...plications may be used. Moreover, the number of replications for any treatment needs not to be equal. A Completely Randomized Design is considered to be most useful in situations where:

(i) The experimental material is homogeneous.
(i) The experiments are small such as laboratory experiments.
(ii) Some experimental units are likely to be destroyed or may fail to respond in the experimental process.

Advantages of Completely Randomized Design

(i) The design is completely flexible, i.e., any number of treatments and of replications may be used. Moreover, the number of replications for any treatment needs not to be equal.
(ii) It gives maximum degrees of freedom for error sum of squares as compared with the other designs for the same situation.
(iii) The design is very simple and easy to lay out.
(iv) The statistical analysis is very simple both for equal and unequal number of replications.
(v) If the data from some experimental units is missing, it does not complicate the analysis. The missing observations can be discarded without affecting the results of the experiment and efficiency of this design is not severely affected by this act.

Disadvantages of Completely Randomized Design

(i) The design is applicable only to a small number of treatments.
(ii) The design is applicable only to homogeneous experimental material.
(iii) If the experimental units are not homogeneous, then the use of this design gives the large experimental error as compared to some other designs, which use the homogeneous experimental units as blocks and ultimately reduce the experimental error.
(iv) There is possibility of entering the whole of the variation among the experimental units into the experimental error, as the randomization is not restricted in any direction.

2) ***Randomized Complete Block Design***

A Randomized Complete Block Design (RCBD) is a design in which:

(i) The experimental material is divided into blocks or groups in such a manner that the experimental units within a particular block are relatively homogeneous.
(ii) Each block contains a complete set of treatments, i.e., it constitutes a replication of treatments, and
(iii) The treatments are assigned at random to the experimental units within each block, which means the randomization is restricted within blocks. A new randomization is made for every block. The purpose of this type of arrangement is to control a source of variation in the experimental material.

The RCBD is perhaps the most frequently used experimental design. The main objective of blocking is to reduce the variability among experimental units within a block as much as possible and to maximize the variation among blocks. If there are no differences among the blocks, this design would not contribute to improve the precision in detecting treatment differences rather blocking may have detrimental effects. The word "Complete" here indicates that each block contains all the treatments.

Advantages of Randomized Complete Block Design

(i) The design is flexible, i.e. any number of treatments and of replication (but not less than 2) may be used.
(ii) The statistical analysis is fairly simple when there are no missing observations.
(iii) It is easy to adjust for missing observations.
(iv) Grouping the experimental material controls the source of extraneous variation and hence the estimate of the experimental error is decreased.
(v) When the variability among blocks is large then precision increases because the sum of squares for blocks is extracted from the sum of squares for experimental error leading to smaller error mean square (MSE).
(vi) Placing blocks under different conditions increases the scope of the experiment.
(vii) It provides unbiased estimates of the means of the blocking factor.
(viii) A Randomized Complete Block Design is generally more efficient than Complete Randomized Design subject to proper block orientation.

Disadvantages of Randomized Complete Block Design

(i) It controls variability only in one direction.
(ii) It is not a suitable design when the number of treatment is very large or when the blocks are not homogeneous.
(iii) With the increase in block size, within block variability increases which is not the aim of this design because our purpose is to reduce variability within the blocks and to maximize the among block variability.

(iv) Missing observations in the data cause problem in the analysis. One or two missing observations can be handled easily but more missing observations affect the efficiency of the design.

(v) The degrees of freedom for error are less for RCBD because of the formation of blocks as compared with the CRD. This loss can be dangerous when blocks effect is non-significant.

Latin Square Design The Latin square design is used to estimate two nuisance sources of variability; i.e., it systematically allows blocking in two directions. Thus, the rows and columns actually represent two restrictions on randomization. In general, Latin square for p factors, or a $p \times p$ Latin square, is a square containing p rows and p columns. Each of the resulting p^2 cells contains one of the p letters that corresponds to the treatments, and each letter occurs once and only once in each row and column.

It should be noted that in a Latin square design, the number of rows, the number of columns and the number of treatments must be equal. The objective is to eliminate the variability due to rows and columns from the experimental error. It is advocated that these designs are useful when the number of treatments is between 5 and 10. When the number of treatments increases it becomes laborious to use this design.

Advantages of Latin Square Design

(i) A Latin square design reduces the error variance by controlling two source of variation.
(ii) The analysis without missing values is straightforward.
(iii) A Latin square design is generally more efficient than a RCBD.
(iv) Each row and column is a complete replication.

Disadvantages of Latin Square Design

(i) A Latin square design is less flexible than a RCBD. It is practical only for 5 to 10 treatments. When the number of treatments exceeds 10, the design is seldom used.
(ii) For a small number of treatments, a Latin Square design does not provide sufficient number of replicates to give a valid estimate of error.
(iii) When number of treatments is less than 4, the degrees of freedom for error is rather small thus validity of experimental error becomes questionable.
(iv) Replication in Latin Square design is costly.
(v) In agricultural experiments, the land requirement is rigid, the actual layout in the field may be laborious and approach to the central most plots becomes difficult.
(vi) If there are missing observations in the experiment, then the analysis becomes complicated.

