Ottimizzazione attraverso il CAE
- introduzione all'uso di Hyperstudy -

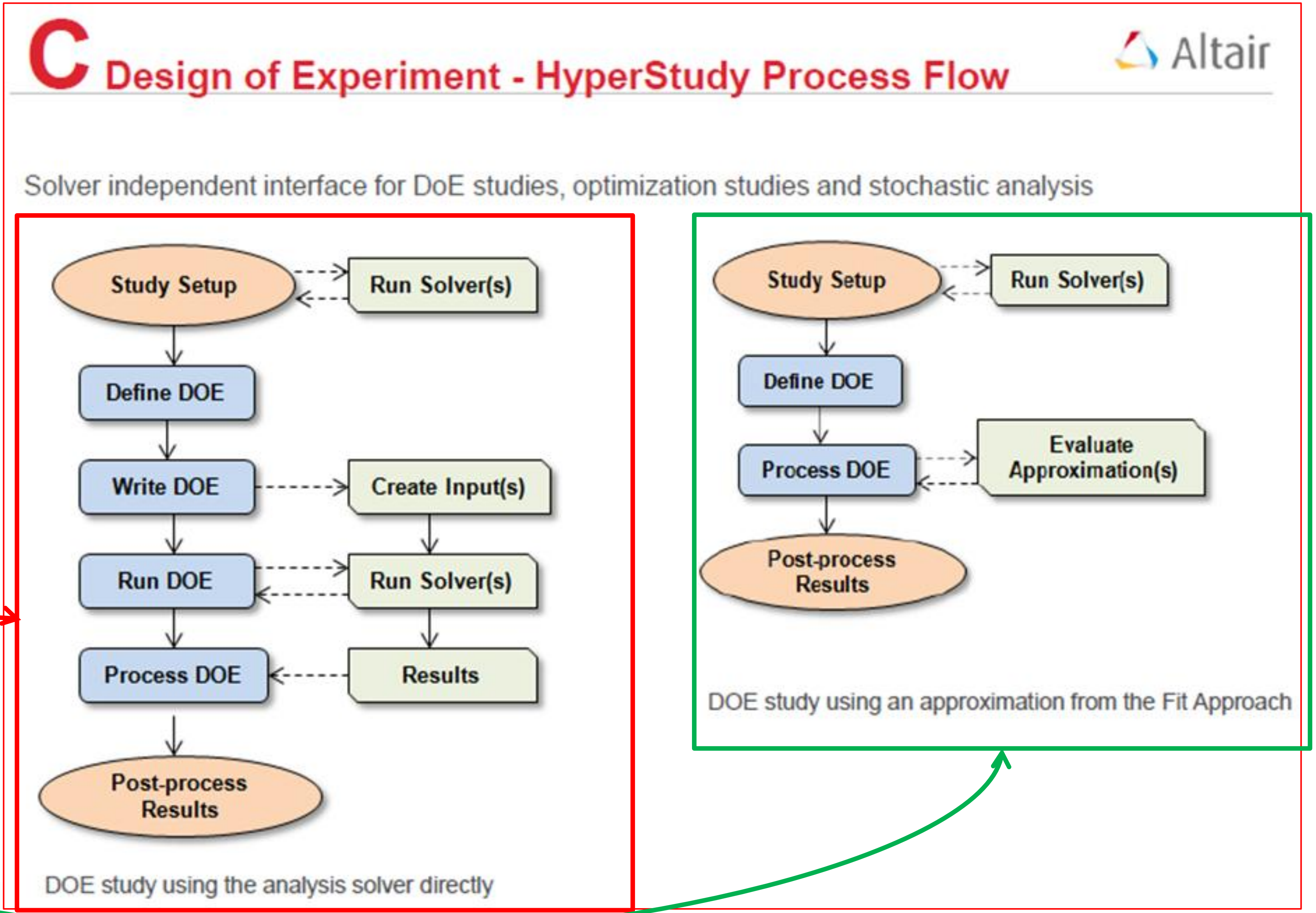
L'analisi DOE

(immagini e esempi presi dai tutorial Altair University)

Nell'analisi DOE sono possibili due schemi di lavoro:

1) Definisco il piano e lancio in successione le simulazioni

2) Ho già disponibili una serie di simulazioni, definisco un DOE e le elaboro



Nel secondo caso in genere segue un metamodel

Richiami sul DOE (1/3)

C Design of Experiment - Concepts

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What is Design of Experiments (DoE)?

Design of Experiments (DoE) is a structured, organized design/run matrix creation method that once run will be used to determine the relationships between the different factors/variables (Xs) affecting a process and the output of that process (Y).

Objectives of DOE Study

- To determine which factors are most influential on the responses.
- To determine where to set the influential controlled input variables so that:
  - The response is close to the desired nominal value.
  - Variability in output response is small.
  - The effects of the uncontrolled variables are minimized.
- To construct an approximate model that can be used as a surrogate model for the actual computationally intensive solver.

Richiami sul DOE (2/3)

C Design of Experiment - Terminology

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- **Factors** are system parameters (or design variables) that change the system performance. Factors can be controlled or uncontrolled.
  A factor can be either **Discrete** i.e., slow (-) or fast (+) or **Continuous** i.e. temperature.

- **Variables** are system parameters that can be changed to improve the system performance. Since this chapter is part of a design study process, we will be using factors and variables interchangeably.

- **Reduced variables.** In DOE terminology, it is standard practice to work with reduced variables that have a range of -1 to 1 for each real variable.

- **Levels** are discrete (or continuous) values of the factor/variable. The values taken by in the range [-1; +1]. Number of levels per variable to be considered depends on the level of non linearity in the problem; for a linear model two levels are sufficient; for a quadratic model three levels are needed.

Richiami sul DOE (3/3)

C Design of Experiment - Terminology

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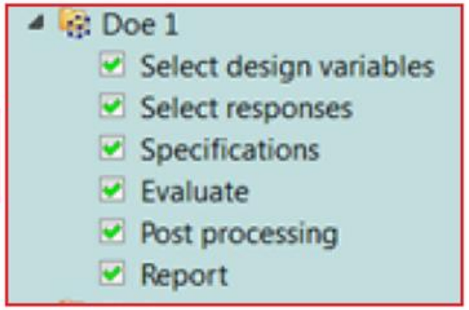
- **Controlled factors** are design variables that can be realistically controlled in the production (real world) environment. In HyperStudy, these are assigned to a distribution role of Design or Design with Random; depending on whether they are deterministic or probabilistic variables.
  Examples include gauge thickness of sheet steel, shape of a support bracket, and mold temperature.

- **Uncontrolled factors (Noise)** are variables that cannot be realistically controlled in the production (real world) environment, but can be controlled in the lab. In HyperStudy, these are assigned to a distribution role of Random parameter.
  Examples include ambient temperature and occupant seating positioning.

- **Confounding** is the inability to distinguish between main effects and interaction effects. Confounding occurs when a fractional design is chosen instead of a full-factorial design. The consequence of confounding is that the values calculated for main effects will have error coming from inclusion of higher order interactions in the calculation and interaction effects will be unknown.



