GLOSSARY FOR DESIGN OF EXPERIMENTS

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ANOVA -- An acronym for "**AN**alysis **O**f **VA**riance," a statistical technique that separates the variation in an experiment into categories relating to the causes of the variation. For example, ANOVA will separate variation into categories for each factor and each combination of factor interactions.

Average -- calculated by adding all replicates of a measurement together and dividing by the number of replicates.

b-coefficients -- Coefficients for the mathematical model representing a response surface. When all factors are coded on the -1 to 1 scale, the b coefficients can be ranked by magnitude to determine the importance of a factor's or interaction's contribution to the total variation in an experiment.

Block -- A group of experiments. Blocks are often used to eliminate "nuisance factors", factors that influence a response, but are of no interest in an experiment.

Box-Cox Plot -- A plot of the log of the average vs. the log of the standard deviation for a set of replicates. This plot can be used to test for consistent, or homogeneous estimates of standard deviation. If the plot shows a slope, the standard deviation estimates may not be consistent. The slope can be used to determine a logical transformation of the data to make the standard deviation estimates consistent.

Box-Cox Transformation -- A transformation used to make standard deviation estimates consistent. The transformation is made by raising each response to the power of a number called "lambda.". Lambda is equal to 1 minus the slope of the line in a Box-Cox Plot.

Central composite -- Central composite designs allow for the collection of data to fit full quadratic models. They have spherical geometries. They are one type of "Interaction Plus Star" design.

Coding -- As it applies to DOE, coding changes factor levels from their natural units (such as time or temperature) to a -1 to 1 scale. This provides greater accuracy during computations and allows b-coefficients to be ranked by their magnitude for screening.

Coefficients -- Coefficients are constants that are multiplied by factors in a mathematical model. They are often referred to as "b-coefficients" in DOE.

Combined s -- When standard deviation estimates for different trials in an experiment are consistent, they can be combined to give a better estimate of the standard deviation. The method used to combine standard deviations is called "pooling." Other names for consistent standard deviation are "pooled s" and "pure error."

Confidence limits -- Confidence limits are numbers between which an average is expected to lie with a certain probability (confidence). For example, "The long term average for Young's Modulus for hot melt inks lies between 2.38 and 2.99 with 95% confidence."

Consistent standard deviation estimates -- When the estimates for standard deviation at different trials all estimate the same underlying standard deviation the estimates are consistent. In other words, the standard deviation for all trials is approximately the same -- the estimates only differ because of sampling.

Constrained mixture -- A constrained mixture is a mixture whose components are not allowed to vary over the entire range of 0% to 100%. For example, a constrained mixture might require water to vary from 50% to75%. **Constrained mixture design** -- A constrained mixture design restricts the upper and lower levels for one or more components to a range less than 0% to 100% and requires that the components in each trial add to 100%.

Constraint -- A constraint is a limitation. For example, in a mixture all of the components must add to 100%. This constraint is imposed by nature. Some constraints are imposed by the experimenter, such as "the sum of the laser pulses and the laser power must be less than 89."

Continuous -- Continuous means that you can always find a number between any other two numbers, no matter how close together they are. Time is continuous -- you can always find a moment in time between any two other moments in time.

Contour plots -- Contour plots are plots that show lines of equal value. In DOE, contour plots show lines of equal responses, usually equally spaced in response values. They provide an easy way to determine a response value for a response surface.

Correlation -- Correlation is the linear relationship between two variables.

Cubical experimental space -- When all factors in an experiment may vary from highest to lowest regardless of the levels of the other factors the geometry is cubical. The easiest way to see this is to consider the cube formed by the high and low levels of three factors.

D-Optimal -- D-Optimal refers to a type of experiment design that attempts to produce the most accurate b- coefficients for a model. These designs are quite useful for screening experiments. The D stands for "determinant," a property of a matrix that is useful in generating these designs.

Degrees of freedom –(df)- Degrees of freedom provide a measure of the quality of a standard deviation estimate -- the larger the degrees of freedom, the better the quality of the standard deviation estimate.

Design -- This is sort for "experiment design." Various types of experiment designs are

central composite design -- a design with spherical geometry that can be used to fit a full quadratic model. It is one type of interaction plus star design.

constrained mixture design -- a design that restricts the levels on at least one component to less than 0% to 100% and requires the levels in each trial to add to 100%.