Standard Latin Square A Latin square in which the treatments in the 1st row and in the 1st column are arranged in alphabetical or numerical order is called a Standard or Reduced Latin Square. Each standard square of size $p \times p$ yields $p!(p-1)!$ different squares by permuting the rows except the first and all the p columns.

Crossover Design Occasionally, one encounters a problem in which time periods are a factor in the experiment. In general, there are p treatments to be tested in p time periods using np experimental units.

There are the designs in which experimental units receive more than one treatment application in the experiment. The other names for these designs are Changeover designs. In these designs individual experimental units are used for the treatment application for two or more periods in a manner similar to Latin Square design. Each experimental unit receives all treatments and each treatment should appear an equal number of times. The experiment is split into different periods each unit receiving one treatment in each period and each unit is intended to be treated the same number of periods denoted by p. This design is used when the number of treatments is less than or equal to 3. For example, a human performance analyst is studying the effect of two replacement fluids on dehydration in 20 subjects. In the 1st period, half of the subjects (chosen at random) are given fluid "A" and the other half fluid "B". At the end of the period, the response is measured and period of time is allowed to pass ("washout" period) in which any physiological effect of the fluids is eliminated. Then the experimenter has the subjects who took fluid "A" take fluid "B" and those who took fluid "B" take fluid "A". This design is called a **Crossover design**. It is analyzed as a set of 10 Latin Squares with two rows (time periods) and two treatments (fluid types). The two columns in each of the 10 squares correspond to subjects.

Time	Treatments																			
	A										B									
Time Period 1	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Time Period 2	11	12	13	14	15	16	17	18	19	20	1	2	3	4	5	6	7	8	9	10

Limitations of Cross Over Design

(i) Number of rows is equal to the number of treatments.

(ii) Number of columns is multiple of number of treatments.

(iii) Number of replications is equal to the component multiple of number of treatments.

Where Cross Over Design is Appropriate?

(i) *Cross Over Design* may be preferable in small experiments, where few degrees of freedom are available for error.

(ii) Where the difference between the rows is substantially same in all replicates i.e. where each replicate is homogeneous.

(iii) When we have good pairs and bad pairs, because in this design we divide good and bad pairs equally.

Application of Cross Over Design

(i) *Cross Over Design*, combining the features of Latin Square Design & Randomized Complete Block Design, is used in some dairy husbandry and biological studies.

(ii) *Cross Over Design* is applicable to experiments, such as those involving the rotation of crops, in which several treatments are applied in succession to the same experimental units.

(iii) *Cross Over Design* is also used to advantage in psychological and marketing research.

Advantages of Cross Over Design

(i) This design allows using each experimental unit several times and makes easier to compare many treatments in one design.

(ii) Important contrasts can be measured within each unit by the residual variation between measurements on the same unit.

Disadvantages of Cross Over Design

(i) There are drawbacks in using the same unit several times. Although each sequence may be comparable at the start but may not remain so because of carryover effects. The carryover effects can be mitigated including washout periods between the experimental periods.

(ii) When using more periods interpretation may be hindered by treatments × periods interaction that may arise because of the length of the experiment.

The Graeco-Latin Square Design Consider a p×p Latin Square, and superimpose on it a second p×p Latin Square in which treatments are denoted by Greek letters. If the two squares when superimposed have the property that each Greek letter appears once and only once with each Latin letter, the two Latin squares are said to be orthogonal, and the design thus obtained is called a Graeco-Latin Square.

The Graeco-Latin Square design can be used to control systematically three sources of extraneous variability, i.e. to block in three directions. The design allows investigation of four factors (rows, columns, Latin letters and Greek letters), each at p levels in only P^2 runs. Graeco-Latin square exist for all $p \geq 3$ except $p=6$. It should be noted that not more than $(p-1)$ Latin squares of order p could be orthogonal. A set of $(p-1)$ orthogonal squares of order p, is called a complete set of Latin squares.

The concept of the orthogonal pairs of Latin squares forming a Graeco-Latin square can be extended. A $p \times p$ hyper square is a design in which three or more orthogonal $p \times p$ Latin squares are superimposed. In general, up to $p+1$ factors could be studied if a complete set of p-1 orthogonal Latin squares is available. Such a design would utilize all $(p+1)(p-1) = p^2-1$ degrees of freedom, so an independent estimate of the error variance is necessary. Of course, there must be no interaction between the factors when using hypersquares.

Analysis of Covariance (ANCOVA) Suppose that in an experiment with a response variable Y there is another variable, such as X, and that Y is linearly related to X. Furthermore, suppose that X cannot be controlled by the experimenter but can be observed along with Y. The variable X is called a covariate or concomitant variable. The analysis of covariance involves adjusting the observed response variable for the effect of concomitant variable. If such an adjustment is not performed, the