Post DOE Robust Simulation.
Topics, Techniques and Tools

About SixSigmaIn Team

The distinguishing feature of SixSigmaIn Team consists in the merging of competencies related to Statistical Problem Solving, Adult Learning, Tools Development and Business Intelligence.

SixSigmaIn Team,

- delivers advanced and customized courses on DoE, QbD, DFSS and Reliability Analysis with the best statistical tools,
- provides solutions and support for an effective industrial application of statistical analysis.

SixSigmaIn Team has been the Stat-Ease referent in Italy since 2004.

The Team

[Maria Pia] I studied Chemistry at the University of Milan and worked as Failure Analyst at Agusta Helicopter and as process engineer in metallurgical Companies for about 15 years.

I have been involved in the Statistic and Six Sigma activities since 1997 and I am BMG Certified Master Black Belt. (original Belt standard, NOT Lean-Six Sigma, quite different)

My main activities are coaching, tutoring and supporting people to get a breakthrough in their processes.

Franco studied Chemistry at the same University, but he had worked for 5 years only in chemical companies as marketing developer manager. After completing his economic studies, he completely abandoned chemistry (1983), starting his activity of Independent Developer on Decision Support Systems.
He is the author of 'R&M - Rules and Maps', a strategic marketing & position analysis software (and book) used in universities, banks and international companies, in years 1985–2000.

He started dealing with Big-Data for some big pharma companies in the early 2000s, when this 'term' was not trendy.
He his highly pragmatic, challenges orthodoxy at all levels and believes that there is always room for improvement and he has a bad opinion for how Big-Data is evolving now.

- What will be presented in this speech is related to what should be done downstream of a DoE ***(or at least what we try to do in our consulting activities).***

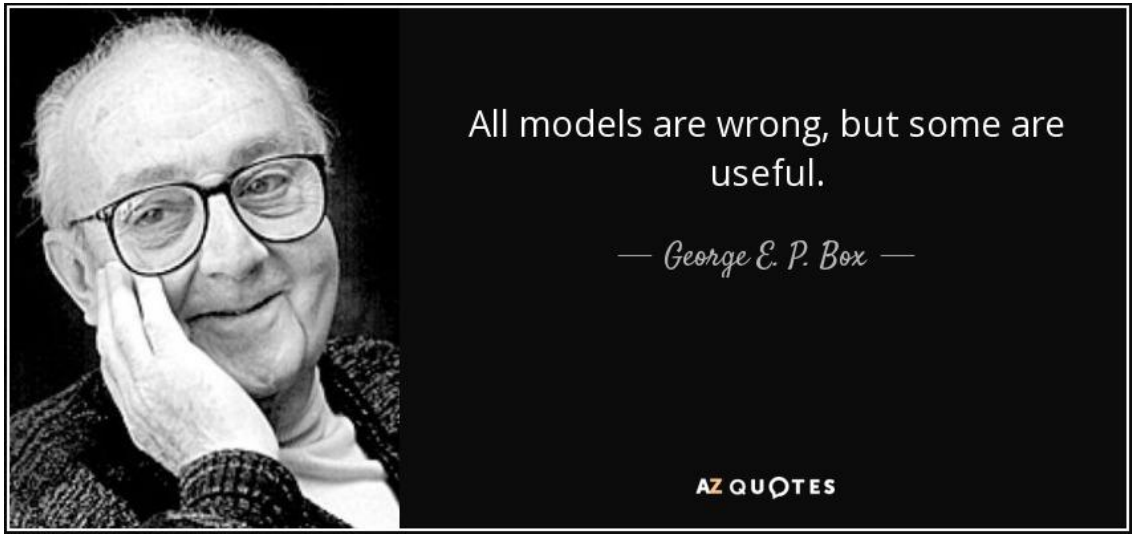
- To simplify, we will talk about what all of us normally do in a DoE Evaluation step, but applied to a Monte Carlo simulation Evaluation step.

- Let's say immediately that the issue is quite complex and it will not be possible, with the time I have available, to go to the specifics.

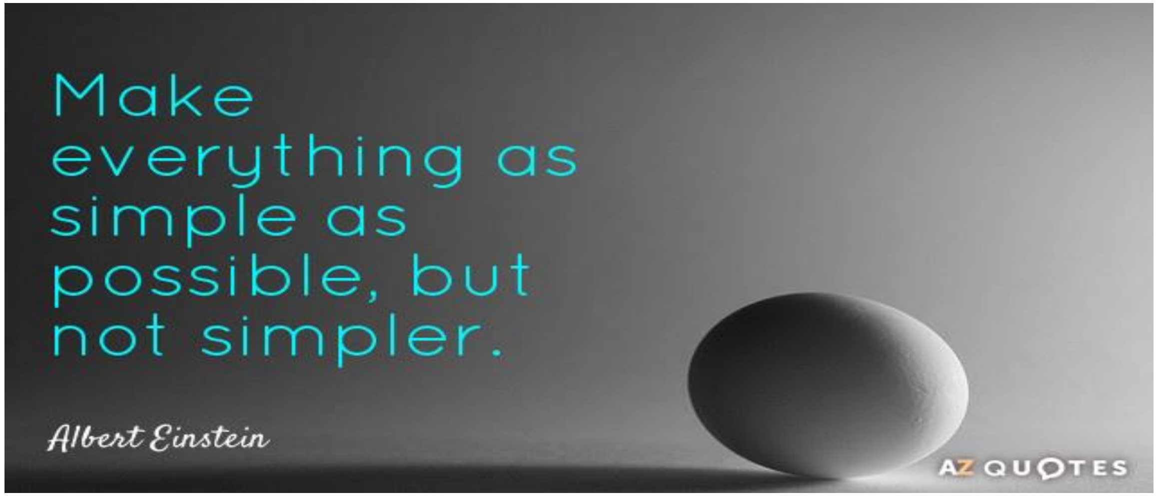
- I would be satisfied if I could provide you the basic guidelines.

