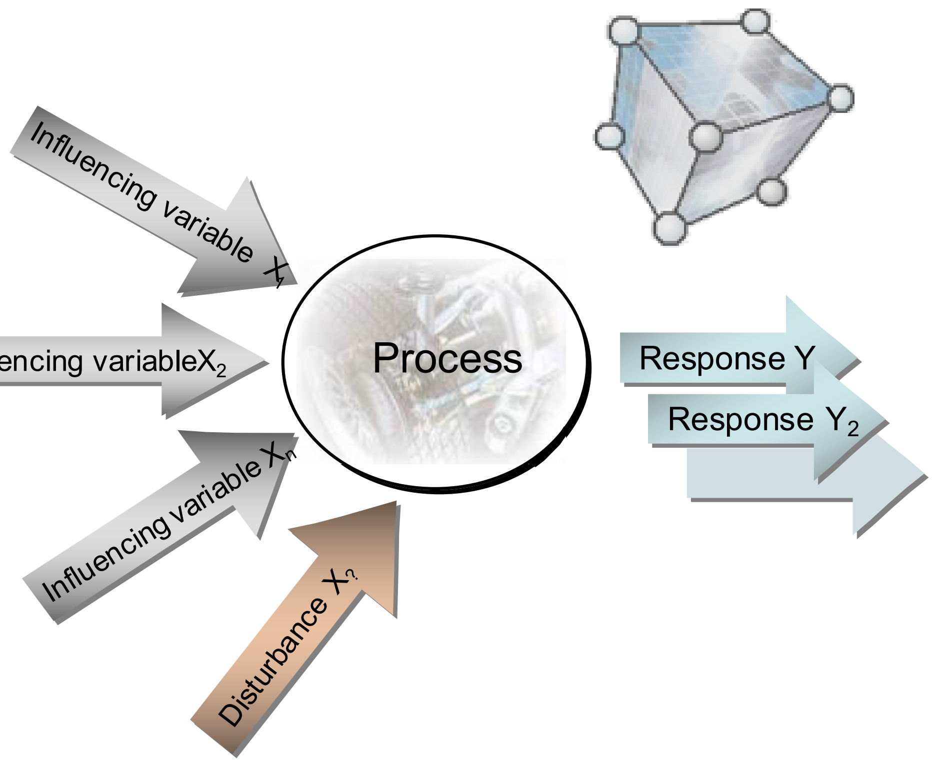
DoE
Design of Experiment



Contents

Requirement and related topics

Basics of statistics are beneficial for these descriptions. Further and related topics include: www.weibull.de/COM/System_Analysis.pdf

Keywords

DoE, Design of Experiment, Plackett-Burman, D-Optimal, Definitive Screening Designs, interaction, effects, orthogonal, fractional, full factorial, Decision matrix, Software

Introduction

The aim of experimental design is to clearly determine the effects of multiple influencing parameters on a target variable (response) and identify potential interactions.

The task is to combine experiments in such a way that the relationships between a function or process can be best reproduced for subsequent evaluation. There are influencing variables that can be varied in a targeted manner, but there are also often disturbance variables. In DoE, influencing variables are also referred to as factors.

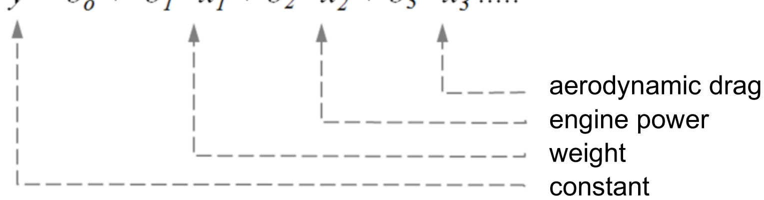
Purpose and benefit

Compared to individual experiments, the DoE method allows the identification of interactions. The evaluation capability is significantly improved compared to unplanned data collection. By determining a model equation, optimal settings can be determined, even if they were not part of the experimental design. The DoE method reduces the number of experiments and costs.

