BRUTOMIZER© Ver 1.1 Manual

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Example case study

Consider that using laser cutting experimental data two mathematical models for the prediction of surface roughness (R_z) and material removal rate (MRR), in terms of laser power (P), assist gas pressure (p) and cutting speed (v) were obtained as:

$$\begin{split} R_z &= 240.3 - 18.9 \cdot P - 4.8 \cdot p - 111.2 \cdot v + 8.3 \cdot P^2 - 0.04 \cdot p^2 + 29.5 \cdot v^2 \\ &+ 2.8 \cdot P \cdot p - 19.5 \cdot P \cdot v - 0.6 \cdot p \cdot v \end{split}$$

$$MRR = 3558 + 11167 \cdot P + 1198 \cdot p - 16297 \cdot v - 1726 \cdot P^{2} - 11 \cdot p^{2} + 3124 \cdot v^{2} + 106 \cdot P \cdot p + 116 \cdot P \cdot v - 387 \cdot p \cdot v$$

Suppose the developed mathematical models are valid in experimental hyper-space defined with the following ranges of variables: P = 3 - 4 kW, p = 6 - 10 bar and v = 3 - 3.5 m/min.

Capabilities of BRUTOMIZER© for solving various formulations of optimization problems will be illustrated on the afore-given case study.

NOTE:

Given example case study can be imported directly by clicking on the button *Import DEMO* (located on the top right) and selecting *Manual Demo* in the opened dialog. But before importing this demo, we strongly recommend that you follow the steps and examples given in this tutorial, as they will give you all the necessary information for using BRUTOMIZER©.

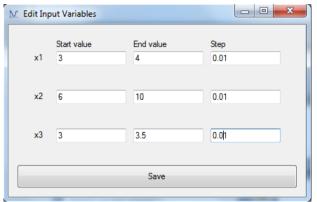
Step 1: Create New project

To create new project, one needs to click on the button *New* and enter the number of variables (for our case study, enter 3).

\mathbb{N} New project	_		\times
Enter the number of variable 3	s		
ОК		Cancel	
UK		Cancel	

Step 2: Definition of variables ranges and steps

By clicking on the button in (located on the bottom left side of the main screen) one can define variable's ranges as well as step size of each variable. Considering the covered experimental hyper-space in our example case study, start and end values of each variable were selected and for, each variable, step size of 0.01 was selected. This means that © will consider 2065551 different combinations of variable's values.



Step 3: Definition of mathematical models

Definition of given mathematical models is a necessary step. One needs to click on the button in the *Math Models* tab (located in the center of the main screen) and select mathematical model type. Two types of mathematical models are offered by default: *General (powered by NCalc)* and *Regression model of order 2*.

in Select math model type	-	×
General (Powered by NCalc) Regression model of order 2		
ОК	Cancel	

If desired mathematical model is a polynomial up to order 2 (with 2-way interactions), then one should select *Regression model of order 2* type. In the opened window, mathematical model for surface roughness (R_z) is defined by typing in the regression coefficients in the appropriate fields and finally by clicking the *Add* button. Note that x1, x2 and x3 stands for *P*, *p* and *v*, respectively.

Туре								
Regression r	nodel of	order 2						
Name								
Rz								
240.3	· .	+	-18.9	x1 +	-4.8	x2 +	-111.2	x3 +
			8.3	x1^2 +	2.8	x1x2 +	-19.5	x1x3 ·
					-0.04	x2^2 +	od	x2x3
					-0.04	X2 2 .	-0.0	1213
							29.5	x3^2
				А	dd			

The mathematical model for the material removal rate (MRR) is defined in the same manner as previously shown mathematical model for surface roughness (R_z).

If the desired mathematical model is more complex, then one should select *General (powered by NCalc)* type. This type covers a broad spectrum of mathematical functions and operators, and is powered by an open source library **NCalc** (<u>https://ncalc.codeplex.com/</u>). However, its generality affects its performance - working with this type of model can be much slower than working with *Regression model of order 2* type of model.