Those, who are interested in an in-depth study, will be able to download the tool we have created to illustrate this presentation.

A solution (model) must be … the right compromise between …



and ..

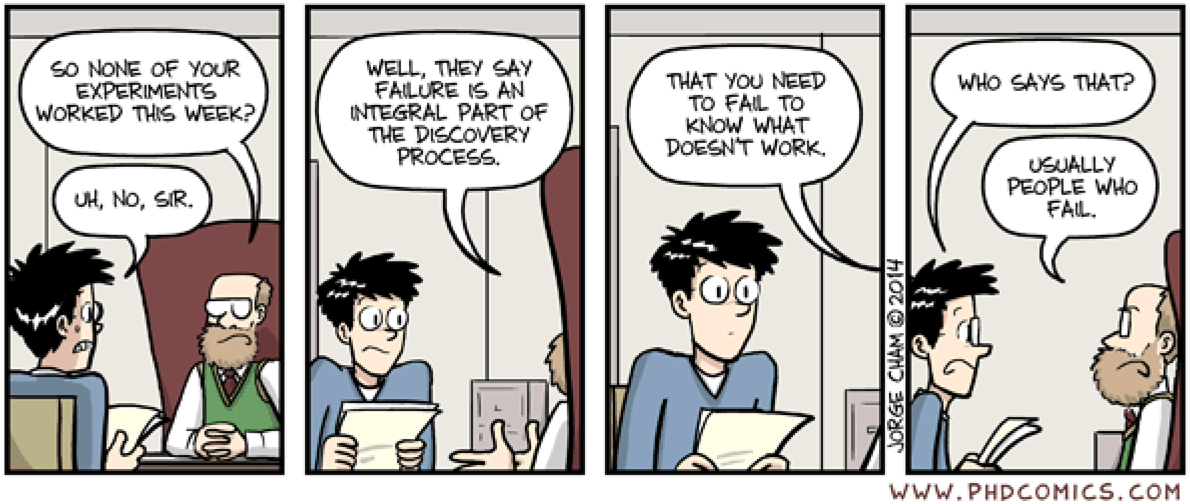


and ..

the 'marketable' solution must be the best Long Term solution, otherwise …

… your Boss, sooner or later …

Defects, Defects, Defects, …..