Basics

Reality should be described by a simplified model. For example, if the fuel consumption of a vehicle is to be determined based on the influencing factors of weight, engine power, and aerodynamic drag, the following simplified approach is initially used:

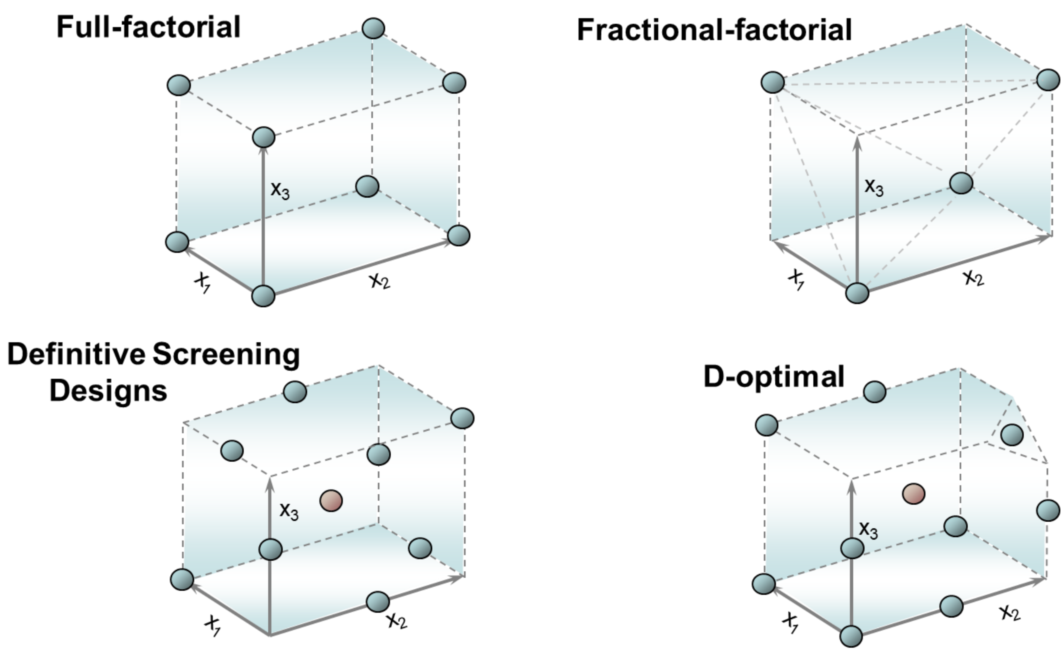
$$y = b_o + b_1 \cdot x_1 + b_2 \cdot x_2 + b_3 \cdot x_3 \ldots\ldots$$



We are looking for a matrix (DoE table) that best solves the system of equations.

Spatial representation

The most important experimental designs for 3 influencing x-variables in a spatial representation:



Model types

The relationships sought can be linear, with interactions or nonlinear:

Type	Attitude	Remark
Linear $Y = b_o + b_1 x_1 + b_2 x_2$	Factors on respectively only 2 steps, min number of tests p +1*	No nonlinearities and interactions determinable
Interactions $Y = ... b_4 x_1 x_2 ...$	Factors on respectively only 2 steps, min number of tests p+p (p 1)/2+1 *	No nonlinearities determinable, but interactions
Square $Y = ... b_4 x_1^2 ...$	Factors on respectively only 3 steps min number of tests 2 p+p (p 1)/2+1 *	Nonlinearities recognizable. Incl . interactions
Cubic $Y = ... b_4 x_1^2 + b_5 x_1^3$.	Factors on respectively only 4 steps, min number of tests 3 p+p (p 1)/2+1 *	Curses of curve with turning point recognizable, incl . interactions

p = number of factors, min = number of tests related to D optimal

Design overview

An overview of the most important desgins are shown here:

Full factorial	All combinations, full orthogonal	High number of tests, effortful best evaluable
Fractional	Half or a smaller number of tests like full factorial, full orthogonal	Mixing of interactions Unsafe of evaluation
Plackett Burmann	Derivation from fractional design. Very low number or tests.	Interactions are not fully confounded
DSD	Definitive Screening Designs Very low number or tests on 3 levels	Quadratic model possible, interactions are confounded only partially
DSD IA	Definitive Screening Designs Very low number or tests on 3 levels	Quadratic model, interactions can be evaluated
Taguchi	Very low number of tests, multiple fractional full orthogonal	Many interactions mixed with each other and with factors; suitable only for regulation of individual factors
Central Composite Design	The same construction as full-factorial plus cross in the middle. Test space like a ball	High number of tests, effortful good evaluable
Box-Behnken	Evaluation for quadratic models. Middle levels in outlet area.	High number of tests, effortful good evaluable
D-Optimal	Low number of tests, Clear regulation of interactions,	not orthogonal, good evaluable Flexible modeling possible, specific terms can be selected. Existing trials can be taken into account
Mixture	Use of factors whose sum must always amount to 100%	not orthogonal, factors dependent on each other good evaluable

