gives a solution for the generation and randomization of designs for estimating *gca* effects free from *sca* effect under a row-column set up for Type III complete

diallel mating designs with parameters =  $\frac{t(t+1)}{2}$ ,

$p = q = t$ ,  $r_1$  (replication of selfings) = 1 and  $r_2$  (replication of  $F_1$ 's) = 2, where  $t$  is the number of lines. This program was developed using SAS IML in the form of a Macro so that user would be able to get the design by providing only number lines ( $t$ , for odd  $t$ ). User can get the generated design and its randomized layout in Rich Text Format (RTF) by submitting the following code:

```
options nodate nonumber;
%let t=5; /*Enter the number of lines (t should be an odd number)*/
ods rtf file="Merc_TypeIII.rtf";
title 'MERC designs for type III diallel cross experiments';
proc iml;
eve=mod(&t,2);
if eve=0 then do;
print 'Entered number is not an odd number';
end; else do;
c_no=comb(&t,2)+&t;
```

```
n_no=&t;
k=1;
d0=j(n_no,n_no,0);
do i=1 to n_no;
do j=1 to n_no;
d0[i,j]=mod((i-1)+j,n_no);
if d0[i,j]=0 then d0[i,j]=n_no;
end;
end;
*print d0;
d01=j(n_no,n_no,0);
do i=1 to n_no;
do j=1 to n_no;
d01[i,j]=mod(d0[i,j]+(i-1),n_no);
if d01[i,j]=0 then d01[i,j]=n_no;
end;
end;
*print d01;
k=1;
d001=j(n_no*n_no,2,0);
do i=1 to n_no;
do j=1 to n_no;
d001[k,1]=d0[i,j];
d001[k,2]=d01[i,j];
k=k+1;
end;
end;
*print d001;
k=1;
x=j((n_no*n_no),2,0);
do i=1 to n_no;
do j=1 to n_no;
x[k,1]=i;
```

```

x[k,2]=j;
k=k+1;
end;
end;
*print x;
d0001=x||d001;
d002=j(n_no,5,0);
do i=1 to n_no;
do j=1 to 4;
d002[i,j]=d0001[i,j];
end;
d002[i,5]=i;
end;
*print d002;
d00001=j(((n_no-1)*n_no),4,0);
do i=1 to (n_no-1)*n_no;
do j=1 to 4;
d00001[i,j]=d0001[i+n_no,j];
end;
end;
*print d00001;
call sort(d00001, {3 4 1 2}, );
*print d00001;
d1=d00001;
do i=1 to (n_no-1)*n_no;
if d00001[i,3]>d00001[i,4] then
do;
d1[i,3]=d00001[i,4];
d1[i,4]=d00001[i,3];
end;
end;
*print d1;

call sort(d1, {3 4 1 2}, );
*print d1;
vec=j(n_no*(n_no-1),1,0);
d2=d1||vec;
k=1;
do i=1 to ((n_no-1)*n_no)/2;
do j=1 to 2;
d2[k,5]=n_no+i;
k=k+1;
end;
end;
*print d2;
/*****code for generating
designs*****/
ww=j(n_no,n_no,0);
do i=1 to n_no;
do j=1 to n_no;
ww[i,j]=d0[i,j];
ww[i,j]=ww[i,j]-1;
end;
end;
print ww;
ww1=j(n_no,n_no,0);
do i=1 to n_no;
do j=1 to n_no;
ww1[i,j]=d01[i,j];
ww1[i,j]=ww1[i,j]-1;
end;
end;
print ww1;
ww_=char(ww,4,0);
ww1_=char(ww1,4,0);

```

```

www=j(nrow(ww),ncol(ww),' x');
MERC_design=ww_+www+ww1_;
print MERC_design;
/*****
*****/randomization*****/
*****/
*****/row-randomization*****/
r=j(1,nrow(ww),0);
call randgen(r,'uniform');
*print r;
rr=rank(r);
*print rr;
ra=j(nrow(ww),ncol(ww),0);
random_row=char(ra,10,0);
do i=1 to nrow(ww);
do j=1 to ncol(ww);
random_row[i,j]= MERC_design[rr[i],j];
end;
end;
*print random_row;
/*****/
/*****/column-randomization*****/
r=j(ncol(ww),1,0);
call randgen(r,'uniform');
*print r;
rr=rank(r);
*print rr;

```

```

Randomized_Layout=char(ra,10,0);
do i=1 to nrow(ww);
do j=1 to ncol(ww);
Randomized_Layout[i,j]= random_
row[i,rr[j]];
end;
end;
print Randomized_Layout;
/*****/
end;
run;
ods rtf close;
quit;

```

#### SAS Output for V=5

MERC_design				
0 x 0	1 x 1	2 x 2	3 x 3	4 x 4
1 x 2	2 x 3	3 x 4	4 x 0	0 x 1
2 x 4	3 x 0	4 x 1	0 x 2	1 x 3
3 x 1	4 x 2	0 x 3	1 x 4	2 x 0
4 x 3	0 x 4	1 x 0	2 x 1	3 x 2

Randomized_Layout				
2 x 3	3 x 4	1 x 2	4 x 0	0 x 1
1 x 1	2 x 2	0 x 0	3 x 3	4 x 4
0 x 4	1 x 0	4 x 3	2 x 1	3 x 2
3 x 0	4 x 1	2 x 4	0 x 2	1 x 3
4 x 2	0 x 3	3 x 1	1 x 4	2 x 0