La scelta dell'analisi DOE richiede il rispetto di questa sequenza di lavoro

The steps to set up a **DOE** Approach in HyperStudy are:

1. **Select Design Variables**
   - Review the lower bounds, initial values, upper bounds.
2. **Select Responses**
3. **Specifications**
   - Methods
   - Settings, Levels, Interaction
4. **Evaluate**
5. **Post-Processing**
   - Effects Table
   - Linear Effects
   - Interactions Table
   - Interactions.
6. **Report**

C Design of Experiment - Select Design Variables

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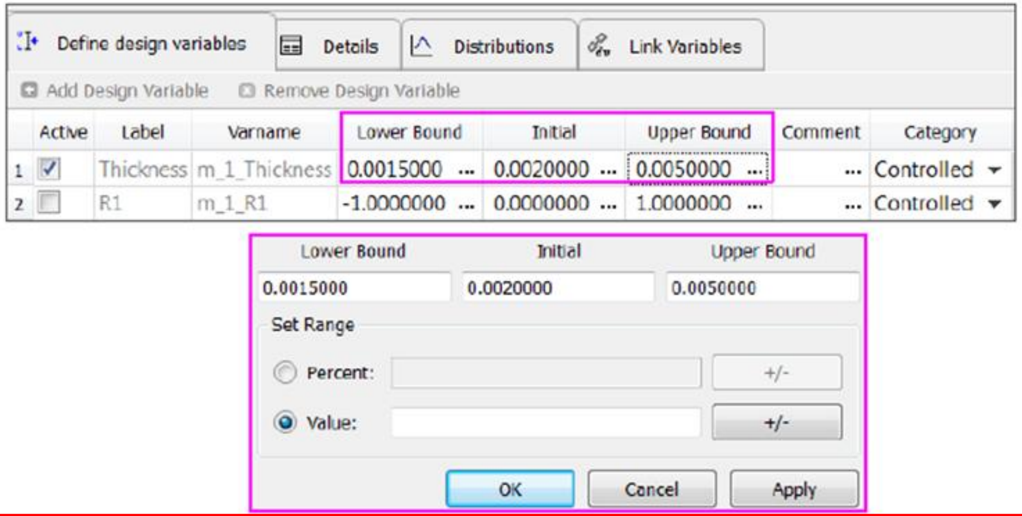
In this step, you can exclude some of the design variables from the approach if you need to do so. You can also review and change the attributes for the included design variables if needed. This step is similar across the four approaches with the following exceptions.

For a **DOE**, you can:

- Review the lower bounds, initial values, upper bounds.



C Design of Experiment - Select Responses

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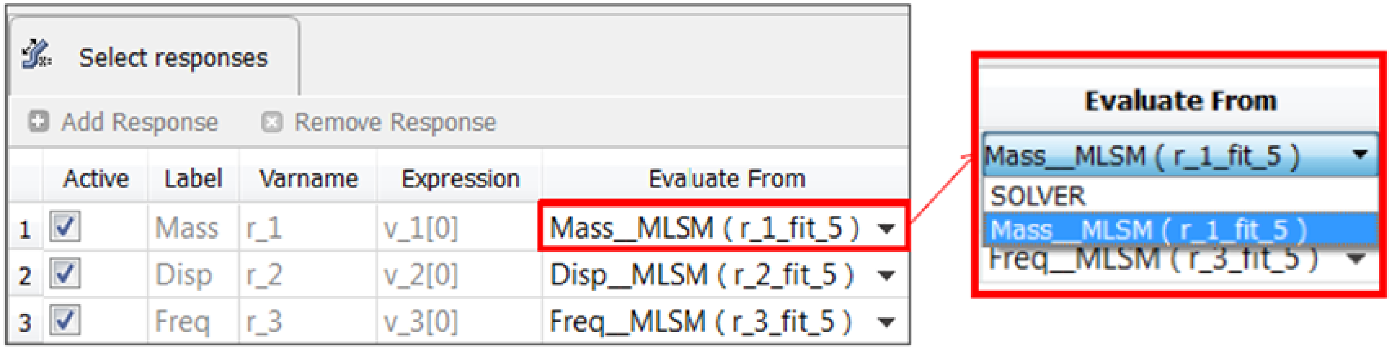
Review your responses and exclude any of the responses from the approach by un-checking the response in the State column.

It is not possible to exclude responses in an optimization approach.

You can also change the evaluation source from its default entry of SOLVER to one of the Fits (if you have any Fit approaches defined prior to this approach).



DOE implementati

I primi tre sono bene noti!

Design of Experiment – Specifications Methods

- Full Factorial
- Fractional Factorial
- Central Composite Design (CCD)
- Latin Hypercube
- Hammersley
- Plackett Burman (PB)
- Box-Behnken
- User-Defined Design
- Run Matrix

Full Factorial	FullFact
Fractional Factorial	FracFact
Central Composite	Ccd
Latin HyperCube	LatinHyperCube
Hammersley	Hammersley
Plackett Burman	PlackBurm
Box Behnken	Box
User Defined	User
Run Matrix	RunMatrix

Design of Experiment - Applications

DOE for Screening

Objective

- A simple DOE study (ex. two level design with no interactions) will provide a global understanding of the complete system i.e give the magnitude and direction of effects
- This initial screening exercise will allow parameters which do not influence the system to be discarded thus reduce the number of factors and runs.
- Lower precision