D-Optimal design -- a design that attempts to provide the most accurate estimates of the b coefficients for a model.

factorial design -- another name for an interaction design. It was called factorial by Sir Ronald Fisher because it studies factors. (Designs for quadratic models also study factors, but they are not called factorial designs!)

fractional factorial design -- interaction designs that include only a fraction of the corners of the hyper cube. Fractional factorial designs typically fit interaction models that include only 2-factor interactions. **I-Optimal design** -- a design that attempts to provide the best predictions for any given trial. The I stands for "Integrated Variance," the average variance for a design. I-Optimal designs minimize the average variance for responses throughout a region of interest.

interaction design -- a design that collects data to fit an interaction model. This design uses the corners of a cube or hyper cube as trials. Also called a factorial, full factorial, or fractional factorial design. **interaction plus star design** -- a design specifically intended to fit a full quadratic model. This design uses the corners of a cube or hyper cube, the center point, and the star points. Examples of this design type are the central composite design and the face centered cubic design.

face centered cubic design (FCC) -- a type of interaction plus star design in which the star points are in the centers of the faces of a cube or hyper cube.

Plackett-Burman design -- a type of screening design that spreads the contamination from interactions equally over the main effects.

screening design -- a design that seeks only to identify the strongest main effects from a number of possibilities.

simplex lattice design -- a mixture design that allows each component to vary from 0% to 100% of the mixture. The trials are vertices, center point, and centers of faces of tetrahedra.

small design -- a term used by STATISTICA to indicate that not all of the trials from the full design are being used. These designs have an interaction order of 2.

Design of Experiments (DOE) -- DOE is a statistical technique that allows you to run the minimum number of experiments to optimize your product or process. It involves determining the best experiments to run to fit a particular mathematical model.

designed experiment -- A designed experiment is an experiment where trials (runs) are carefully chosen to meet specific goals, including fitting a particular mathematical model.

df -- This is shorthand for "degrees of freedom."

discrete -- Discrete indicates that only specific levels are possible for a factor. For example, if you have catalyst A and catalyst B there is no level in between.

effects -- An effect is the average change in a response for a change from low to high level of a factor, interaction, quadratic term, etc. Effects can be ranked by magnitude to determine the strongest to weakest of factors in a screening experiment.

experiment design -- An experiment design is a plan for collecting and analyzing data.

experimental error -- Experimental error is a term used to refer to all of the uncertainty in an experiment, including systematic error and random response variation.

face-centered-cubic (FCC) design -- An FCC design is a type of interaction plus star design in which the star points are in the centers of the faces of a cube or hyper cube.

factor -- A factor is a variable over which you have direct control in an experiment. Some examples are time, temperature, and pressure. Various type of factors are

blocking factor -- a factor identifying which block a trial belongs to, used to eliminate nuisance factors in an experiment. It is used during data collection, but generally ignored during analysis.

discrete factor -- a factor whose levels are discrete, i.e. not continuous. For example, farm plot A or farm plot B.

external factor -- a factor that is not varied in your experiment. External factors should be held constant. Unknown external factors are an ever-present threat. You can protect your self against unknown external factors by using a random run order.

mixture factor -- a continuous factor that is subject to the mixture constraint, i.e. all of the components must add to 100%.

nuisance factor -- a factor that influences your response, but that you are not interested in studying. For example, you may want to run experiments on different days. The passing of time may influence your results, but you are not interested in studying time as a factor. You can use blocking to deal with nuisance factors.

process factor -- a continuous factor that is not subject to the mixture constraint.

restricted factor -- A restricted factor is a process factor that has levels restricted to certain values in a design. For example, you may want to have sandpaper grit as a factor. Grit is a continuous factor, but only certain levels are commercially available. Your design should only include commercially available levels, but you want to be able to predict without limits. If a grit that is not commercially available is predicted to work best, you can have it custom made.

factorial -- Factorial, as used in DOE, means "pertaining to factors." It is only used when referring to interaction designs.

Fisher -- Sir Ronald Fisher, the father of modern experimentation.

fractional factorial -- Fractional factorial refers to an interaction design in which only a portion of the trials is run. These typically have interaction order 2.

Gaussian Distribution -- A Gaussian Distribution is a bell-shaped pile of data. It was named in honor of Karl Friedrich Gauss, the first man to write about random response variation. The distribution is also called the Normal Distribution.

I-Optimal -- I-Optimal is a property of a design that makes it very good at making precise predictions. The I stands for "Integrated Variance," the average variance for a design over its region of interest.