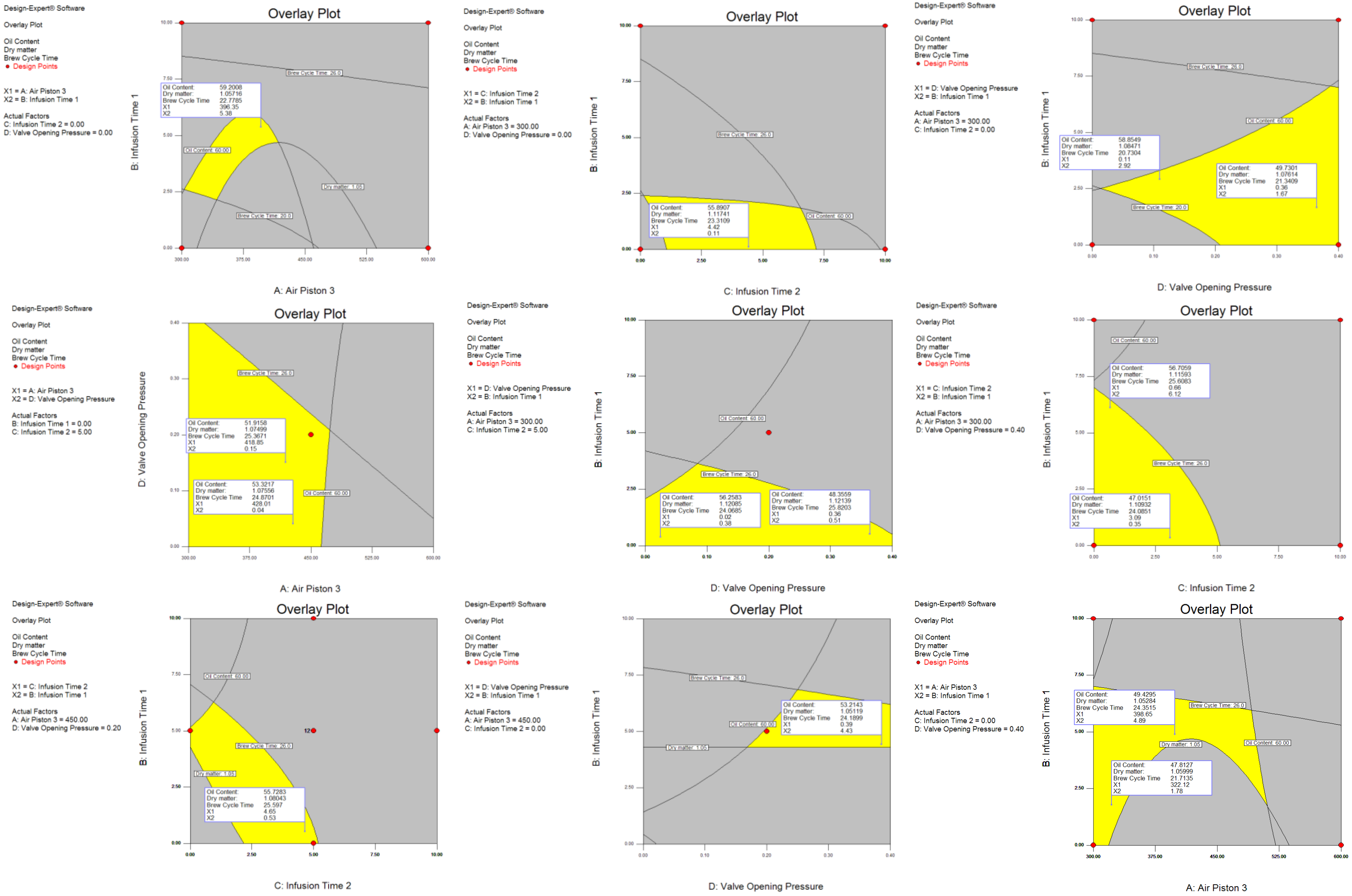


A DoE study (2005)

Although the confidentiality agreement restrictions have expired, after 13 years

- we will not discuss how this DoE was developed and
- we will introduce only the elements that allow you to understand that only the classic ' *internal* ' optimization may not be enough [*in this case and on similar cases*] .

Referring to this process, the ultimate objective was the reduction of the Response Y1 till 40- 60%, starting from a reference value of 100%, maintaining the Response Y2 in a range between 20 and 26 sec and the Response Y3 above 1%.



A DoE study is not the ultimate goal

Same outputs (responses target values), but ..

Different engine setup, different engine stability, …

i.e.

different outputs variability, maintenance costs, etch ..

In other words , for client point of view

different long term capability of (user) coffee generation process …

< … *Ho il piacere di informarvi che il progetto cui avete collaborato è stato accettato dal cliente.*
Questo grazie anche all'ottimo lavoro da Voi svolto, per il quale Vi ringraziamo … >, February 2006

A DoE study is not the ultimate goal, but a fundamental step to understand and optimize the performance of industrial processes.

Passive Data Study

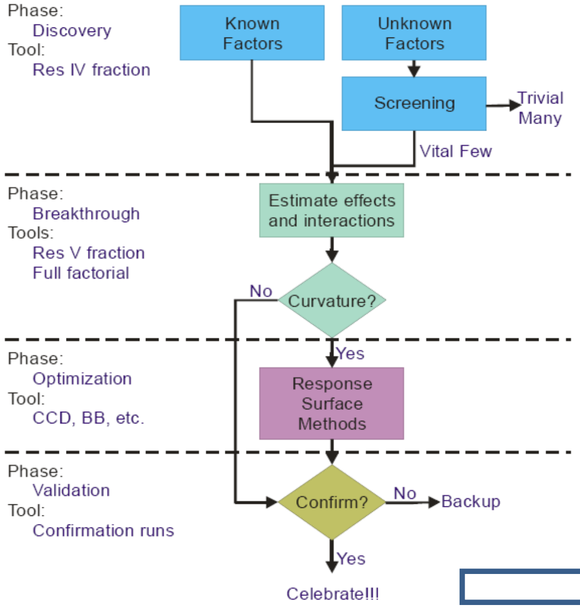


Figure 1: Strategy of Experimentation

Long Term simulation of DoE (best) solution(s)

Monte Carlo simulation

It is not the case to spend many words on Monte Carlo simulation, which is definitely known by all of you. I restrict myself to recall you some key points.

Quasi-random number generation

Mersenne Twister algorithm (32 bit) is the best standard at the moment. New and more powerful algorithms are under study, but in fact Mersenne Twister is the standard used in most of statistical software. (both 32 and 64 bit)
To be independent of problems about generation goodness, this study is achieved using the NTRAND software (*), probably the best MT generator available on Internet.

' Watch out, if you are using a personal computer or workstation for evaluation of positioning derivatives.
A computer has a daemon inside. To be frightened, to the knowledge of experts who are engaged in numerical calculation, there are number of problems restrained from disclosure or active opening due to the business operation reasons of computer manufacturers. Numerical calculation is an abyss even to the system engineers. ' **[from NTRand FAQ]**

The goodness of the generator certainly has its importance, but also other aspects (too often underestimated) are important too (or perhaps more relevant).

Monte Carlo simulation Error

Denoting the count of simulation by n, the theoretical performance (computing error) of the quasi-random number Monte Carlo relies on the dimensional number d is expressed in the following formula:

$$O\left(\frac{(\log n)^d}{n}\right)$$

Customer or Client Process Identification

Customer (Client) is the one who buys or uses your products/services and he/she is the one who receives the process output.

We broadly classify customers into two categories:

- **External Customers**

  External Customers are not a part of the organization. They are either the ones who use our product(s) or service(s) or have interest in the organization. For e.g. Clients, End-Customers, Shareholders, among others.

- **Internal Customers (**)**

  Internal Customers are the ones who are internal to the organization (next department or next process).

(**) Why this slide ??
Because even a single computer calculation step is a Client of a previous calculation Process.

Solver 'Black Hole' in Optimization

We can summarize a Common Design Optimization process with this pseudo code

Traditional Numeric (engineering) approach

Do

Design (Numerical) Optimization Algorithms .....
Exit when Target(s) value is (are) ...

