Gram Optimization using Taguchi Method of Parameter Design and Neural Network Process Model in Packaging Industry

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Abstract. *Costumer satisfaction is best achieved by improvement of quality product. One way to improve the quality of a product is to optimize the process output. This research paper describes the methods of manufacturing process optimization, using the basis of Taguchi parameter design and Neural Network model. Taguchi experimental design used to predict the optimum process parameters in manufacturing process, while Neural Network model forecasts the responses from the process parameters. This combination approach identifies the important factor settings to develop a setting design for the optimum operating condition that can stand from noise variables (Robust Design), without conduct an actual experiment on process. A case study illustrates this approach, collects real production data from the laminating machine in a packaging plant using gram (sheeting weight of packaging material) as quality response from the process.*

Keywords: *Process design, optimization technique, process quality improvement, Taguchi method, Neural Network for prediction, lamination extrusion process.*

1. INTRODUCTION

In the industrial world of competition which becomes more tightly these days, every manufacture or service industry had to keep their business process performance in order to produce products that are acceptable by costumers. This is meant to reach company's goal in that gaining profit as much as possible. To reach this goal, the company has to give products that meet to the quality characteristic determined by costumers in order to reach customer satisfaction. If the product does not meet the desirable quality, the company will lose its market share and costumers are changing their choices into other competitor's products .

The quality control method which has been conducted only after the product are completed the process (inspection method) can both increase the customer satisfaction and production cost, because there will be many products that are being rejected either by the customer or the process itself.

Regulating the production machine with the newer one can not answer those questions otherwise it increases the production cost by adding the investment cost. To solve this problem the production process will need a Quality Engineering (Ilmi, 1999). Quality Engineering method had broadly introduced by Genichi Taguchi in 1985 along with publication of American Society for Quality Control journal. Refers to Sukthomya and Tannock (2003), Taguchi method is a part of Design of Experiment (DoE) method that are simpler, and has been modified and broadly adopted by the industry. But term of conducting the actual experiment at the actual process will cause disruption at line production and not economically accepted. Therefore, the actual experiment can be replaced by the experiment at

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the artificial process or modeled process to predict the output of the process.

Artificial Neural Network is a technology from artificial intelligent which has been used broadly in monitoring manufacture processes. This method employs output pattern recognition (Zeydan, 2008) and has been broadly used for process modeling. At this research, it is conducted a case study analyzing an extrusion laminating process in packaging industry. The process laminates the Polypropylene (PP) sheet into the Polyesther Film (PET Print). One of the quality response of this process is the gram (sheeting weight) with unit of gr/m^2. Problems that the grams have been variably disperse, and those become a quality problem. If the gram exceeds the target value even it still in toleration range, it will be appeared as an increasing of production cost. If the product is less than target itself, the customer will complain, and if it exceeds the toleration range, the product would be rejected. An engineering of quality is needed to solve the quality problems so that the extrusion laminating process would have the lowest deviation and fulfilled the specification target. Quality Engineering is conducted by designing a design parameter of the process to generate an optimum operational condition that robust against any other random factors which can affect quality.

2. LITERATURE

2.1 Quality Engineering

Quality Engineering is an interdisciplinary science which is concerned with not only producing satisfactory product for customers but also reducing the total loss (manufacturing cost plus quality loss) (Park,1996). Quality Engineering method had broadly introduced by Genichi Taguchi in 1985 along with publication of American Society for Quality Control Journal. Taguchi asserts that product and process design have a much greater impact on product quality than manufacturing and inspection. Quality should be designed into the product and does not inspected into it. Taguchi method also known as *Robust Design*, an engineering methodology for optimizing the product and process condition which are minimally sensitive to the various cause of variation, and which produce high quality products with low development and manufacturing cost (Park, 1996).

2.2 Taguchi Method of Parameter Design

Taguchi method of parameter design is a design used to improve quality without controlling or eliminating causes of variation, and to make the product robust against noise factors.

In general, parameter design has the following characteristic. First, it classifies factors which affect quality characteristic into two groups: control factors and noise (or uncontrollable) factors. Second, it generally uses two OAs: for the control factors, an OA which is called an ‘inner array’, and for the noise factors, another OA which is called an ‘outer array’. (Park, 1996). Several steps are needed for parameter design and data analysis, differing slightly according to the type of quality characteristic such as smaller-the-better, nominal-is-best, and larger-the-better.