For more information, please have a look to the Handbook of statistical methods

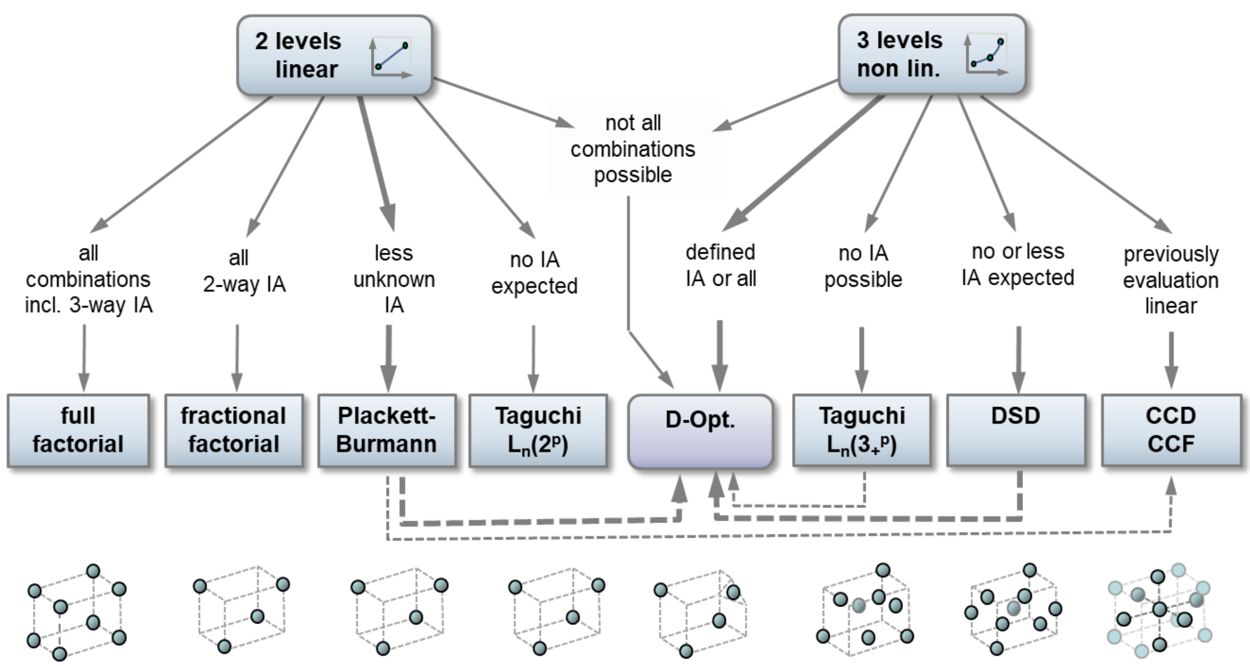
crgraph.de/downloads/docs/weibull/COM/Statistics.pdf

Decision matrix of designs

	Full factorial	Frac- tional	Plackett- Burman	Taguchi	CCD	DSD	D-Opt.
orthogonal	✓	✓	✓	✓	✓	✓	—
quadratic	✓	—	—	partly	✓	✓	✓
cubic	✓	—	—	partly	✓	-	✓
Inter- actions	✓	partly type IV or type V+	partly by enough DF	–	depends on basis	(✓)	✓
Number experiments	very large	middle	small	very little	large	very little	small
partly eval. previously	—	—	—	—	✓	—	—
constrains possible	—	—	—	—	—	—	✓

Decision tree of designs

A best practice is to start with a Plackett-Burman or DSD design and if nonlinearities or interactions are not clear, continue with D-Optimal.