Loop

Common Design Optimization does not mean automatically defects optimization (statistical optimization)

DFFS engineering or QbD experimenters approach should be ..

Do

Design (Numerical) Optimization Algorithms _
And Statistical (variability) Algorithms

Exit when Target value(s) is (are) _
And Target variability (ies) is (are) ...

Loop

Calculating Cpk and Ppk in simulations

Because there are no subgroups and no concept of long term and short term variation in the simulation context, Cpk and Ppk values are equivalent in a Monte Carlo simulation. We will use Ppk index symbology.

In a Monte Carlo simulations, it is typical for simulated responses to violate the assumption of normality.

Used procedures

- Clements : Low size Nonparametric method,
- Brute Normal : No data identification, fixed distribution i.e. normal, *[typically used in all the well-known Risk optimizer Excel add-ins with Six Sigma functionality]*
- ISO D_ID method : the generally used parametric method, *[Franco's definition: Is [a] Stupid Operation]*
- Bothe D_ID or equivalent method : robust parametric procedure,
- Derivative calculation techniques with or without Taylor correction - typically used in user code *[using math languages]* or in most commercial Engineering Tolerance Design and Multiphysics tools.

Presented procedure

- LuLu ®, high size Nonparametric optimized procedure.

Data Metric

Out of Spec (QbD) or DPMO (Six Sigma).

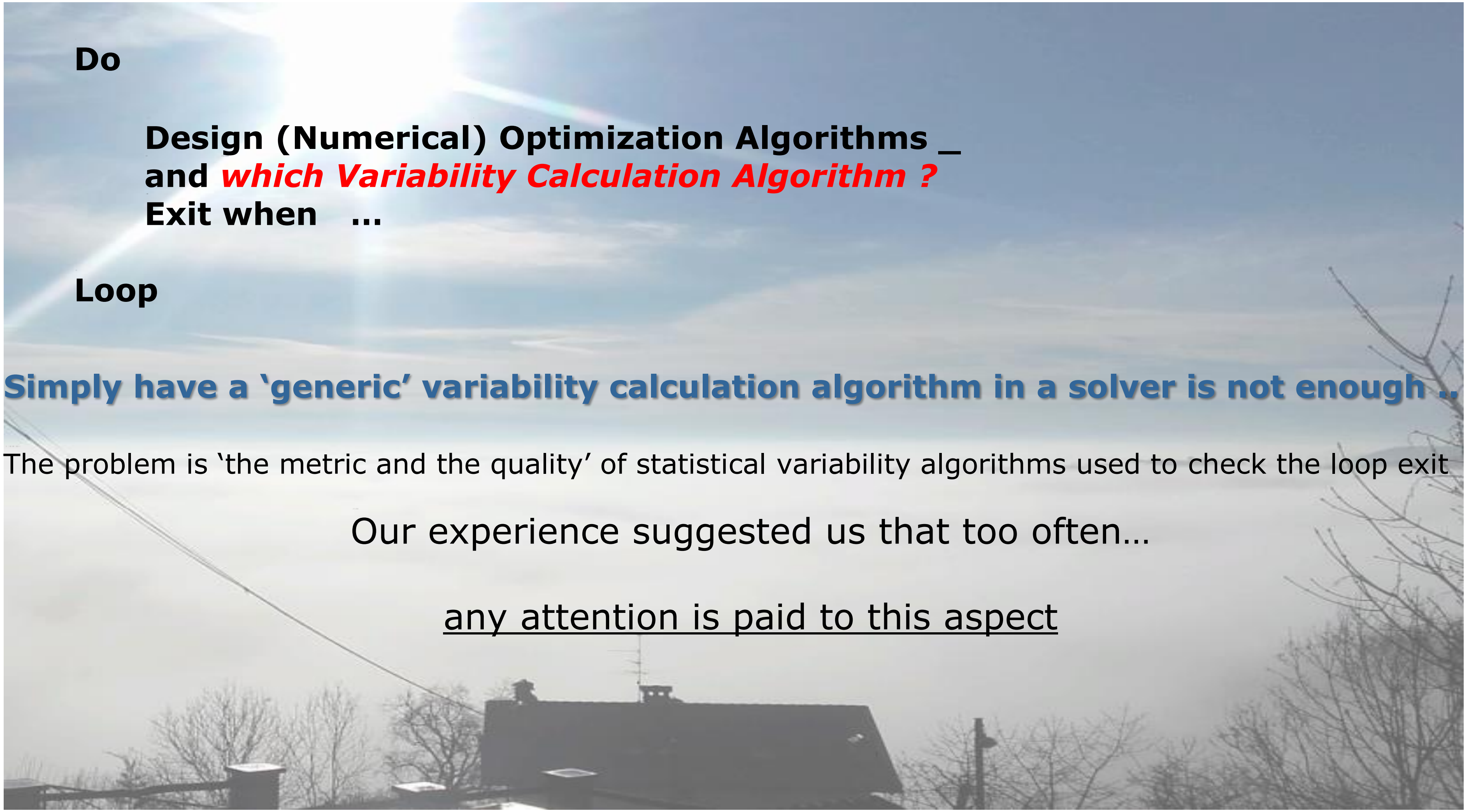
In other word, the unit metric reference is part per million (PPM).

The metric for calculating the variability 'should' be adjusted to this metric.

In addition ...

Every step in a Optimization Loop is a client of a previous step in same Loop !