Types

- Full Factorial
- Fractional Factorial
- Plackett-Burman

DOE for Response Surface (RSM) Evaluation

Objective

- Fewer factors
- Model of relationships
- Accurate prediction
- Optimization

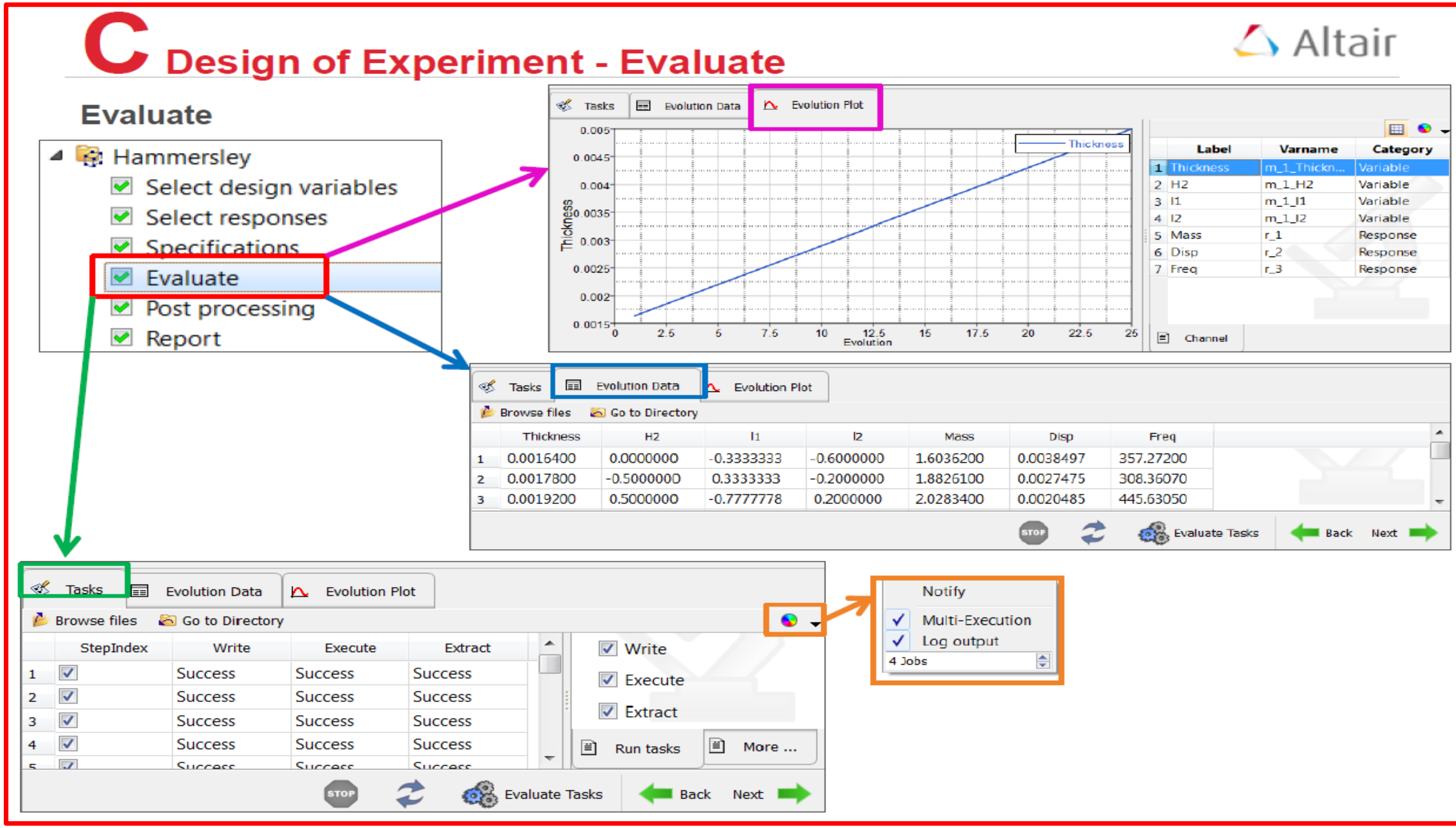
Types

- Box-Behnken
- Central Composite Design
- Latin HyperCube Sampling
- Hammersley Sampling

Design of Experiment - Specifications Methods Summary

DOE Type	Levels	Notes
Full Factorial	Any	Requires high number of points & therefore unsuitable for most FE studies
Fractional Factorial	2 or 3	Selected fraction of full factorial. Typically, half, quarter, eighth of full factorial
CCD	3	Developed to build a quadratic response surface, typically 5 levels for each point. Limited to 20 factors & should only be used if the responses are known to be quadratic
Box-Behnken	3	3 levels for each design variable including central point, economic DoE for building a quadratic response surface. May be used if the responses are known to be quadratic & predictions not required at the edge of design space.
Plackett Burman	2	Used for initial screening, number of points can be as small as N-1. Use when all factors are boolean (eg on/off, 0/1,+/-). Not suitable for an approximation.
Latin Hypercube	Any	Number of points not related to number of design variables. Used when response surface is highly non linear.
Hammersley	Any	Used when response surface is highly non linear, better space filler than LCH – generally best for FE work

La fase “Evaluate” lancia le simulazioni



N.B. Al termine dei run di simulazione la cartella di lavoro potrebbe essere piena di file di output FEM non funzionali all’analisi. Si consiglia un PURGE dei file per eliminare file non necessari

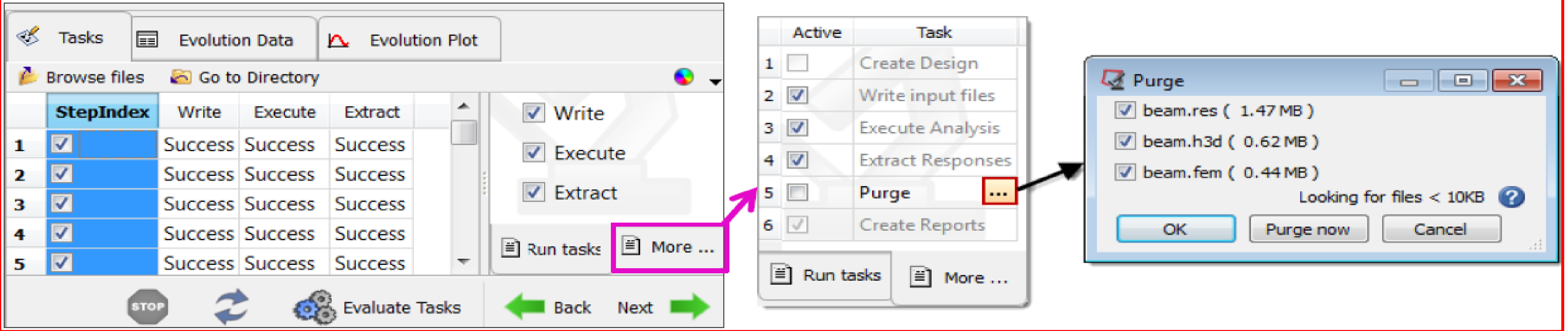
Evaluate → *Purge*

During and/or after an evaluation, use the **Purge** tool to minimize the size of your study directory by removing unnecessary run files.
To access the Purge tool, go to the **More…** tab and click ***Purge***.
The Purge tool displays a list of all the files available for purge, which are sorted by size. Files smaller than 10kb will not be listed in the **Purge** tool because they do not pose as a problem to disc space usage.

1. Select one or all of the runs from the ***StepIndex*** column of the **Tasks** tab.

2. Go to ***Tasks*** → ***More…*** tab, click **…** next to **Purge**.

3. In the **Purge** dialog, select the check boxes of the files that you would like to purge from your study directory, click on ***Purge now*** then click ***OK.***
   Optional: To apply purge selection to future approaches, select **Purge** check box in the **Active** column.



Post Processing

Questa fase gestisce la visione degli output dell'analisi

C Design of Experiment - Post-Processing

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Post processing options for the approaches of a study are split into two groups; one group is available regardless of approach, and another group provides approach-specific options.

Run Summary, **Statistics**, **Histogram, Box Plot** and the **Scatter plots** (**2D and 3D**) are available across all approaches. Any approach-specific post processing options will appear in a second group of tabs.

The DOE-specific **Post-Processing** includes **Effects Table**, **Linear Effects**, **Interactions Table** and **Interactions.**

In the **Explorer** select ***Post-processing*** step, ☑ Post processing to proceed with DOE Post-Processing.

- **Run Summary**
- **Statistics**
- **Histograms**
- **Box Plot**
- **Scatter 2D**
- **Scatter 3D**
- ...

Hammersley
- ☑ Select design variables
- ☑ Select responses
- ☑ Specifications
- ☑ Evaluate
- ☑ Post processing
- ☑ Report

Design of Experiment - Post-Processing

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Run Summary

The **Run Summary** tab displays a table of all runs for design variables and responses.
As all the tables in HyperStudy, the **Run Summary** table offers sorting (ascending/descending order) and finds features, which can be accessed from the **context menu**.

Run Summary | Statistics | Histogram | Box Plot | Scatter 2D | Scatter 3D

Browse files | Go to Directory

	H1	H2	I1	I2	Mass	Disp	Freq
1	00000	0.0000000	0.0000000	0.0000000	2.1609100	0.0020732	368.83110

Launch Post Processing | Back | Next

Statistics

The **Statistics** tab provides a series of statistical measures on the variables (DOE Factors) and responses.
Columns can be turn on or off and adjusted using the **context menu**. Each column in the **Statistics** table provides several statistical indicators for response.

