

# **Optimisation in Cutting Down Parameters for Industrial Bamboo**

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## **Abstract**

The purpose of this research paper is to determine the optimum cutting down parameters of bamboo, namely, the age of a bamboo tree (in years) to be felled and the part of a bamboo log to be cut (in metres from the base) which would endanger quality of the bamboo material affecting area of the defects occurred during mechanised production process. The Response Surface Methodology (RSM) was used in order to design the experiments, followed by the Genetic Algorithm (GA) that was applied to finding the optimum cutting down parameters for minimum area of the defects in the bamboo during furniture production. The results show that minimum area of the defects of the bamboo material varied in the age of a bamboo tree to be felled and the part of a bamboo log to be cut. A minimum area of the defects was obtained when the cutting down parameters, namely, the age of a bamboo tree (in years) to be felled and the part of a bamboo log to be cut (in metres from the base) were at 3.7 years old and 2.2 metres from the base respectively.

**Keywords**—bamboo, cutting down parameters, defects, quality, optimisation, RSM, GA

## **I. INTRODUCTION**

**B**AMBOO, in the course of last twenty years, has developed as an incredibly precious alternate wood [1]. In many industrial applications nowadays, there has been a trend towards the substitution of wood with bamboo, resulting in rejuvenation and preservation of tropical forests [2]. In Indonesia, bamboo is utilized for major construction materials, furniture, handicrafts and lots of other things. This country is endowed with an immense bamboo resource which sprouts all over the country. Total area of Indonesian bamboo forest includes 2.10 million Ha at which 0.69 Ha million Ha lie in state forest lands and 1.41 million Ha lie in community lands [3].

Despite those facts of potential bamboo for socio-economic development, the optimum use of this vast bamboo resource in Indonesia has not been done yet, especially for furniture products [4]. Its total export value was only USD 94 million in 2007 whereas this was less than 4 percent of the trade value worldwide and just contributed to 20% of rattan products' total export value [3]. Jennifer Gottron and her colleagues [5] argue that low utilization of bamboo resources is deemed to be caused by an inappropriate procedure of cutting down bamboo tree which would endanger the bamboo quality afterwards. Quality of the bamboo material, as raw materials for furniture production, affects frequent occurrence and severity of defects that might take place during mechanised production process. Such defects involve raised grain, fuzzy grain, torn grain and chip mark [3]. Therefore, procedure for cutting down a bamboo tree should consider certain parameters. The optimum age of bamboo for mechanised production process is one of the aforementioned parameters. The other parameter is which particular part of a bamboo log would have the best physical and mechanical properties; i.e. where we should cut a bamboo tree in order to obtain part of a bamboo log that has optimum condition for furniture production. Those two parameters significantly influence quality of the bamboo log with regard to the moisture content. The less the moisture content is available in a bamboo log, the more the level of bamboo quality could be attained. The moisture content affects dimensional stability, toughness, density, strength, working properties and durability of the bamboo material for mechanised production process [6].

This paper reports on results of the research into establishing the optimum age of a bamboo tree to be felled, as well as the optimum part of a bamboo log to be cut which gains the best physical and mechanical properties.

Both parameters are deemed to be factors affecting the bamboo quality for furniture production. The optimisation method adopted in this research is to apply the integrated RSM (the Response Surface Methodology) and GA (the Genetic Algorithm) approach. The following parts of the paper explains the use of both methodologies in optimisation, a case study in an Indonesian Small Medium Enterprise (SME) producing bamboo furniture alongside the results of optimising the cutting down parameters and finally the conclusions.

## II. OPTIMISATION METHOD: RSM AND GA

### A. RSM and GA

RSM is a methodology that develops a model to examine the response function related to the design variables in predicting the optimum values. It is a set of statistical and mathematical approach to modelling problems at which the response is influenced by various variable where the objective itself is to optimize that response [7].

GA seeks optimization concerning minimisation as well as maximisation of the process parameters. The notion of GA is inspired by the theory of evolution based on natural genetic selection [8]. Therefore, when RSM is incorporated with GA, RSM will have a role in modeling experimental responses in term of mathematical modeling while GA plays a part in optimisation of the aforementioned mathematical model.