Solver Variability Calculation **'Black Hole' or 'White Fog'**



Do

Design (Numerical) Optimization Algorithms _
and *which Variability Calculation Algorithm ?*
Exit when …

Loop

Simply have a 'generic' variability calculation algorithm in a solver is not enough ..

The problem is 'the metric and the quality' of statistical variability algorithms used to check the loop exit

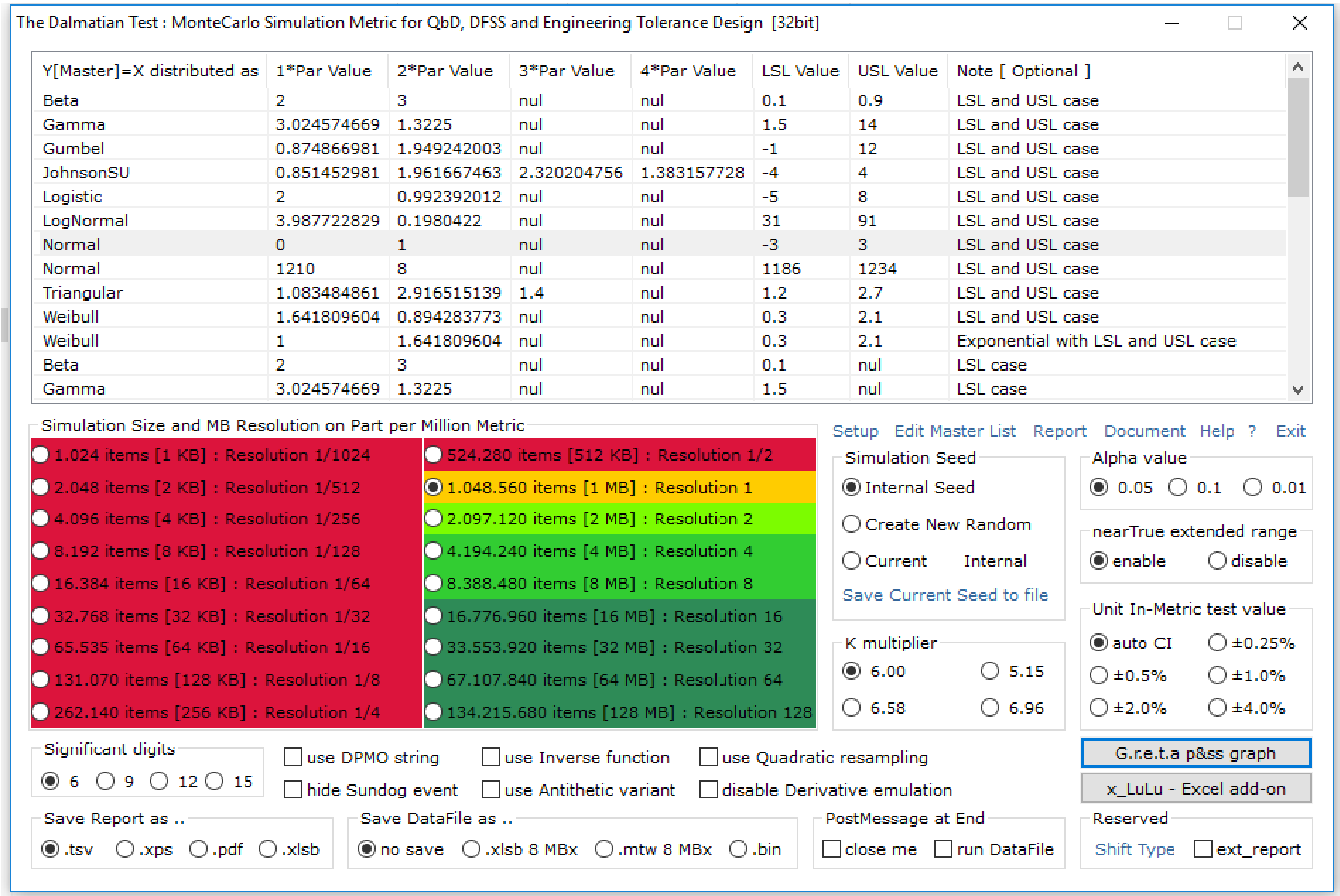
Our experience suggested us that too often…

any attention is paid to this aspect

Netro, Feb 25, 2016 (from our [*Microsoft*] Windows Office) : Fog in Po Valley. *[a typical Italian byword when you have not understood something well]*