\/\ Add Math Model	-		×
Туре			
General (Powered by NCalc)			
Name			
ММ			
Variables notation: [x1], [x2], [x3]			
Output =			
0			
	Po	wered by	
	FU	wered by I	<u>vCalC</u>
Add			

At any moment, given mathematical model can be edited by clicking on the button $\boxed{100}$, or deleted by clicking on the button $\boxed{100}$.

CUSTOM MATHEMATICAL MODELS

If you are dealing with billions of input combinations and complex mathematical models, it is smart to have your mathematical models custom developed – it can improve performance up to 100 times. Custom mathematical models can become available for selection in BRUTOMIZER©, just for You! Just contact us on http://www.virtuode.com/index.php/contact/.

Step 4: Definition of constraints

Some formulations of optimization problems incorporate optimization constraints. In order to add constraint in BRUTOMIZER© one needs to click on the button in the *Constraints* tab (located in the center of the main screen), select appropriate mathematical model and select condition (simple or interval). In our case, let's consider that MRR should be greater or equal to 4000 mm³/min.

M Add constraint	
Math model	
<r2> MRR</r2>	•
Condition	
 Simple condition 	
>= 🔹 🖌	
Interval condition	
From	Include boundary
То	Include boundary
Add	
, Aug	

At any moment, given constraint can be edited by clicking on the button $\boxed{2}$, or deleted by clicking on the button $\boxed{2}$.

The main screen after definition of mathematical models, variables ranges and steps is as follows.

Project Tools Help				
New Open	Save	Save As	Import DEMO	
Number of input variables: 3				
Input Variables x1:[3,4] step 0.01 x2:[6,10] step 0.01 x3:[3,35] step 0.01 Number of possible combinations: 2065551	Math Models Constraints		Working Math Model	
			Watched Models	
FIND MIN .	/ MAX	1	TARGET VALUE	

At this point it is a good idea to save current settings and defined input variables, models, constraints etc. This is performed by clicking on *Save* or *Save As* buttons on the top of main screen.

Example 1. Optimization without constraints

Let us consider that it is necessary to determine laser cutting parameters values so as to obtain minimal and maximal surface roughness. To this aim, one needs to select the defined surface roughness model in the *Math*

Math Models Constraints	Working Math Model
	Working Constraints
	Watched Models

Models menu and select \Rightarrow button so as to select this model as working model.

Afterwards one needs to click on button in the lower part of the main screen to run optimization. Optimization is started by clicking on the button *START*. As it could be observed, BRUTOMIZER© determines extreme values (minimal and maximal) of objective function with corresponding values of independent variables for less than 1 sec. Note that BRUTOMIZER© can determine a larger number of optimization solutions (just type in the desired number in the *Minimums (maximums)* field).

FIND MIN / MAX

v Opti	imization			-		-						
Met	thod						Pro	gress:				
Ex	haustive It	erative S	earch			•						
Min 1	imums (ma	eximums)						STAF	RT		Cancel	
	us results						Basic	information				
E		lterative	Search	[07/22/2016	12:36:54]		Start f	od: Exhaustive time: 07/22/2 ime: 07/22/20 ution time: 00:	016 12:36:5	i4 5		۸ ۲
Minimu												
-	x1 3.94	x2 6.00	x3 3.25	Rz 19.42813								
•	3.34	0.00	3.23	13.42013								
Maxim	iums											
•	x1 4.00	x2 10.00	x3 3.00	Rz 37.4								
											Clear all result	s

Based on the obtained optimization solutions values, one can conclude that surface roughness varies between 19.43 and 37.4 μ m.

Similarly, it can been observed that material removal rate (MRR) varies between 3528 mm^3/min and 5238 mm^3/min .