### B. Optimisation Method Applied to The Case Study

This research can be done with logic as follows, (1) INPUT: identification of control factors and response variables as well as design of experiment using RSM; (2) PROCESS: conducting the experiments, data analysis, building the mathematical model and model optimisation using GA; (3) OUTPUT: optimum parameters. Fig. 1 shows the steps of optimisation with the use of RSM and GA.

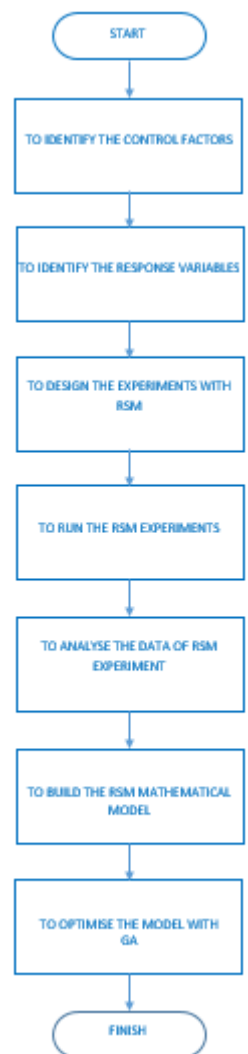


Fig. 1. The Optimisation Method of RSM-GA

This optimisation method was applied to a case study of a bamboo furniture SME located in Yogyakarta, Indonesia. The following elucidates the application of the optimisation method in the case study.

### 1) To Identify the Control Factors

Control factor ( $x_i$ ) also known as independent variable is a variable that is thought to be affecting the response variables. These are factors that will be manipulated to analyse the cause-effect phenomenon occurred among the design parameters. In this steps, a range of values (Level) of each  $x_1$  and  $x_2$  and so forth (the control factors) is also determined.

In the case study, the control factor was 1) the age of bamboo factor ( $x_1$ ) which was comprised of 2 Levels:

$x_{11}$  = a bamboo aged 3 years old

$x_{12}$  = a bamboo aged 4 years old

also, 2) the part of the bamboo log ( $x_2$ ) which was comprised of 3 Levels:

$x_{21}$  = base part of the bamboo log (0-2 m  $\rightarrow$  2)

$x_{22}$  = middle part of the bamboo log (2-4 m  $\rightarrow$  4)

$x_{23}$  = end part of the bamboo log (4-6 m  $\rightarrow$  6)

### 2) To Identify the Response Variables

Response variables ( $y_i$ ), namely dependent variables, are variables deemed to be affected by the control factors. They are usually the process parameters to be analysed concerning the presence of control factors.

In the case study, the response variables covered:

$y_1$  = defects caused by sawing test

$y_2$  = defects caused by milling test

$y_3$  = defects caused by lathing test

$y_4$  = defects caused by drilling test

$y_5$  = defects caused by sanding test

### 3) To Design the Experiment using RSM

The screening response model used for the 1<sup>st</sup> order situation is as follows [7]:

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \epsilon \quad (1)$$

while the 2<sup>nd</sup> order situation where it is believed that the value is somewhere near “the hill tip” is formulated underneath [7]:

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_{12} x_1 x_2 + \beta_{11} x_1^2 + \beta_{22} x_2^2 + \epsilon \quad (2)$$

Levels of each control factor is given a code number; +1 represents a level with high value whereas -1 represents a level with low value. Table 1 shows the 1<sup>st</sup> order of the experimental design.