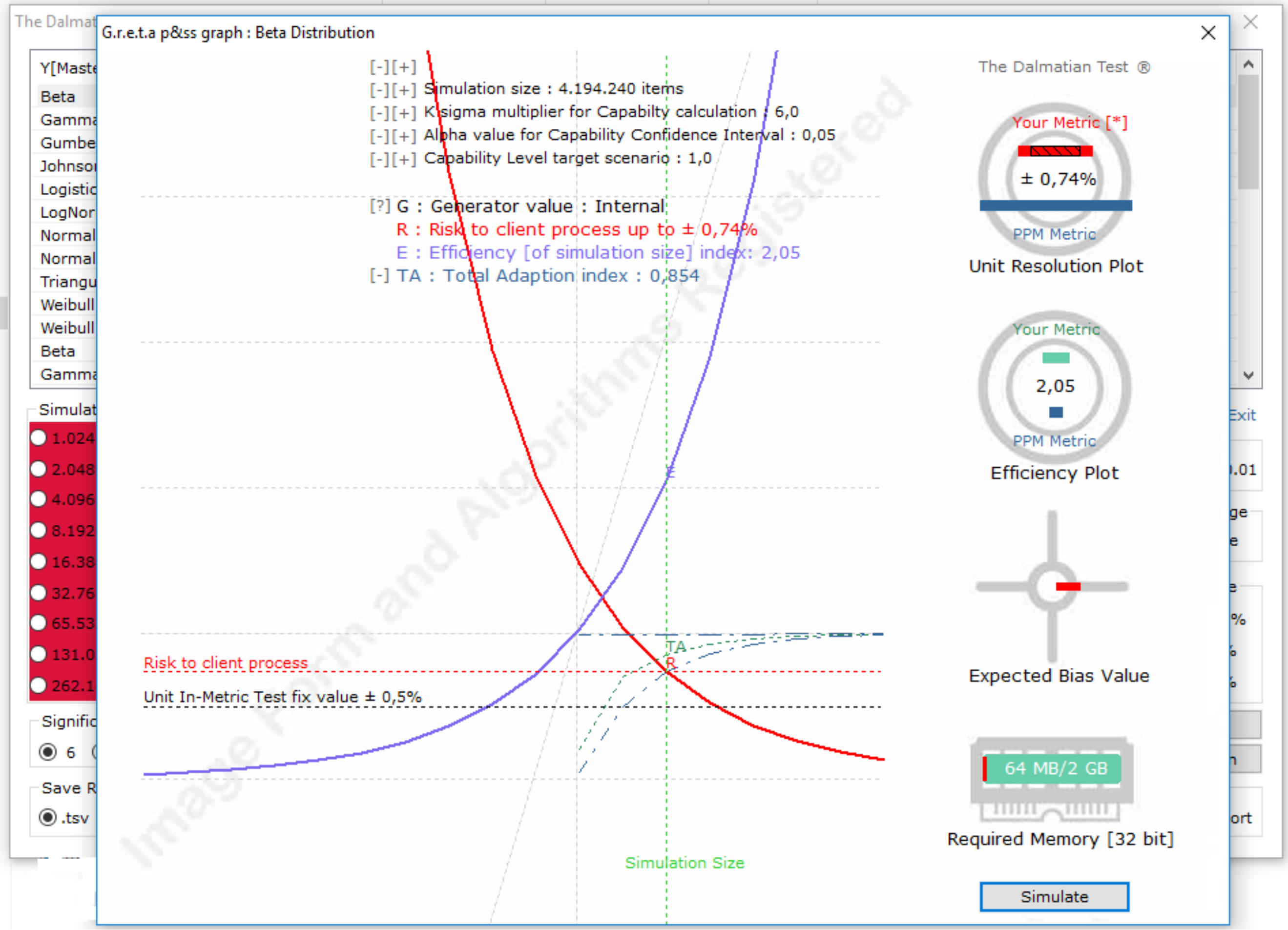
The Dalmatian Test

This tool is designed and developed to evaluate the calculation reliability of defects and Process Capability using Monte Carlo simulation.



It is only the first step ***before applying engineering tolerance optimization*** concepts to a simulated process. The Dalmatian Test is rigorous, and it entails questioning the way everything is done (calculated).

Cost-Benefit Analysis



Unit resolution Plot: This value is the intrinsic max Risk % you should accept to transfer to a client process [get decision / optimize / solve] at a certain simulation size value.

Efficiency Plot: This value is related to size efficiency of your simulation process (i.e. the Capability of Monte Carlo Simulation process itself).

Bias/Sundog Indicators: An estimation of your expected bias and sundog event probability. The numeric values can't be easily quantified and depends on different parameters (mainly from simulation size, quality of random generator and used seed entropy)

Memory plot: A measure of estimated max Win32 memory peak [MB] required by the simulation process at a certain simulation size value.

The Dalmatian Test

To understand this test, you can simply use the function Y = X, where X are the data of a KNOWN distribution.

You have to set the specification limits to calculate the Process Capability.

Generate X data. Calculate the moments. Compare these values with X [Theo] values.

(i.e. what you ask to have = MASTER) with X[s] (i.e. what you really get = SAMPLE).

They are different! Something wrong? NO!

X[s] is always slightly different from X [Theo] and X[s] could be written as X [Theo] plus a bias.

The bias value mainly depends on the number of simulated items and on the robustness of Random Number Generator you used.

Report : Moments Comparison

Data Entry Summary	[A]	[B]	[C]	[D]	[E]	[F]
Data Distributed as	Beta	Beta	Beta	Beta	Beta	
1* Par Value	2	2	2	2	2	
2* Par Value	3	3	3	3	3	
3* Par Value						
4* Par Value						
Lower Spec Limit	0,1	0,1	0,1	0,1	0,1	
Upper Spec Limit	0,9	0,9	0,9	0,9	0,9	

Moment Values	[A]	[B]	[C]	[D]	[E]	[F]
Procedure	Master	Brute Normal	ISO D_ID	Bothe D_ID	LuLu	
Moment 1 - [Mean]	0,4	0,399831	0,399831	0,399831	0,399831	
Bias		-0,000169	-0,000169	-0,000169	-0,000169	
Sqrt(Moment 2) - [Standard Deviation]	0,2	0,199992	0,199992	0,199992	0,199992	
Bias		-0,000008	-0,000008	-0,000008	-0,000008	
Moment 3 - [Skewness]	0,285714	0,286933	0,286933	0,286933	0,286933	
Bias		0,001219	0,001219	0,001219	0,001219	
Moment 4 - [Kurtosis]	-0,642857	-0,64151	-0,64151	-0,64151	-0,64151	
Bias		0,001347	0,001347	0,001347	0,001347	
Moment 2 - [Variance]	0,04	0,039997	0,039997	0,039997	0,039997	
Bias		-0,000003	-0,000003	-0,000003	-0,000003	
Coefficient of Variability	0,5	0,50019	0,50019	0,50019	0,50019	
Mean Standard Error		0,000138	0,000138	0,000138	0,000138	

(Beta 2 Mb)

View:
Normal 64 kb   Normal 2 Mb
Weibull 64 kb   Weibull 2 Mb
Beta 64 kb   Beta 2 Mb
Triangular 64 kb   Triangular 2 Mb

How big can be (or acceptable) this bias (these bias)?