S/N ratio is a measure of the performance variability of products/processes in the presence of noise factors. S/N ratio is a performance criteria, defined as the signal to noise ratio, in that, S stands for mean and that is called signal and also N stands for standard deviation and that is called noise The higher the SNR, the better the quality of product is. The idea is to maximize the S/N ratio and thereby minimizing the effect of random noise factors has significant impact on the process performance. S/N ratio is formulized with the following equation (Taguchi, 1987):

$$S/N = \; 10\log\left(\frac{\sum_{i=1}^{n}\left(\frac{i}{y_i^2}\right)}{n}\right) \qquad (1)$$

Where n is the number of repetition for an experimental combination and y_i is a performance value of the ith experiment.

2.3 Artificial Neural Network (ANN)

ANN is a computational tool that has similar running nature like the neurons in the brain. The structure of ANN enables them to learn, approximate functions, and classify patterns. Neuron is a basic part from the processing of Neural Network which contain of a group of connector called synapses or connection link characterized by a weight or strength connection, a summing or adder which used to sum all the input signal, and a non-dynamical function which known as an activation function.

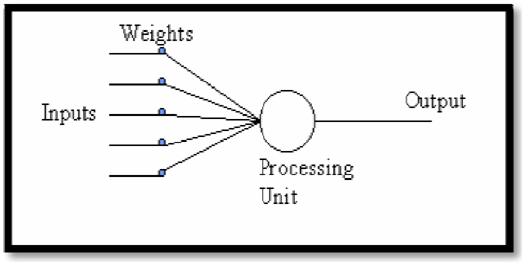

Figure 1: The basic shape of Neuron
(Source: Introduction to Artificial Neural Network by Setiyawan, 2003)

Inputs are used either in training or in recognizing an object. Weight always changes every time if it is being given an input as training process. A processing unit is a place where the recognization of object based on the weight is being held and gives an output from the recognized process.

An equation of a neuron activation function is:

$$O_k = f_{actv}\ (net_k) \qquad (2)$$

Where f_{actv} is an activation function and O_k is neuron output.

3. RESEARCH METHODOLOGY

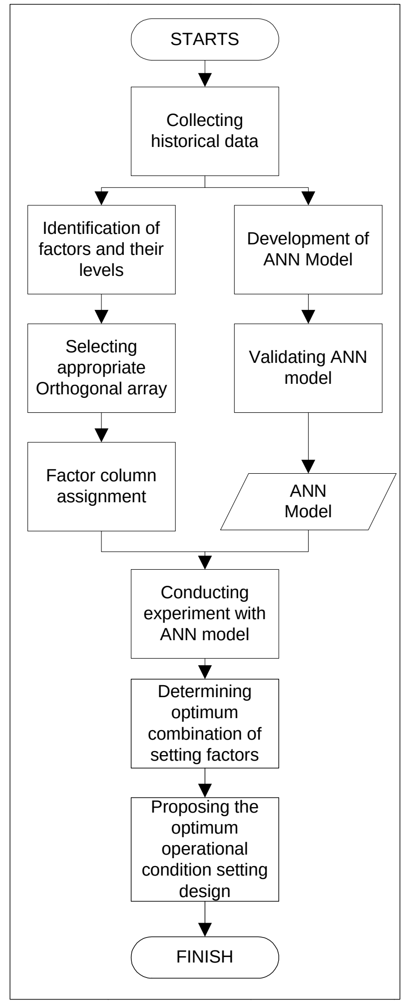

Figure 2: Research methodology flow chart

Based on the flowchart diagram cited at picture number 2 above, steps to conduct this research are divided into three parts which are steps to design the experiment using Taguchi method of parameter design, steps to develop an artificial model using Neural Network model, and steps to conduct the experiment using combination of both method. These steps will guide us to the arrangement of optimum operational condition setting design.

4. DATA AND ANALYSIS

4.1 Collecting Historical Data

The historical data are collected from one of the documented version titled "documentation of product quality". Information being documented and transformed into input for data processing are operational condition data that contain process parameter which decides the running of process.

Collection of gram data is using sample of extrusion laminating product. This sample product has width of 540 mm and it consists of 4 pitches (front side) with size of 135 mm at each pitch. Sample that has been collected was 1 meter long and has been measured (the weigth) at 5 zone of the sample at every pitch side except the one at extreme right.