TABLE 1. MATRIX OF 1<sup>ST</sup> ORDER EXPERIMENTAL DESIGN

experiment	$x_1$	$x_2$
1	-1	-1
2	-1	0
3	-1	+1
4	+1	-1
5	+1	0
6	+1	+1

In 2<sup>nd</sup> order situation, Central Composite Design (CCD) is applied in that it uses 2 free variables with these formulas [7]:

$$x_{i1} = \frac{\xi_{i1} - [\max(\xi_{i1}) + \min(\xi_{i1})]/2}{[\max(\xi_{i1}) - \min(\xi_{i1})]/2} = \frac{\xi_{i1} - (4+3)/2}{(4-3)/2} = \frac{\xi_{i1} - 3,5}{0,5} \quad (3)$$

and

$$x_{i2} = \frac{\xi_{i2} - [\max(\xi_{i2}) + \min(\xi_{i2})]/2}{[\max(\xi_{i2}) - \min(\xi_{i2})]/2} = \frac{\xi_{i2} - (6+2)/2}{(6-2)/2} = \frac{\xi_{i2} - 4}{2} \quad (4)$$

Table 2 tabulates the transformation results using the code number in 2<sup>nd</sup> order, while Table 3 shows the 2<sup>nd</sup>

order of the experimental design.

TABLE 2. LEVEL CODES VS LEVEL VALUES

Level Code	-1,414	-1	0	+1	1,414
Age (years)	2,8	3	3,5	4	4,2
Part of bamboo log ( $i^{\text{th}}$ meter from the base)	6,8	6	4	2	1,2

TABLE 3. MATRIX OF 2<sup>ND</sup> ORDER EXPERIMENTAL DESIGN

$i^{\text{th}}$ experiment	$x_1$	$x_2$
1	0	0
2	1,414	0
3	-1	-1
4	1	1
5	0	0
6	0	1,414
7	-1,414	0
8	0	0
9	0	0
10	0	0
11	1	-1
12	0	-1,414
13	-1	1

#### 4) To Run the RSM Experiment

Subsequent to the accomplishment of the design of experiment, the experiment of 1<sup>st</sup> order and 2<sup>nd</sup> order are then conducted. Table 4 and Table 5 show the results of experiments in 1<sup>st</sup> order and 2<sup>nd</sup> order situation respectively.

TABLE 4. RESULTS OF THE 1<sup>ST</sup> ORDER EXPERIMENT

No	Factor Code		Response (%)				
			Sawing	Milling	Lathing	Drilling	Sanding
	$x_1$	$x_2$	$y_1$	$y_2$	$y_3$	$y_4$	$y_5$
1	-1	-1	3,83	5,09	15,13	33,46	5,66
2	-1	0	1,03	4,13	9,34	30,82	1,32
3	-1	1	1,18	7,35	12,59	20,77	3,47
4	1	-1	3,74	4,44	9,84	20,46	3,48
5	1	0	2,57	1,27	2,25	21,71	1,45
6	1	1	2,67	1,08	8,19	24,95	3,06

TABLE 5. RESULTS OF THE 2<sup>ND</sup> ORDER EXPERIMENT

No	Faktor Code		Response (%)				
			Sawing	Milling	Lathing	Drilling	Sanding
	$x_1$	$x_2$	$y_1$	$y_2$	$y_3$	$y_4$	$y_5$
1	0	0	0,73	0,25	6,17	21,28	0,11
2	1,414	0	0,64	0,23	4,25	19,01	0,77
3	-1	-1	3,07	3,14	9,11	27,82	3,19
4	1	1	1,17	0,33	3,97	10,9	0,64
5	0	0	0,57	2,24	6,12	14,88	1,23
6	0	1,414	1,36	0,57	5,48	11,43	0,82
7	-1,414	0	2,37	3,01	10,22	32,64	3,75
8	0	0	1,06	1,1	7,32	18,84	0,63
9	0	0	1,73	2,14	7,58	16,06	0,55
10	0	0	1,04	2,26	6,35	19,07	1,06
11	1	-1	0,78	4,41	4,28	15,72	0,12
12	0	-1,414	3,84	3,17	10,61	20,18	0,88
13	-1	1	0,74	3,22	7,72	12,37	3,74

#### 5) To Analyse the Data of RSM Experiment

##### i) Sawing Test:

Regarding Table 6, the equation of regression for sawing test can be formulated as follows:

$$\hat{y}_1 = 1,031 - 0,541x_1 - 0,683x_2 + 0,080 x_1^2 + 0,639x_2^2 + 0,680x_1x_2 \quad (5)$$