It depends on the goal (or scope) of key parameters derived from your simulation!

Data Identification

Now suppose that the Y[s]= X(s) values come from an UNKNOWN DATA DISTRIBUTION .
Use KS algorithm to get Distribution Identification (and D_ID computing time).

(KS algorithm is used in this tool mainly to get these info without additional memory requirement. If you use a different algorithm, the time and memory needed for the GoF cycle will increase significantly, or alternatively the simulation size must be reduced).

Capabilities Calculation

Calculate the Y[p] Capability and Y[p] DPMO using the following procedures / algorithms:

- ~~[A] Clements ,~~
- [B] Brute Normal ,
- [C] ISO D_ID, ,
- [D] Bothe D_ID ,
- [E] LuLu ® ,
- [F] Derivative calculation techniques.

Compare the SAMPLE [procedure] results with the MASTER [Theo, n= 1 million] results.

Report : Capabilities Calculation Comparison

Calculated parameters i.e. Output to Client Process Capability Algorithm		L	U	[A] Theo	[B] Normal	[C] ISO D_ID	[D] Bothe D_ID	[E] LuLu	[F]
PpK				0,540983	0,499739	0,770856	0,540651	0,540904	
Bias					-0,041244	0,229873	-0,000333	-0,00008	
PpK - Metric Test		0,539989	0,541978		false	false	true	true	
PpL				0,540983	0,499739	0,770856	0,540651	0,540904	
Bias					-0,041244	0,229873	-0,000333	-0,00008	
PpL - Metric Test		0,539989	0,541978		false	false	true	true	
PpU				0,892762	0,83365	0,946574	0,893019	0,892566	
Bias					-0,059112	0,053812	0,000257	-0,000196	
PpU - Metric Test		0,891363	0,894161		false	false	true	true	
Pp				0,716873	0,666695	0,875355	0,716835	0,716735	
Bias					-0,050178	0,158483	-0,000038	-0,000138	
Pp - Metric Test		0,715879	0,717866		false	false	true	true	
L-OofS				52300	66908,50095	10373,19996	52406,80041	52325,57031	
Bias					14608,50095	-41926,80004	106,800408	25,570306	
L-OofS - Metric Test	[auto CI]	51981,8666	52619,6775		false	false	true	true	
L-OofS - Metric % Variation	[auto CI]	-0,61%	0,61%		27,93%	-80,17%	0,20%	0,05%	
U-OofS				3700	6193,053264	2257,633168	3691,493608	3706,511788	
Bias					2493,053264	-1442,366832	-8,506392	6,511788	
U-OofS - Metric Test	[auto CI]	3653,88737	3746,633961		false	false	true	true	
U-OofS - Metric % Variation	[auto CI]	-1,25%	1,26%		67,38%	-38,98%	-0,23%	0,18%	
OofS				56000	73101,55421	12630,83313	56098,29402	56032,08209	
Bias					17101,55421	-43369,16687	98,294016	32,082094	
OofS - Metric Test	[auto CI]	55635,75397	56366,31146		false	false	true	true	
OofS - Metric % Variation	[auto CI]	-0,65%	0,65%		30,54%	-77,44%	0,18%	0,06%	

(Beta 2 Mb)

View:

Normal 64 kb	Normal 2 Mb
Weibull 64 kb	Weibull 2 Mb
Beta 64 kb	Beta 2 Mb
Triangular 64 kb	Triangular 2 Mb

The Dalmatian Test

Only Bothe and LuLu procedures are robust or acceptable, BUT with very different processing speed.

At the end of your exercises, you will realize that to get reliable values of Capability or defects, you will still need to simulate at least two million items (*ppk=1, k=6, a=0.05*), even if you apply a robust procedure (as Bothe) for data interpretation.

At these high simulation sizes (*), LuLu optimized procedure provides the same robust results, but from 10 to 80 times faster. This is a key feature, because in a solver the whole simulation step could be repeated from hundreds to .. XX of times.