Example 2. Optimization with constraints

Let us consider that it is necessary to determine laser cutting parameters values so as to obtain minimal surface roughness while maintaining MRR of at least 4000 mm³/min. To this aim, one needs to do the following:

1) select the defined surface roughness model in the *Math Models* tab and click on \blacktriangleright button so as to select this model as working model.

2) select the defined MRR constraint in the *Constraints* tab and select \Rightarrow button so as to add this constraint to the list of working constraints.

Math Models Constraints	Working Math Model
	Working Constraints
	····· MRR >= 4000
	Watched Models

Afterwards one needs to click on button in the lower part of the main screen to run optimization. Optimization is started by clicking on the button *START*. Several determined optimization solutions are given in the following figure.

E	thod thaustive	Iterative S	earch			Progress:	
Mir 3	nimums (m	aximums)				START Cancel	
evia	us results					Basic information	
	Exhaustiv	e Iterative	Search	[07/22/2016	13:36:57]	Method: Exhaustive Iterative Search Start time: 07/22/2016 13:36:57 End time: 07/22/2016 13:36:58 Execution time: 00:00:00.7800014	
inim	ums						-
	x1	x2	x3	Rz	MRR >= 4000		
	3.94	6.00	3.25	19.42813	4030.9664		
•			3.25	19.42825	4016.585		
•	3.95	6.00	0.20				
•	3.95 3.93	6.00 6.00	3.24		4023.8862		
					4023.8862		
	3.93				4023.8862 MRR >= 4000		
	3.93 1ums	6.00	3.24	19.42947			
	3.93 nums x1	6.00 x2	3.24 x3	19.42947 Rz 37.4	MRR >= 4000		

Example 3. Achieving desired objective function value

Consider that it is necessary to determine laser cutting parameter's values so as to obtain surface roughness of $R_a=25 \mu m$.

When the defined surface roughness model is set as working model one needs to click on TARGET VALUE

button in the lower part of the main screen.

Based on the given target values for surface roughness and the desired accuracy Δ (maximum difference between the desired and calculated values of surface roughness) BRUTOMIZER© can determine the appropriate values of laser cutting parameters. BRUTOMIZER© can determine these values in two ways:

(1) starting from the smallest values of inputs i.e. laser cutting parameter values (asc option), and

(2) starting from the highest values of inputs (*desc* option)

Which option will be selected in the software prototype depends on the nature of the problem being solved and some other techno-technological aspects.

With selected asc option and accuracy of ⊿=0.1 BRUTOMIZER© determines the solution given in the next figure. As it could be observed, surface roughness of $R_{z} = 24.93 \ \mu m$ can be obtained by using laser power of P = 3 kW, assist gas pressure of p = 6 bar and cutting speed of v = 3.12 m/min.

Target output value Accuracy Querent index 2065551 Order • asc • desc Restant NEXT Cancel Previous results Previous results Basic information 07/22/2016 12:53:47] 24:9283 Target output value: 25 Accuracy 0.1 Stated from: 1 Order: sac Solution index: 13 Stated from: 1 Order: sac Solution index: 13 State from: 10 Order: sac Solution index: 13 State from: 10 Order: sac Solution index: 13 State from: 10 Order: sac Solution index: 13 State from: 10 Order: sac Solution index: 13 State from: 10 Order: sac Solution index: 13 State from: 10 Order: sac Solution index: 13 State from: 10 Details V V V V V Solution index: 13 Solution index: 10 V V Solution index: 13 Solution index: 10			-	
Image:	25 Order @ asc	0.1		
x1 x2 x3 Rz		9288	Target output value: 25 Accuracy: 0.1 Stated from: 1 Order: asc Solution value: 24.9288 Solution index: 13 Statt time: 07/22/2016 12:53:47 End time: 07/22/2016 12:53:47	*
Clear all results	x1 x2 x3			

Example 4. Achieving desired objective function value with constraints

Procedure of selecting constraints is given in <u>Example 2</u>. From then on, one needs to follow the procedure given in <u>Example 3</u>.