4.2 Identification of factors and their levels

The setting factors at the experiment are divided into fixed and random factors. Fixed factor is a factor that can be controlled and has its technical meaning at every level. Fixed factors were called control factors. Random factor is a factor that can not be technically controlled, and are called noise factor. At this factor identification step is conducted direct brainstorming with QC inspector of extrusion laminating process to gain the assumption about factors that significantly affected the gram. From those assumptions, it is chosen some factors which considerably obtaines the most effect on gram and those factors will be the object of this experiment. Determining level for every setting factor should be conducted in order to get the level of each contribution from each independent factor against the process robustness. For the control factors, determining level is conducted by looking for minimum and maximum value from historical data that has been collected. This should be done in order that the combination of factors resulted can cover the most extreme operational condition (minimum and maximum gram). Value from Standard Working Instruction (SIP) can also be entered as the standard level. Table 1 consists all the control factors at this research including its level while table 2 consists of noise factor and its level.

Table 1: Control factors and its level

NO	CONTROL FACTORS	Level 1		Level 2		Level 3	
		EC1	EC2	EC1	EC2	EC1	EC2
A	*T-Die Zone* 1 (C°)	237	300	300	310	308	345
B	*T-Die Zone* 2 (C°)	265	320	290	323	323	330
C	*T-Die Zone* 3 (C°)	280	315	333	324	338	332
D	*T-Die Zone* 4 (C°)	265	313	345	323	350	334
E	*T-Die Zone* 5 (C°)	280	320	330	324	338	334
F	*T-Die Zone* 6 (C°)	270	320	303	323	330	328
G	*T-Die Zone* 7 (C°)	280	320	303	327	330	330
H	cylinder ekstruder 1 (C°)	208	229	225	237	230	329
I	cylinder ekstruder 2 (C°)	230	260	250	265	275	308
J	cylinder ekstruder 3 (C°)	255	300	260	310	280	338
K	cylinder ekstruder 4 (C°)	280	315	300	320	325	330
L	cylinder ekstruder 5 (C°)	300	322	330	330	345	338
M	Adaptor ekstruder (C°)	300	313	315	330	340	332
N	Joint ekstruder (C°)	280	314	315	330	335	335
O	*Line Speed*	57	57	65	65	75	75
P	*Screw rotary*	38	31	39	39	57	40
Q	Ketebalan Litho Paper	38 38 38 38 38		40 40 40 40 40		42 42 42 42 42	

Table 2: Control factors and its level

NO	NOISE FAKTOR	LEVEL 1	LEVEL 2	LEVEL 3
1	Production shift	08.00-16.00	16.00- 00.00	00.00-08.00

4.3. Selecting Appropriate Orthogonal Array (OA) and Factor Column Assignment

Determining the OA is done based on number of factors and levels that are used for the experiment. This experiment used the extended orthogonal array instead of standard OA which is L_{27}^{22} OA and usually called partially OA. From 22 columns exist, 17 are assigned as the factor column and others were assigned as error column. The experiment which is accurately conducted is using two type of OA, inner array and outer array. Inner array consists of column for setting factors and is constructed using the L_{27} OA, while the outer array consists of column for noise factors and was constructed by one way layout. It should be noticed that the used of outer array is for experiment where noise factors that affected process performance could be adjusted. In this case, production shift is the noise factor.

4.4 Development of ANN Model

The purpose of ANN employment at this research is to generate the artificial model of extrusion laminating process which comes near from the actual process in order to replace the actual experiment. ANN which suits this function is NN prediction, a function that can predict the output value in the range of NN value. Multilayer Perceptron (MLP) is used for the network structure and Back Propagation algorithm is used for network algorithm. Along with gradient descent method, this algorithm can be used to train the MPL network.

4.5 Training and Testing the ANN Model

Training was conducted for development of ANN model. Training was conducted by NN prediction software along with the algorithm and the structure that had been determined before. This software is used the macros Visual Basic in the Microsoft Excel. In the mean time the testing process was used for estimating error of the training model. At this training process, task of neuron is is to sum all incoming input to the model based on weight (power) between the connection of input and neuron. Then, by using the activation function, neuron could compute its own output. During the training process, every weight of data set which being given to the model was adjusted to minimize error. Error is the difference between output that had been produced by the model and actual output of the process. This weight adjustment procedure was controlled by training algorithm (weight adjustment function). When the error value was reduced until its desired level, the model was successfully training. Three steps should be conducted at the training and testing with NN prediction software.

- Entered data (Data input)
- Set ANN model parameter (User input)
- Built model

The value of process parameters that are set to build the model were defined by trial and error until it reached the lowest error value. These are ANN parameters which being used to build the model and its final value resulted from trial and error method. The lowest error value produced by this combination of parameters was cited at table 4.