Do

Design (Numerical) Optimization Algorithms and _
Statistical (variability) Algorithms
Exit when …

Loop

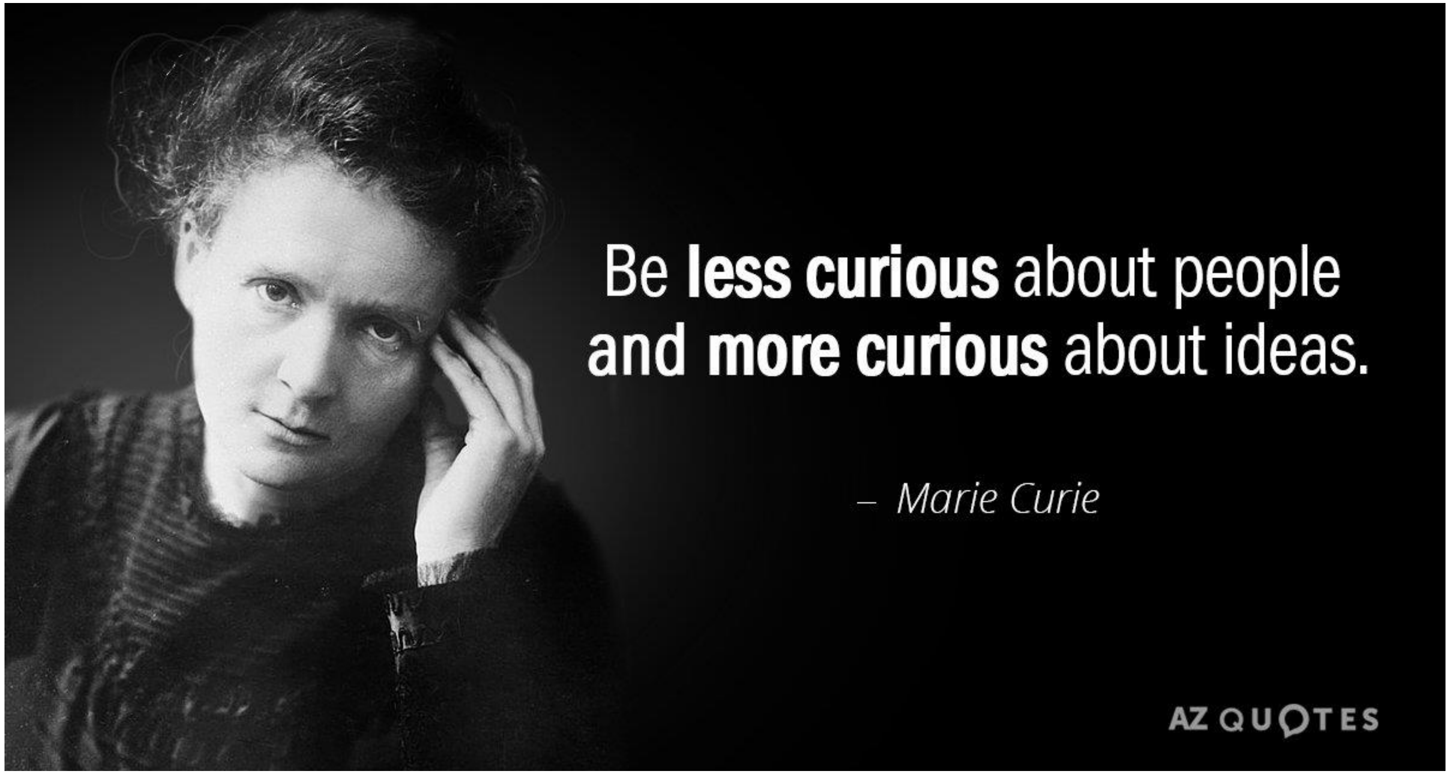
To fully understand what is described above, you will have to practice reproducing examples with not only the normal distribution, but also using all the other distributions and changing the specification limits at your convenience.

(* or doubling the used simulation size)

Conclusion

- DoE must be well planned : plan, plan and plan some more
  "Statistic is honest with your data, .. as much as .. you are honest with its rules ! ", Franco Anzani
- Monte Carlo simulation *[No Cost technique]*, as post-DoE technique, would give further added value to your DoE and will help you to better manage the solutions in a long-term industrial process.
- Use a robust procedure *[area]* for probability evaluation. To calculate a variability index, *high simulation size is not an option, is a MUST!*
  If your optimization process, [your optimization software] , does not use [and certify] these simulation size levels and a strong algorithms for variability calculation, you will probably have a good numerical solution [Accuracy] but with a very limited statistical robustness and reliability on engineering tolerances. [Precision]
- In a high size simulation, an optimized nonparametric procedure provides the same robust results of a right parametric procedure, but significantly faster. *In complex model optimization, this speed can mean hours of calculation saving.*
- If you already use variability optimization in a Engineering Tolerance Design or a Multiphysics tools, *perhaps it is the case that you ask your software provider for information on how this really works*, before accepting the suggested solutions. (***)
- All models and solutions [& *software applications*] must be used with criteria.
  "I fear the day that technology will surpass our human interaction. The world will have a generation of idiots.", Albert Einstein

And as a woman … let me add this quote …



Useful links

NtRand, Random Number Generator, is a copyright of Numerical Technologies https://www.numtech.com
(*) The 3.3 XLL Excel add-in is free available @ http://www.ntrand.com

The Dalmatian Test is part of The Dalmatian Suite tool and is a copyright of SixSigmaIn Team.
The Dalmatian Test tool (**) and x_LuLu Excel add-in are free available @ https://www.sixsigmain.it
(** Excel installation is not required)

[1990] David Goldberg, What Every Computer Scientist Should Know about Floating-Point Arithmetic
[2005] D'Ambrosio, Anzani, …, DFSS e Simulazione Monte Carlo

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Thank you for your kind attention

Q & A

Addendum : The Dalmatian Test videos

What's in it for You

Greta Power and Sample Size - Variable Size

Greta Power and Sample Size - Constant Size

TA index

Simulation set

x LuLu Algo on Minitab Data

x LuLu Algo (mtbEngine) on Minitab Data

Addendum : TA - Total Adaption index

Addendum : 2 GB (Win32 bit memory) scenario

Addendum : (***) weak optimization tool