The statistical summary in HyperStudy DOE ***Statistics*** page gives:

Run Summary | Statistics | Histogram | Box Plot | Scatter 2D | Scatter 3D

	Label	Varname	Category	Points	Unique	Minimum	Mean	Maximum	Range	Median	Variance	Std. Dev.	Avg. Dev.	CoV	Skewness	Kurtosis	RMS
1	Thickness	m_1_Th...	Variable	1	1	0.0020000	0.0020000	0.0020000	0.000...	0.0020000	0.0000...	0.0000...	0.0000...	0.00...	0.00000...	0.000...	0.00...
2	R1	m_1_R1	Variable	1	1	0.0000000	0.0000000	0.0000000	0.000...	0.0000000	0.0000...	0.0000...	0.0000...	0.00...	0.00000...	0.000...	0.00...
3	R2	m_1_R2	Variable	1	1	0.0000000	0.0000000	0.0000000	0.000...	0.0000000	0.0000...	0.0000...	0.0000...	0.00...	0.00000...	0.000...	0.00...
4	H1	m_1_H1	Variable	1	1	0.0000000	0.0000000	0.0000000	0.000...	0.0000000	0.0000...	0.0000...	0.0000...	0.00...	0.00000...	0.000...	0.00...
5	H2	m_1_H2	Variable	1	1	0.0000000	0.0000000	0.0000000	0.000...	0.0000000	0.0000...	0.0000...	0.0000...	0.00...	0.00000...	0.000...	0.00...

The statistical summary in HyperStudy DOE ***Statistics*** page gives:

- **Minimum** (minimum value)
- **Mean** (most probable value the response would take, First statistical moment)
- **Maximum** (the largest of all output response values
- **Range** (Differences between the Maximum and Minimum values)
- **Median** (The median of a scalar is that value itself)
- **Variance** (Second statistical moment)
- **Standard deviation - Std Dev** (measure of dispersion)
- **Average deviation - Avg Dev** (average difference between the vector elements and the average of the vector elements)
- **Coefficient of variation - Cov** (measure of relative dispersion)
- **Skewness** (Indicates whether the probability distribution is skewed to the right or to the left)
- **Kurtosis** (Measure of flatness of a distribution)
- **RMS** (Calculates the square root of the mean of the sum of the squares of all response values)

Design of Experiment - Post-Processing

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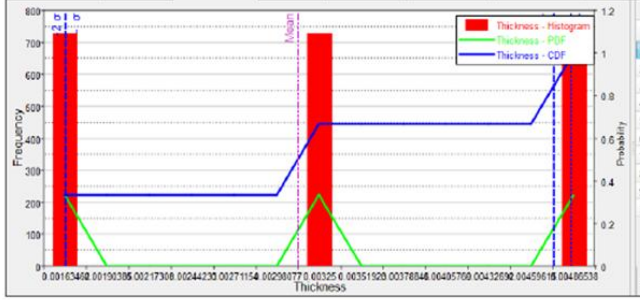
Histograms

The **Histogram** tab displays the histogram, **PDF** and **CDF**, for all variables and responses:

- The **histogram** (Frequency) is displayed via the red bins.
- The **PDF** (Probability Density Function) is displayed as a green curve.
- The **CDF** (Cumulative Density Function) is displayed as a blue curve.

The histogram, PDF, and CDF indicate the probability function of the output response and shows the frequency of runs yielding a sub-range of response values.
The size of the sub-range is defined as the total range of the response value, divided by the number of bins.
The accuracy of the PDF and CDF curves depend on the number of bins chosen.

Run Summary | Statistics | Histogram | Box Plot | Scatter 2D | Scatter 3D | Effects Table | Linear Effects | Interactions Table | Interactions



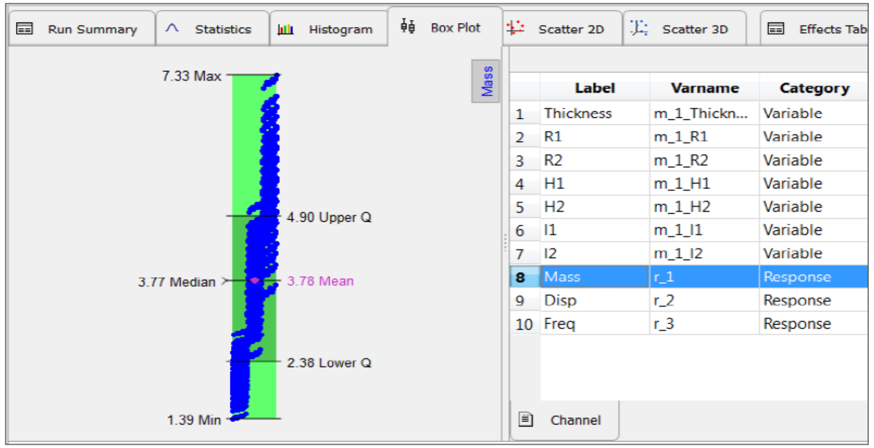
	Label	Varname	Category
1	Thickness	m_1_Thickn...	Variable
2	R1	m_1_R1	Variable
3	R2	m_1_R2	Variable
4	H1	m_1_H1	Variable
5	H2	m_1_H2	Variable
6	I1	m_1_I1	Variable
7	I2	m_1_I2	Variable
8	Mass	r_1	Response
9	Disp	r_2	Response
10	Freq	r_3	Response

Channel

Box Plot

A **box plot** is a graphical representation of data.
In this representation, data is sorted and a box is drawn from the lower quartile (1st quartile, Q1, 25%) to the upper quartile (3rd quartile, Q3, 75%), hence the name box plot. Quartiles of a sorted data set consist of the three points (Q1, Q2 which is also the median, and Q3) that divide the data set into four groups, each group comprising a quarter of the data.
The median and mean of the data are also marked in the box.

In HyperStudy, this box is painted dark green (see images below).



C Design of Experiment - Post-Processing
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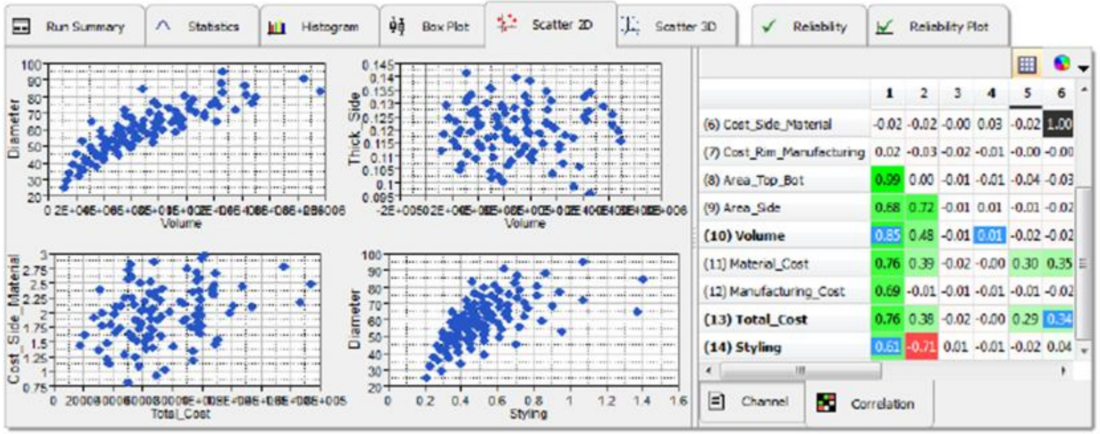
Scatter 2D (… continue)

Correlation

In the right-hand panel, click the ***Correlation*** tab to view a map that presents correlation values.
By default, the correlation coefficient values are set to **Pearson product-moment correlation**.
To change the correlation coefficient values to **Spearman's rank correlation coefficient**, click .

Click one or multiple cells in the map to display a scatter plot of the selected correlation values.
Correlation measures the strength and direction between associated variables.
Correlation coefficients can have a value from -1 to 1; -1 indicates a strong but negative correlation and 1 indicates a strong and positive correlation.