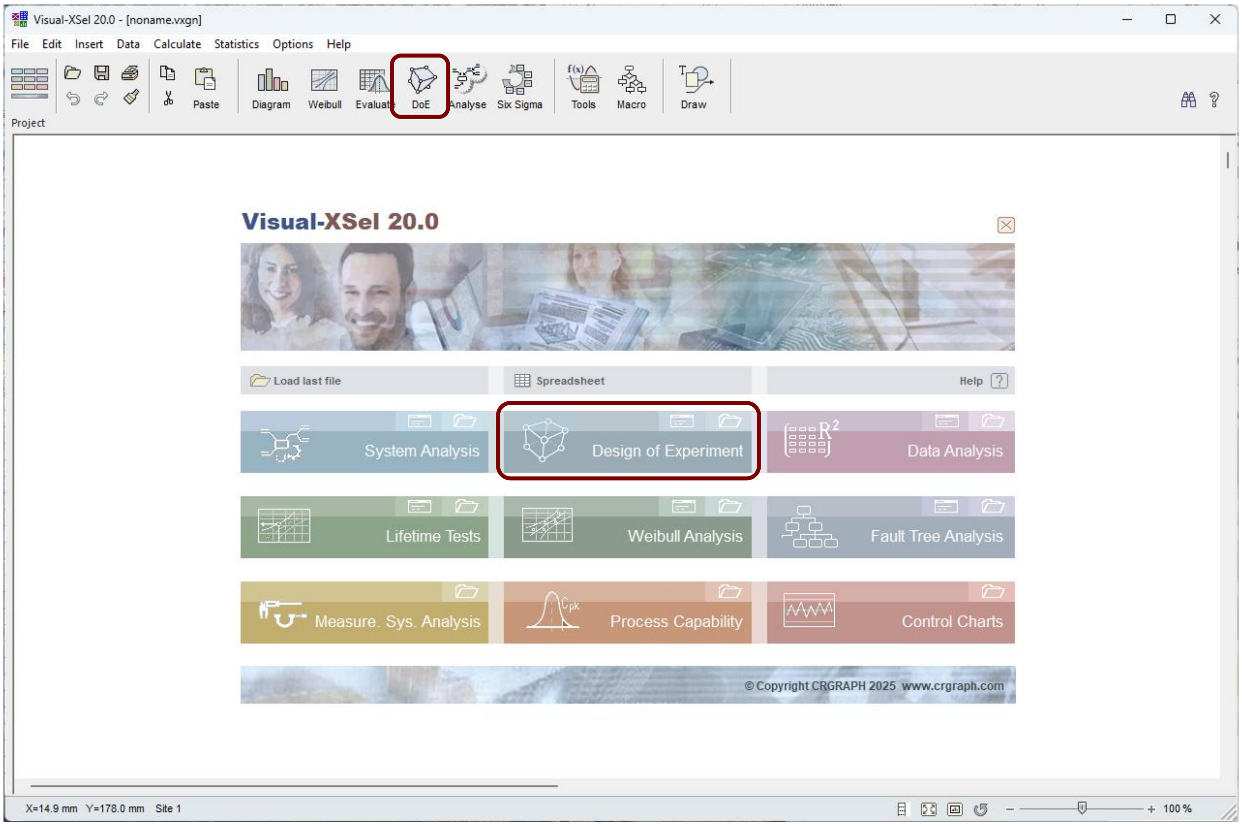


IA = Interactions

Application in Visual-XSel

www.crgraph.com

Our software Visual-XSel is a powerful tool for all important statistical quality and reliability methods. To get started, use the topic areas in the guide (see also crgraph.de/en/themen-index), or the icon **DoE**.



Here you can find an introduction and a short video:
crgraph.de/en/visual-xsel-software/

Here you can also find some introductory videos:
crgraph.de/downloads/software/Visual-XSel_Basis_Functions.mp4
crgraph.de/downloads/software/Visual-XSel_Methods.mp4

It is not for nothing that this software is used in many well-known companies
References

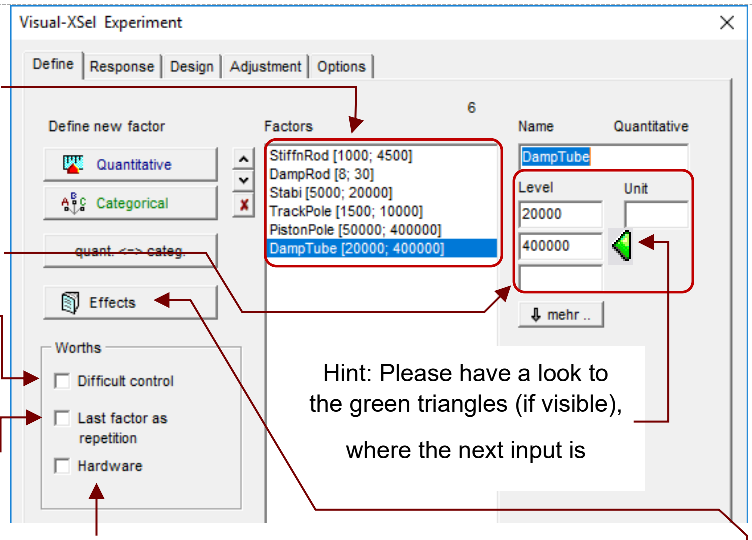
The following description is a guide and introduction to the topic shown

On the following pages the most important steps are shown. First use the ***Statistical Experiments*** from the Main-Guide.