TABLE 6. 2ND ORDER COEFFICIENT ESTIMATION FOR SAWING

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	1.031	0.236	4.38	0.003	
x1	-0.541	0.187	-2.89	0.023	1.00
x2	-0.683	0.187	-3.65	0.008	1.00
x1*x1	0.080	0.203	0.40	0.704	1.01
x2*x2	0.639	0.203	3.15	0.016	1.01
x1*x2	0.680	0.263	2.58	0.036	1.00

ii) Milling Test:

Table 7 concludes that the equation of regression for milling test is:

$$\hat{y}_2 = 1,59 - 0,696x_1 - 0,965x_2 + 0,277x_1^2 + 0,405x_2^2 - 1,04x_1x_2 \quad (6)$$

TABLE 7. 2ND ORDER COEFFICIENT ESTIMATION FOR MILLING

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	5	16,9987	3,3997	3,99	0,050
x1	1	3,8361	3,8361	4,50	0,072
x2	1	7,3699	7,3699	8,64	0,022
x1*x1	1	0,5198	0,5198	0,61	0,461
x2*x2	1	1,1078	1,1078	1,30	0,292
x1*x2	1	4,3264	4,3264	5,07	0,059
Error	7	5,9701	0,8529		
Lack-of-Fit	3	2,7608	0,9203	1,15	0,432
Pure Error	4	3,2093	0,8023		
Total	12	22,9687			

iii) Lathing Test:

Based on Table 8, the equation of regression for lathing test can be defined as:

$$\hat{y}_3 = 6,719 - 2,139x_1 - 1,12x_2 - 0,09x_1^2 + 0,322x_2^2 + 0,27x_1x_2 \quad (7)$$

TABLE 8. 2ND ORDER COEFFICIENT ESTIMATION FOR LATHING

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	5	47,2941	9,4588	6,90	0,012
x1	1	36,2242	36,2242	26,42	0,001
x2	1	9,9608	9,9608	7,26	0,031
x1*x1	1	0,0560	0,0560	0,04	0,846
x2*x2	1	0,7019	0,7019	0,51	0,497
x1*x2	1	0,2916	0,2916	0,21	0,659
Error	7	9,5989	1,3713		
Lack-of-Fit	3	7,7006	2,5669	5,41	0,068
Pure Error	4	1,8983	0,4746		
Total	12	56,8930			

iv) Drilling Test:

With regard to results shown in Table 9, it produces the equation of regression for drilling test as follows:

$$\hat{y}_4 = 134,7 - 78,8x_1 - 15,78x_2 + 11,60x_1^2 + 0,553x_2^2 + 2,66x_1x_2 \quad (8)$$

TABLE 9. 2ND ORDER COEFFICIENT ESTIMATION FOR DRILLING

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	5	398,21	79,642	7,75	0,009
x1	1	51,51	51,507	5,01	0,060
x2	1	67,57	67,567	6,57	0,037
x1*x1	1	56,80	56,796	5,53	0,051
x2*x2	1	33,11	33,113	3,22	0,116
x1*x2	1	28,25	28,249	2,75	0,141
Error	7	71,94	10,278		
Lack-of-Fit	3	45,84	15,280	2,34	0,215
Pure Error	4	26,10	6,526		
Total	12	470,15			

v) Sanding Test:

Regarding Table 10, the equation of regression for sanding test can be formulated as:

$$\hat{y}_5 = 0,713 - 1,306x_1 + 0,124x_2 + 0,879x_1^2 + 0,159x_2^2 - 0,008x_1x_2 \quad (9)$$

TABLE 10. 2ND ORDER COEFFICIENT ESTIMATION FOR SANDING

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	5	18,8638	3,7728	16,07	0,001
x1	1	13,5047	13,5047	57,53	0,000
x2	1	0,1228	0,1228	0,52	0,493
x1*x1	1	5,2166	5,2166	22,22	0,002
x2*x2	1	0,1712	0,1712	0,73	0,421
x1*x2	1	0,0002	0,0002	0,00	0,976
Error	7	1,6433	0,2348		
Lack-of-Fit	3	0,8586	0,2862	1,46	0,352
Pure Error	4	0,7847	0,1962		
Total	12	20,5071			

Once all of the equation of regression for each test can be determined, the mathematical model alongside its objective function for optimisation is subsequently set up. Estimation of optimum value for each test can also be

done with the contour plot. Fig. 2 shows an example of contour plot result, i.e. the milling test.