I-Optimal design -- An I-Optimal design is a design that attempts to provide the best predictions for any given trial. The I stands for "Integrated Variance," the average variance for a design. I-Optimal designs minimize the average variance for responses throughout a region of interest.

I-Optimal Design Library -- The I-Optimal Design Library is a collection of I-Optimal designs created using Gosset. The designs provide for a wide variety of experiments that cannot be performed using classical designs. Designs can include different types of factors in the same experiment, such as mixture and process factors in the same experiment. The library is free and available at http://www.mathoptions.com/i-optimal

interaction -- An interaction is a joint effect of factors. For instance, time and temperature interact when baking a cake. Both must be set together to get good results. Another common example is drug interaction, where two medicines taken together produce an effect that neither could produce by itself.

interaction design -- An interaction design is a design to fit an interaction model. Other names are factorial design and fractional factorial design.

interaction order -- The interaction order is the highest number of factors for which an interaction term exists in a model. For example, models that include only 2-factor interactions have interaction order 2. Models that include 3-factor interactions, but no higher, have interaction order 3.

interaction plus star design -- The interaction plus star design is a design specifically intended to fit a full quadratic model. This design uses the corners of a cube or hyper cube, the center point, and the star points. Examples of this design type are the central composite design and the face centered cubic design.

level -- The value to which a factor should be set in an experiment. For example, 6 hrs. is a level for time.

main effect -- The main effect for a factor is the effect on a response due to that factor only.

mathematical model -- A mathematical model is an equation that can be used to make predictions of experimental results. In DOE mathematical models are typically polynomials.

mean -- The mean is a particular average, the sum of a number of replicates divided by the number of replicates. Other types of average are the "median," the number above which half of the replicates lie and below which half of the replicates lie, and the "mode," the most frequently occurring value among the replicates.

mixture -- A mixture is a combination of components. Examples of mixtures are gasolines, inks, and your favorite soda.

model -- A model is a theory expressed as a surface. Various types of model are

> **interaction model** -- a mathematical model that is a polynomial including a constant term, a term for each factor, and terms for various factor interactions. These models can fit tilting and twisted planes.
>
> **full quadratic model** -- a mathematical model that is a polynomial including a constant term, a term for each factor, terms for all 2-factor interactions, and terms for each factor squared.
>
> **main effects model** -- a mathematical model that is a polynomial including a constant term and terms for each factor. It can only fit tilting planes. These models are only used for screening factors.

Normal Distribution -- A Normal Distribution is a bell-shaped pile of data. It is a very normal shape for a pile of industrial data. Same as Gaussian Distribution

Normal Probability Plot -- A Normal Probability Plot, or Normal Plot, is a plot that makes data from bell-shaped piles plot as a straight line. It is used to test for the consistency of standard deviation estimates.

OFAT -- This is short for "One-Factor-at -A-Time," an experimental technique in which only one factor is varied in any experiment, the remaining factors being held constant. It fails to look for interactions among the factors.

orthogonal -- Orthogonality is a mathematical property of a matrix. In DOE the term is often used to indicate a very good design.

polynomial -- A polynomial is an equation that is the sum of a number of terms.

pooled standard deviation -- The pooled standard deviation is the combined standard deviation for a number of trials. This is another name for combined standard deviation.

Predictions vs. Residuals Plot -- This is a plot used to help determine if standard deviation estimates are consistent.

probability -- Probability is the proportion of time a given event can be expected to happen. For example, if the probability of confidence limits being correct is 0.95 (95%), then you can expect your confidence limits to be correct 95 times out of every 100 times you report them.

pure error -- Pure error is another name for combined standard deviation. It is called pure error because it only includes random response variation that you measured in your experiments.

r -- r is the correlation coefficient. It can vary from -1 to 1. Values near -1 or 1 indicate very good correlation. Values near 0 indicate very poor correlation.

r2 -- r2 is the coefficient of determination. It can range from 0 to 1. It represents the percentage of the variation observed explained by the correlation.

r-critical -- r-critical is a tabulated value that helps you to judge if r is statistically significant. If your r is greater than r-critical, your r is statistically significant, i.e. your correlation appears to be real.

random -- Random means that no pattern is followed. Given a series of random numbers, you cannot predict the next number.

regression -- Regression is a mathematical technique used to fit data to a mathematical model.

region of interest -- The region of interest is the set of all experiments you may wish to predict results for. It is generally represented by a cube.