The first step to create a DoE is to define the Factors (parameter). Push the button ***Quantitative*** for continuing measurable factors, or ***Categorical*** for factors described by text. The names should not be longer than 20 chars.

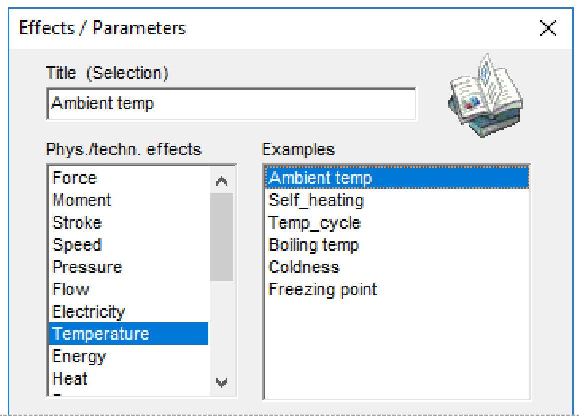
Type for each factor the ***levels*** of the combinations and use optional a ***Unit***.

If ***Difficult control*** is selected the order of the experiments is created with as few changes as possible are necessary.
The option ***Last factor as***.. means, that the combinations of all factors before will repeated depending on there levels.



If ***Hardware*** is selected for some factors later on a list can be shown of parts to provide.

Under the button ***Effects*** a little library of the most important physically effects is available. Own factors can be added here. Use a double click to use a selected item, which is then shown in the Title.
This library is also a good check-list, so that no factor is forgotten in your project.



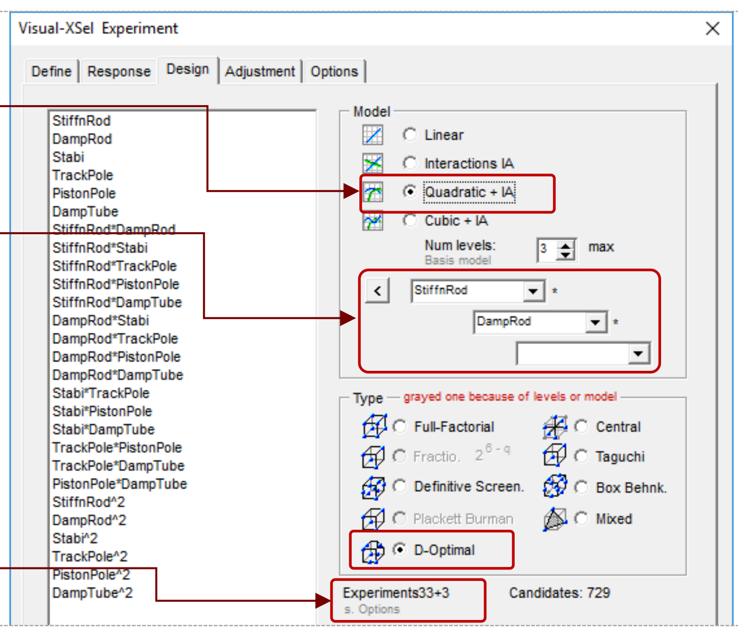
Via the rubric ***Response***, one or more "Y" can be defined for the results of the DoE

The next step is to define the ***Model*** and the ***Type*** of the experiment. In this example a quadratic model with interactions is selected (this is sometimes called Response-Service-Model).

Also certain triple interactions can also be defined.

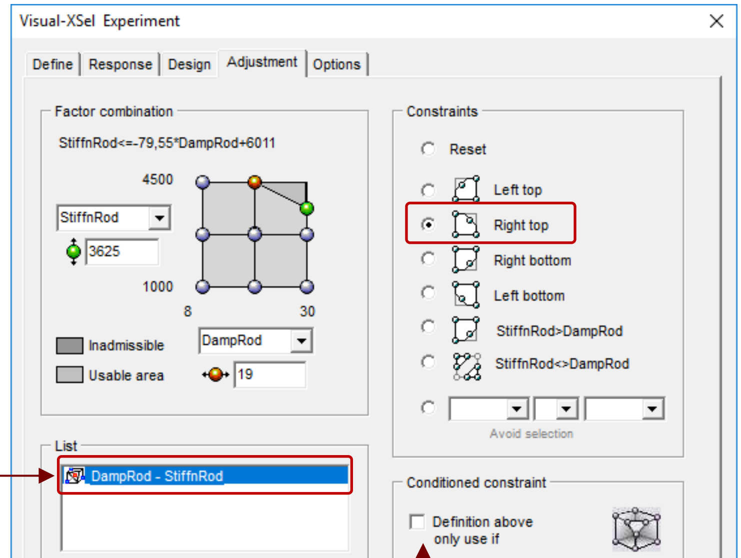
The standard-type is ***D-Optimal***, which allows the most options. If the used type is not suitable for the model or the number of factors, you will get a message later, or some options are grayed out.