C Design of Experiment - Post-Processing

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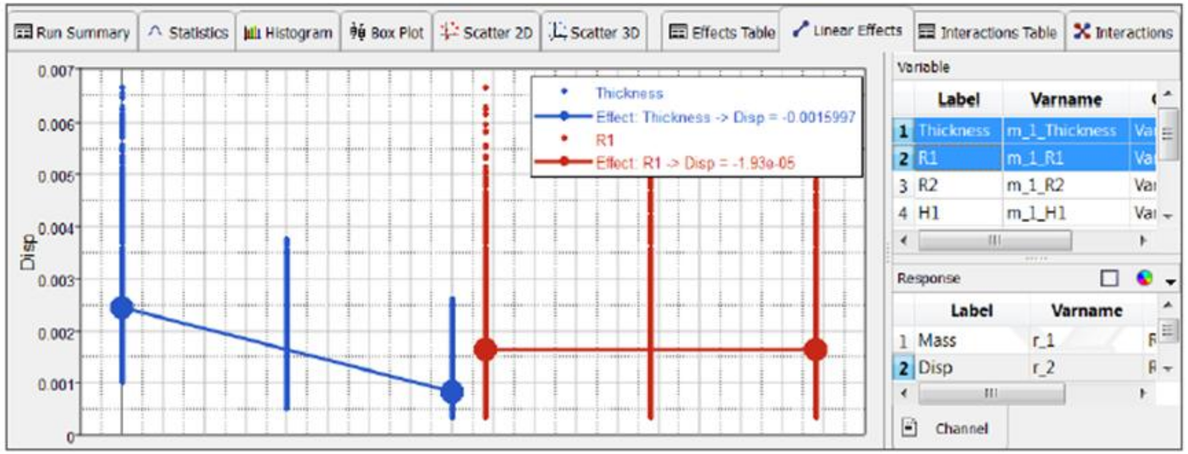
Linear Effects

Linear Effects plots the effect of a design variable on a response ignoring the effects of other design variables.

Linear Effects are plotted by drawing a line between the average value of the response when the design variable is at its **lower bound** and the average value of the response when the design variable is at its **upper bound**.



C Design of Experiment - Post-Processing

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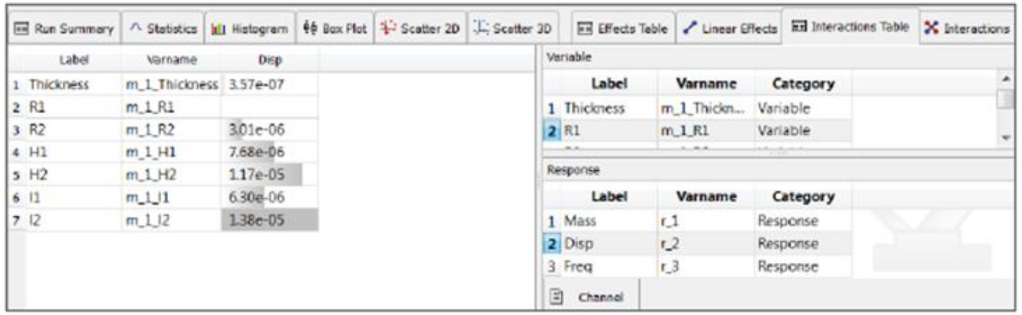
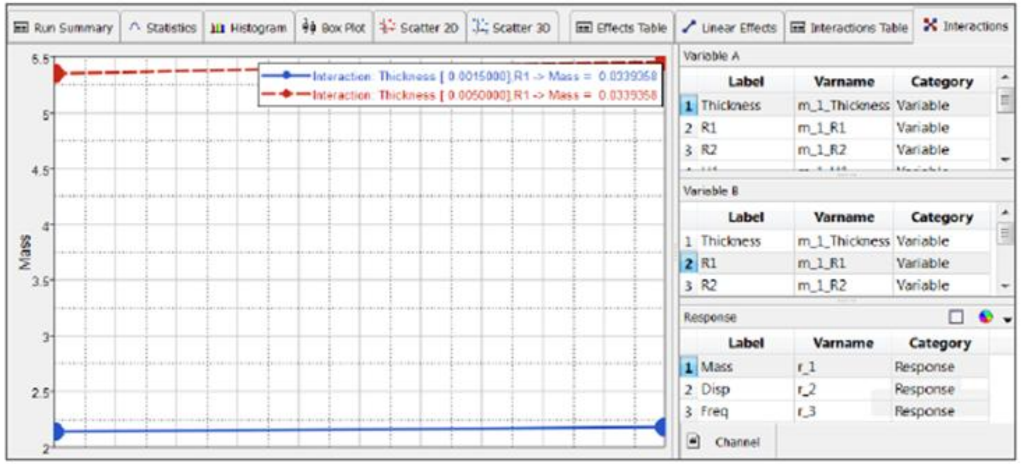
Interactions (Table & Plot) (continue…)



Interactions Table



Interactions Plot

Reporting

Questa fase automatizza la fase di scrittura del report di analisi

C Design of Experiment - Reporting

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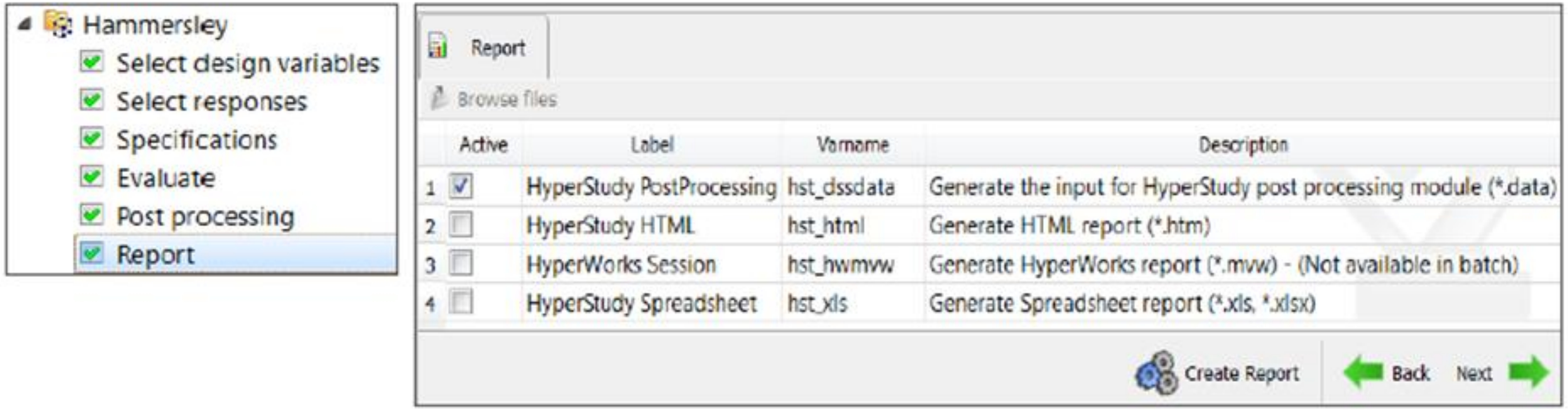
Reporting