- Number of hidden layer : 2
- Learning parameter : 0.5
- Momentum : 0
- Hidden layer sizes : 6 and 6
- Initial weight range : 0.5
- Number of *training* cycles : 150
- *Training* mode : Sequential

It can be seen at table 3, the final value of MSE and ARE from the ANN model. MSE (*Mean Squared Error*) calculated the difference between actual output and predicted output. While ARE (*Absolute Relative Error*) is the percentage form of the difference.

Table 3 : Error prediction of ANN model

Average Error per Input			
Training Set		Validation Set	
MSE	ARE (%)	MSE	ARE (%)
1.085	0.86	0.973	0.88

4.6. Running the experiment with ANN Model

Steps that should be conducted for the experiment using ANN model are done by entering the value of each factor based its determined level at the OA matrix. Every experimental run has its different combination of level factors. L_{27} inner array indicates the existence of 27 factor control combination that should be enter into the ANN model. The output from this experiment is 5 gram values for 5 difference parts of the sample.

4.7. Determining the Optimum Control Factors

Optimum control factors are the factors that significantly contributed to the making of robust design process. Park (1996) divides the significant control factors into 3 categories, which are:

Dispersion control factors	: Factors which significantly contributed to *S/N Ratio* or variability
Mean adjustment factors	: Factors which significantly contributed to sensitivity
Non significant factors	: Other control factors

Determining significant control factors is conducted by beforehand converting value of gram into *S/N Ratio* and *sensitivity* value, and calculated it with Pareto ANOVA method (park). Pareto ANOVA is a method which calculated value of contribution ratio from each factor toward the variability or sensitivity and accumulated it with

Pareto diagram. Those control factors are considerably has significant contribution if they reached up to 90% accumulation toward both of variability and sensitivity. The Pareto ANOVA and Pareto diagram for gram section 1 (G1) can be seen at table 4 and figure 3.

Table 4: Pareto ANOVA cited only 10 from 17 control factors at gram section 1 (G1)

[redacted]

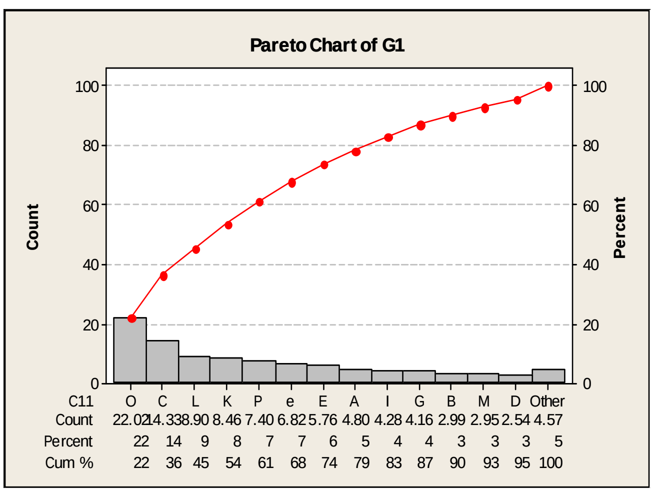

Figure 3: Pareto diagram at gram section 1 (G1)

After we found out the significant and non-significant factors, this research is carried out by determining its optimum level from each control factor. For the dispersion control factors, the optimum level is reached by level that contribute the biggest *S/N Ratio*, while for the mean adjustment factors, the optimum level is reached by level that contributes the mean of gram value which is the closest to the mean target, 89.5 g/m^2.The figure 4 describes the identification of optimum level at gram section 1(G1) for the dispersion control factors.

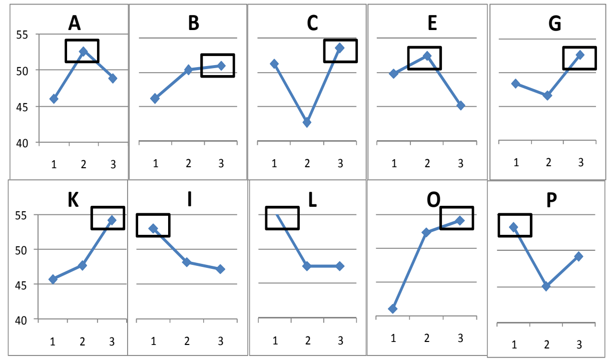

Figure 4: Mean effect plot Dispersion control factors G4

4.8. Determining the Optimum Setting Design

Table 5: Optimum setting design G1-G5

[redacted]

The table cited above shows the combination of optimum level which is different at each quality response section (G1-G5). This can result the different operational condition setting designs, while there should be only one setting design resulted from this experiment. To solve it, the ANN model is used to predict the resulted output (gram) at five sections of the sample based on the level of production shift. This test intends to find the most optimum gram for the most optimum setting design that has the lowest variability and was closest to the mean target among other setting design.