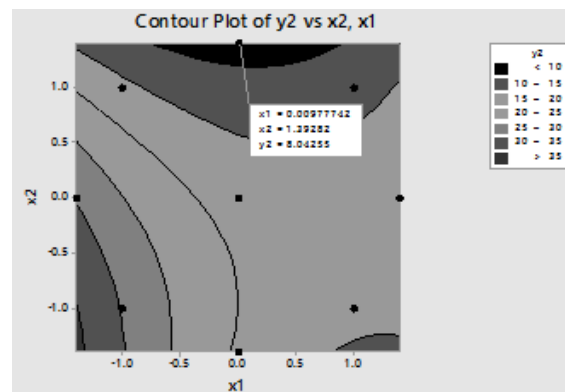


Figure 2. Contour Plot of Milling Test Result

#### 6) To Build the RSM Mathematical Model

The objective function is,

$$\text{to minimise } y = y_1 + y_2 + y_3 + y_4 + y_5 \quad (10)$$

The decision variables are,

$x_1$  = age of bamboo (years)

$x_2$  = part of the bamboo log (n metres from the base)

The constraints are,

age of bamboo:  $3 \leq x_1 \leq 4$

part of the bamboo log:  $0 \leq x_2 \leq 6$

non negativity:  $x_1, x_2 \geq 0$

#### 7) To Optimise the Model with GA

This step begins with creating a random initial population followed by a sequence of creating new populations. To create the new population, the algorithm follows these steps:

- compute the fitness value in order to score each of the existing populations
- convert the fitness value by scaling its scores into a more usable range of values
- based on their fitness, select members (a.k.a parents)
- select individuals in the initial population which have low level of fitness (a.k.a elite), these elite individuals should go to the next population
- produce children from parents either by mutation or crossover
- replace current population with the children to create next / new population

With the use of MATLAB, the optimum values for  $x_1$  (age of bamboo in years) and  $x_2$  (part of the bamboo log in metres from the base) are determined as shown in Fig. 3 below.

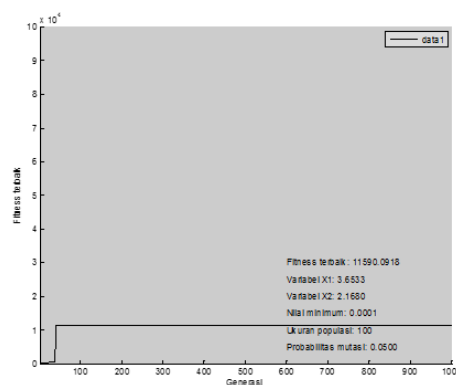


Figure 3. The Optimisation result of GA

As can be seen in Fig. 3, changes in the fitness value starts from the first generation of population until the 40<sup>th</sup> generation. From that point, i.e. the 40<sup>th</sup>, to 1000<sup>th</sup> generation of population, the fitness value is constant.

This leads to the conclusions that - given the minimum area of the defects of only 0.1% - the optimum value for parameter  $x_1$  (age of bamboo) is 3.6533 years or 3.7 years old maximum, whereas the optimum value for parameter  $x_2$  (part of the bamboo log) is 2.1680 metres or 2.2 metres maximum.

### III. CONCLUSION

The implementation of RSM-GA optimisation for area of the defects of the bamboo material during mechanised production process in consequence of the cutting down parameters is presented in this paper. The mathematical model was eventually formulated with RSM using experimental results as per Central Composite Design, considering age and part of the bamboo log as cutting down parameters. The minimisation of area of the defects was conducted by GA with the RSM mathematical model. The results show that minimum area of the defects of 0.1% occurred in processing the bamboo for furniture with mechanised production process under particular optimum values of cutting down parameters, i.e. under the age of the bamboo of maximum 3.7 years old and under the part of the bamboo log of maximum 2.2 metres from the base.

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