replicate -- A replicate is a measurement. If one measurement is made, you have one replicate. If two measurements are made, you have two replicates, etc.

residual -- A residual is the difference between a prediction and an observation.

response -- A response is a variable over which you do not have direct control. You have to vary factors to change a For example, you must vary the ingredients (factors) in a cake to change its flavor (response).

response surface -- A response surface is a surface that represents predicted responses to variations in factors. It can have any number of dimensions depending on the number of factors.

response surface methodology (RSM) -- RSM is a technique that uses response surfaces to analyze experimental data. It is very powerful in that it allows you to predict the results of experiments you have never performed. It can also be used to predict the Sweet Spot.

response variation -- Response variation refers to differences in replicate measurements. It refers specifically to the random variation that is a part of nature and cannot be entirely eliminated.

run -- A run is the execution of an experimental trial. Multiple executions of the same trial count as separate runs.

run order -- The order in which experimental trials should be executed. This order should be random whenever possible.

s --- s is the symbol for **standard deviation**.

scientific method -- The scientific method is a means of learning about nature. It is composed of observation, reason, and experimentation.

screening -- Screening is a technique used to determine which factors in a list of contenders are most important. Screening generally neglects interactions to keep the design as small as possible.

simplex lattice design -- A simplex lattice design is a mixture design that can include vertices, center point, centers of edges and centers of faces. All components can range from 0% to 100% of the mixture.

slope -- Slope measures the degree of tilt of a line. It is the rise of the line divided by the run of the line. Positive slope indicates rising from left to right. Negative slope indicates rising from right to left. Zero slope indicates a horizontal line.

small design -- "Small design" is a term used by STATISTICA to indicate that not all of the trials from the full design are being used. These designs typically have an interaction order of 2.

spherical experimental space -- When some factors in an experiment may vary from higher or lower levels when the levels of the other factors are at their middle levels the geometry is spherical. The easiest way to see this is to consider the sphere that encloses the cube formed by the high and low levels of three factors. The star points on this sphere are above the centers of the cube faces.

standard deviation -- The standard deviation is the width of half the bell-shaped pile, or Normal distribution, at half of its height. This width can be used to estimate the full width of the pile.

star points -- These are points added to an interaction design, or factorial design, to allow fitting a full quadratic model. They are in the centers of faces for cubical geometries and on the sphere surrounding the cube for spherical geometries.

STATISTICA -- A full-featured statistics software that can be used for experiment design and analysis.

statistical test -- The "statistical test" compares the prediction limits for a trial that was not used to fit your model with the observation for that trial. If the observed value lies between the prediction limits, the test passes. If not, it fails.

Student's t value -- Student's t is a correction factor for standard deviations calculated from small sample sizes. It allows you to state confidence limits.

Sweet Spot -- The Sweet Spot is the experimental trial that meets all of your response goals simultaneously. **systematic error** -- Systematic error is experimental error that can, at lease theoretically, be eliminated. It includes mistakes, instrument drift, external factors that are not held constant, etc.

t -- Student's t value. Student's t is a correction factor for standard deviations calculated from small sample sizes. It allows you to state confidence limits.

term -- A term is a part of an equation that is separated by plus and / or minus signs. For example, in Y = b0 + b1X1, b0 and b1X1 are terms.

tolerance limits -- Short for "statistical tolerance limits," they are limits between which a large proportion of all individual measured responses will lie with some confidence. For example, 95% tolerance limits on 99% of the population tell you the limits between which 99% of all future response measurements should lie with 95% confidence.

transformation -- A transformation is a mathematical operation performed on responses to make their standard deviation estimates consistent.

trial -- A trial is a set of factors and their associated levels that completely specifies an experiment to run. For example, "Temp = 100 deg C, Time = 2 hours, and Pressure = 35 PSI" is a trial.

triangular plots -- Triangular plots allow you to make contour plots for mixtures in which all of the components are shown.

type I model -- A type I model is a model for mixtures that includes every component and has no constant term.

type II model -- A type II model is a model for mixtures that includes every component but 1 and includes a constant term.

variance -- Variance is the square of the standard deviation. Variance is useful because variances can be added while standard deviations cannot.

variation -- Variation refers to differences in replicate measured responses for the same trial.

X1, X2, etc. -- These are symbols used to indicate factors in a mathematical model.

Y -- Y is used to indicate a response in a mathematical model.

Y-bar -- This is a term that refers to the average for a response.

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