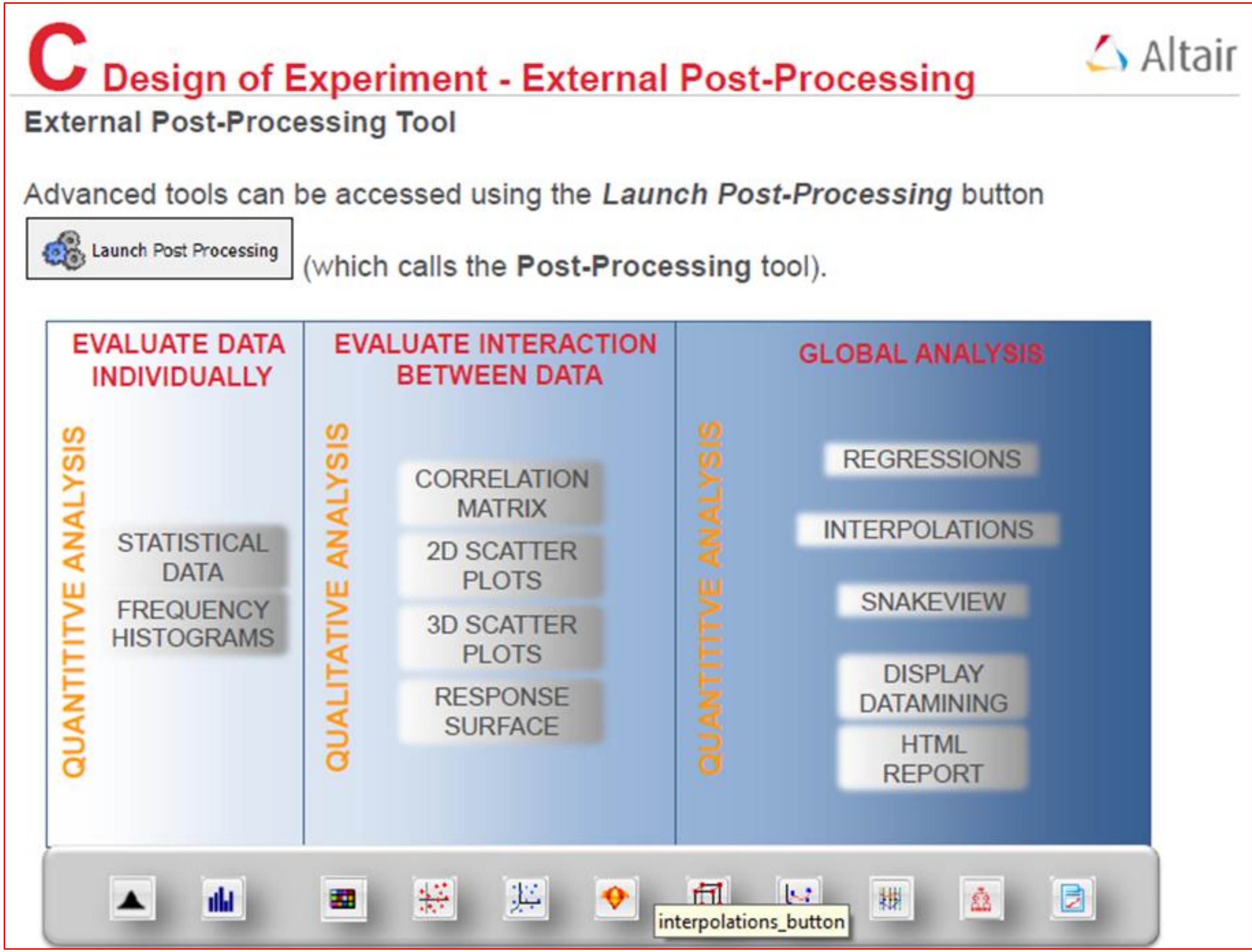
There are currently four reporting options for all approaches:

- **HTML** - Generates a HTML report and opens it in your default web browser
- **HyperWorks** - Generates a HyperWorks report and opens it in HyperWorks Desktop.
- **Post-Processing** tool (review help) - Launches the post-processing and data mining tool
- **Spreadsheet** - Generates a spreadsheet report and opens it in Excel.

In the **Explorer** select ***Report*** step ☑ Report , to proceed with DOE Reporting.



N.B. con <<launch postprocessing>> si possono elaborare dati qualsiasi senza la necessità di simulare



Design of Experiment - Exercise 2a

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Input file:

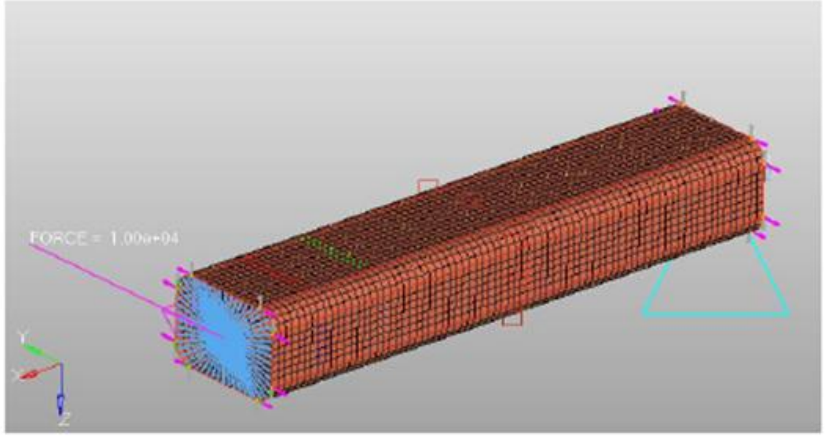
Under Study_2a dir , use the dir "***Study-2A-BASE-FILES***" or the archive "***Study-2a-base-files-archive.hstx***"

Goal:

To create a DOE for screening purposes and comparing and contrasting the interactions indicated by each DOE to determine the impact of each design variable on the performance of the system. The nominal run and first three DOEs have been completed.

Variables:

PSHELL Thickness (0.002), Shapes R1, R2, H1, H2, I1, I2 (all shapes = 0)



Define a DOE:

1) This study already has 3 DOE's: 3L Full Fact, 2L Full Fact, 3L Fr Fact
2) Create 2DOEs: 2L Fract Fact, Plackett Burman

Responses:

Mass (2.1609Kg), Mag of Displacement at node 19021 (0.00207311) and First Frequency (368.835)

2.16Kg 2.07Kg 368.8Hz

C Design of Experiment - Exercise 2a Major Steps

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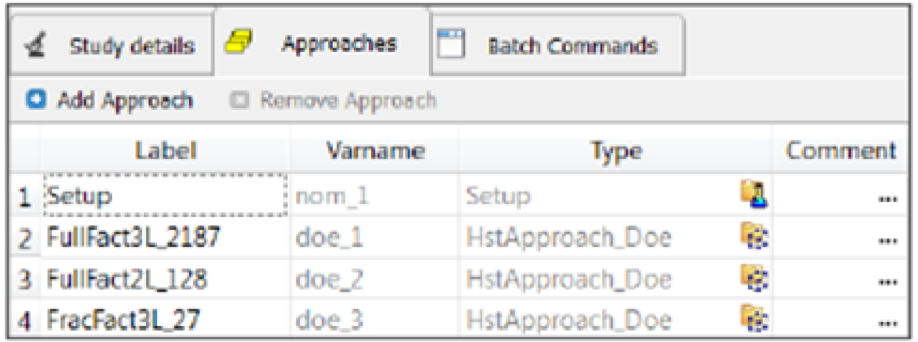
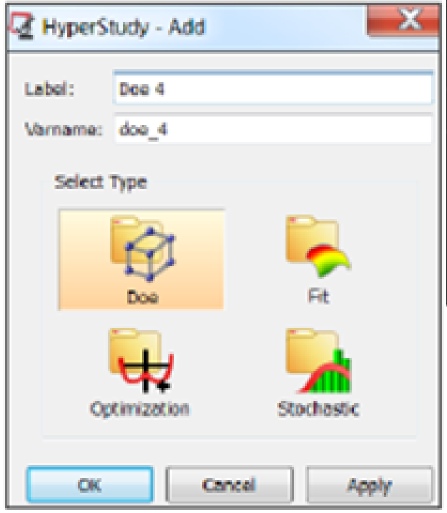
1) Open the study archive within HyperStudy (**Study-2a-base-files-archive.hstx**)