Right below the number of experiments is shown + 3 for the number repetitions.



On the next page it is possible to define ***Constrains***. Maybe there is a technical restriction, which is not possible. In the shown example the StiffnRod=4500 cannot be tested in combination with DampRod=30. But DampRod=15 is possible. To fix this constrain, push the button New, which is below of the ***List***.

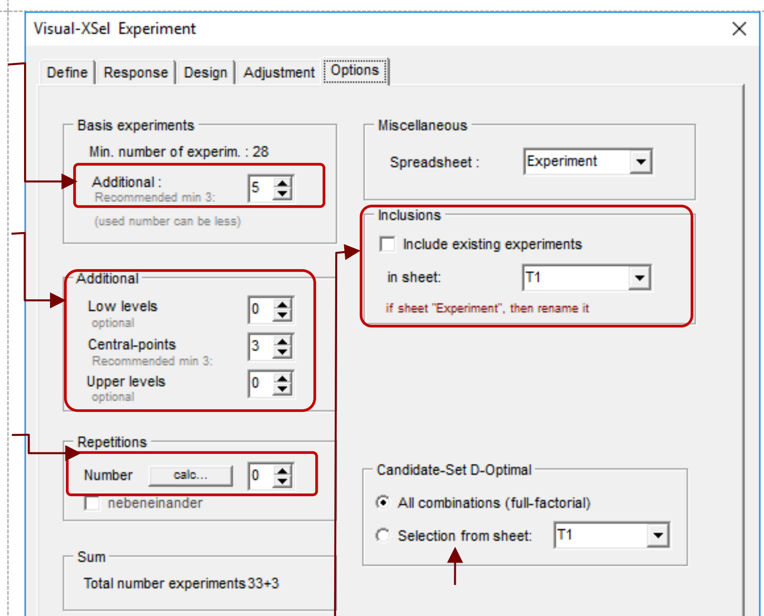
Note:
The view of the Factor combinations is only possible for quantitative factors and for D-Optimal design.



Hint: Constrains can be combined with other conditions, so that only an edge will be excluded from the DoE.

Under the rubric ***Options*** you can define additional experiments for D-Optimal design to ensure that the p-values can be calculated in the evaluation later on. The minimum is 1.

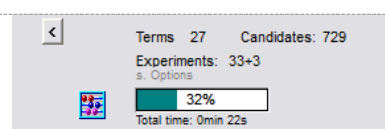
Under ***Additional*** you can define repetitions with the same factor values to determine the so called "pure error". This is needed to get the information of the inaccuracy of the measurement-procedure (equipment).
Alternatively ***Repetitions*** for each trial can be set. Under the button ***calc*** it is possible to calculate how much trials are needed to detect the effect sure.



Especially for D-Optimal designs, a very important feature is the possibility to use already existing measurements. Use ***Inclusions*** and define the table where are these results. The column-names must be in the same order like in the list before (first col. is always no.)

Hint: For D-Optimal designs a pre-defined table can be used, from which the algorithm will try to get the best determinant. This is an alternative to constrains, may be if complex restrictions with categorical factors are excluded from the sheet.

Now start to create the plan with button ***Create***. If D-Optimal is selected the iterations begins.



Finally the table with the DoE matrix is shown, where the empty column for the “response” have to be filled.

A	B	C	D	E	F	G	H
No	StiffnRod	DampRod	Stabi	TrackPole	PistonPole	DampTube	Y
1	2750	19	12500	5750	225000	210000	
2	1000	8	20000	1500	225000	210000	
3	4500	8	5000	5750	50000	400000	
4	2750	30	5000	10000	400000	210000	

The next step is to evaluate the results. For this please use

www.weibll.de/COM/Data_Analysis.pdf

If there are any suggestions or hints about this short introdution, please give us a feedback to

info@crgraph.de