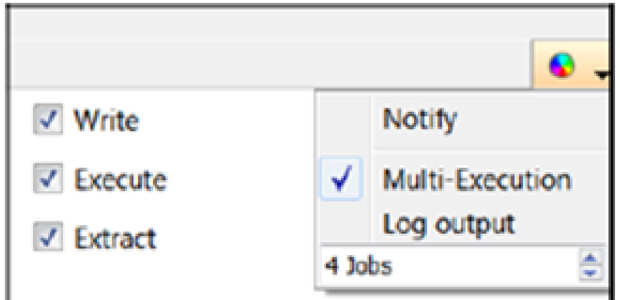


2) Add 2 DOE to the study



DOE Label $ Varname	DOE Type (Specifications Mode)	Levels (number)	Interaction	Settings (Number of runs)
FracFact2L_8	Fractional Factorial	2	No changes	No changes
PlacBurm_12	Plackett Burman	No Changes	No changes	AutoSelect (pbdgn12, 12 runs)

- Run both DOE, use the option **Multi-execution**



C Design of Experiment - Exercise 2a

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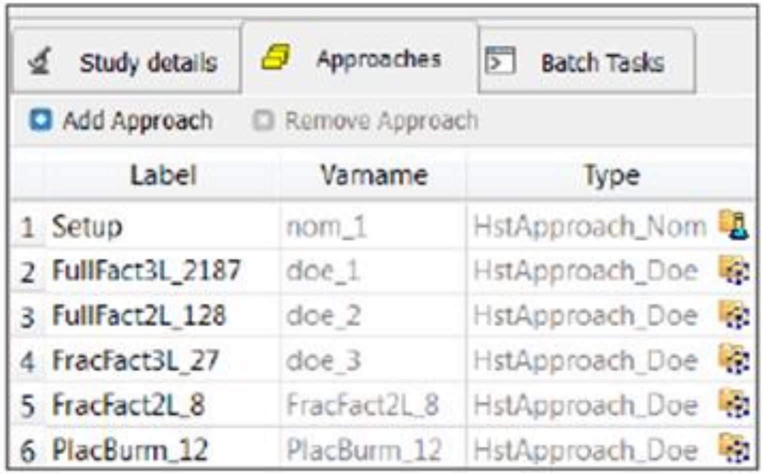
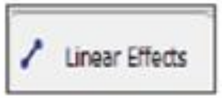
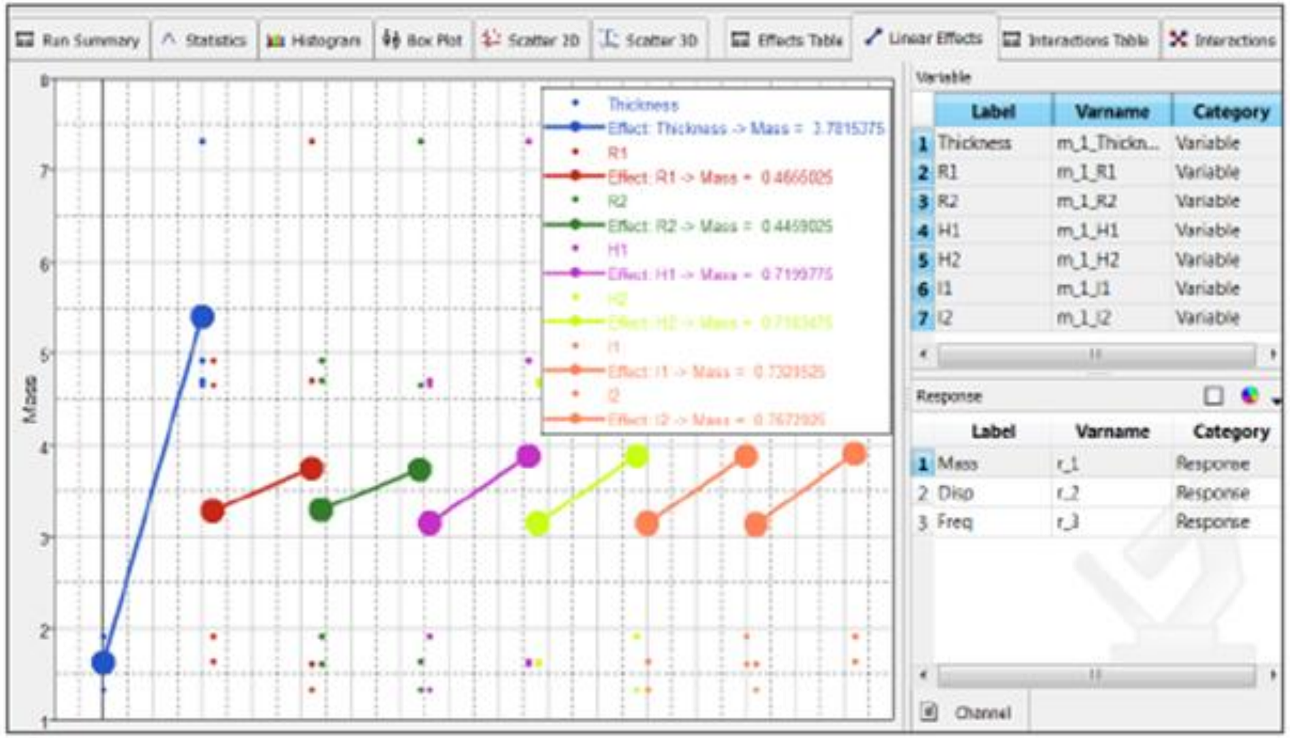
3) Post-process the DOE run "*FracFact2L_8*"

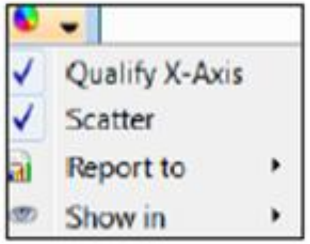
- Analyze the main effect
- Analyze the interaction
- Click on the Visualize button and analyze correlations (PDA)
- Compare these to the other DOE's
- Does the model can be reduce to less variables ?



a] Linear Effetcs (Mass)







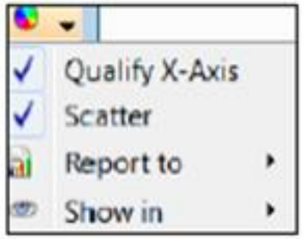
C Design of Experiment - Exercise 2a

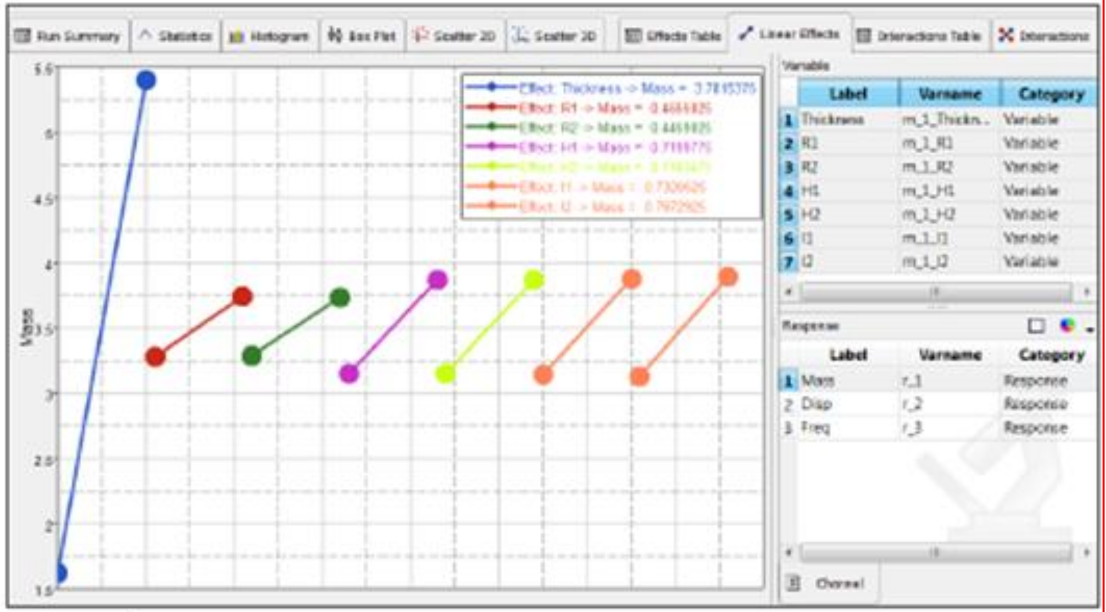
3) Post-process the DOE run "*FracFact2L_8*"

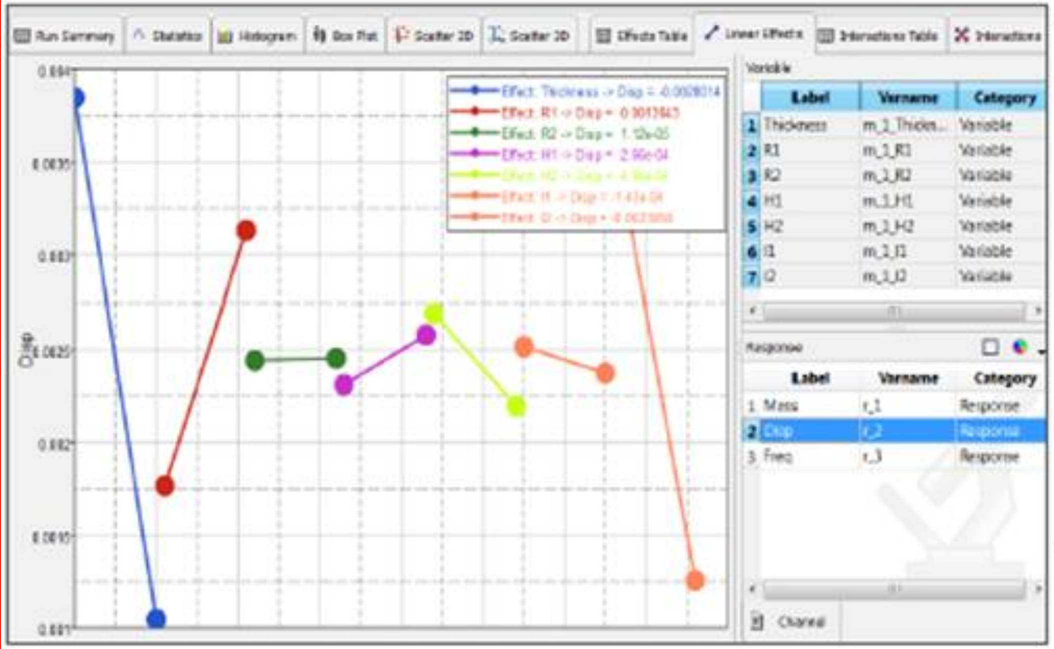
b] Linear Effetcs:

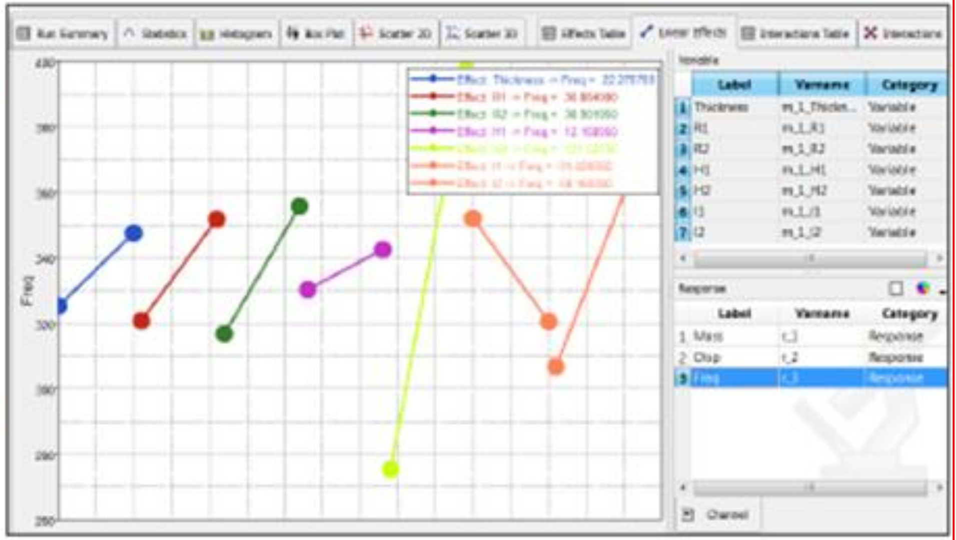
(Mass, Displacement, Freq)

[turn off the scatter by unchecking Scatter]









Design of Experiment - Exercise 2a

3) Post-process the DOE run "*FracFact2L_8*"

e] Post-process the DOE run "`PlacBurm_12`" (Post-processing step)

- Placket Burman with 12 runs gives similar results as Full Fact 3L with 2187 runs.
- Fractional Factorials give different results for some of the design variables.
- Design Variables 2, 3, 4 (R1, R2 and H1) can be eliminated from further runs.

→ ***Sapresti dire perché?***

4) Save the study and Export Archive

Design of Experiment - Plackett-Burman (PB)

A **Plackett-Burman (PB)** DOE can screen the maximum number of main effects with the leas number of experimental runs in case of two-level factors. PB designs are very economical designs, and are efficient in screening when only main effects are of interest.

- Two level saturated fractional factorial designs
- Number of runs (N) is always a multiple of 4
- Are used for studies involving up to (N-1) design variables
- Only suitable for two-level factors

Example DOE with 12 experiments:

Run	A	B	C	D	E	F	G	H	I	J	K
1	+	-	+	-	-	-	+	+	+	-	+
2	+	+	-	+	-	-	-	+	+	+	-
3	-	+	+	-	+	-	-	-	+	+	+
4	+	-	+	+	-	+	-	-	-	+	+
5	+	+	-	+	+	-	+	-	-	-	+
6	+	+	+	-	+	+	-	+	-	-	-
7	-	+	+	+	-	+	+	-	+	-	-
8	-	-	+	+	+	-	+	+	-	+	-
9	-	-	-	+	+	+	-	+	+	-	+
10	+	-	-	-	+	+	+	-	+	+	-
11	-	+	-	-	-	+	+	+	-	+	+
12	-	-	-	-	-	-	-	-	-	-	-

These designs are very useful for economically detecting large main effects, assuming all interactions are negligible when compared with the few important main effects.