Table 6: Selection of optimum setting design

[redacted]

At the table above, 5 setting design that are being tested by the ANN model, the 4th setting design has the closest-to-target gram value (89 gr/m2) and the lowest variable (0.051276), so this setting design was chosen to be the optimum setting design.

4.9. Analyzing the Optimum Setting Design

If the optimum dispersion control factors were added to another optimum factors (mean adjustment and non-significant factors), the overall optimum operational condition (table 7) could be reached. Those optimum conditions were represented by *S/N Ratio* as indication of process robustness and mean value as indication of process capability to reach target.

Table 7: Optimum setting design of operational condition

CONTROL FACTORS	LEVEL	Value	
		EC1	EC2
Suhu *T-Die Zone* 1 (C)	2	300	310
Suhu *T-Die Zone* 2 (C)	1	265	320
Suhu *T-Die Zone* 3 (C)	1	280	315
Suhu *T-Die Zone* 4 (C)	1	265	313
Suhu *T-Die Zone* 5 (C)	1	280	320
Suhu *T-Die Zone* 6 (C)	3	330	328
Suhu *T-Die Zone* 7 (C)	2	303	327
Suhu *Silinder Ekstruder* 1 (C)	3	230	329
Suhu *Silinder Ekstruder* 2(C)	3	275	308
Suhu *Silinder Ekstruder* 3 (C)	3	280	338
Suhu *Silinder Ekstruder* 4 (C)	3	325	330
Suhu *Silinder Ekstruder* 5 (C)	1	300	322
Suhu *Adaptor Ekstruder r* (C)	3	340	332
Suhu *Joint Ekstruder* (C)	1	280	314
Line speed (m/min)	3	75	75
Screw rotary (Rpm)	1	38	31
Kertas Litho (micrometer)	3	42 42 42 42 42	

Taguchi has an equation to predict those two values. Predicting *S/N Ratio* value was conducted by calculate every effect from optimum level that could change the average *S/N Ratio*. The calculation was done using Taguchi (1986) equation written in Ross (1989, p. 73):

$$\bar{T} + (\bar{A}_2 - \bar{T}) + (\bar{B}_1 - \bar{T}) + (\bar{C}_1 - \bar{T}) + (\bar{D}_1 - \bar{T}) + (\bar{E}_1 - \bar{T}) + (\bar{F}_3 - \bar{T} + (\bar{G}_2 - \bar{T}) + (\bar{H}_3 - \bar{T}) + (\bar{I}_3 - \bar{T}) + (\bar{J}_3 - \bar{T}) + (\bar{K}_3 - \bar{T}) + (\bar{L}_1 - \bar{T}) + (\bar{M}_3 - \bar{T}) + (\bar{N}_1 - \bar{T}) + (\bar{O}_3 - \bar{T}) + (\bar{P}_1 - \bar{T}) + (\bar{Q}_3 - \bar{T})$$

Figure 5 : The calculation of Taguchi (1986) equation written in Ross (1989, p. 73)

Where is $\bar{T}$ average *S/N Ratio* from the overall experimental results, $\bar{A}_2$ average *S/N Ratio* for 2nd level of factor A (optimum condition), and $(\bar{A}_2 - \bar{T})$ Represent effect of 2nd level of factor A to change *S/N Ratio* value from $\bar{T}$ into $\bar{A}_2$. Average *S/N Ratio* at the optimum operational condition is:

S/N Ratio optimum = 78.78 dB
S/N Ratio initial = 45.45 dB

Compare to setting design at standard condition (initial condition), there is 33.33 dB of difference at the average *S/N Ratio*. It means that the process is 1000 more robust against noise factors than the process at standard condition before.

Taguchi equation can also be used to predict the average gram value by calculating its mean value. Average gram at the optimum operational condition is:

Mean optimum = 89.907 gr/m²
Mean initial = 88.434 gr/m²

Compared to setting design at standard condition (initial condition), average gram at optimum setting design is 37% closer to the target value than the current one.

5. CONCLUSIONS

From the results of experiment which have been conducted, the conclusions are as follows.

- ANN model of extrusion laminating process is able to predict laminating process output only by entering values of all process parameter in operational condition. This model is built by *Neural Network* Prediction Software. Probability of error from the model is 0.86% or 0.88%
- Control factors identification in process can be done by Pareto ANOVA method. This method calculate percentage of contribution each factor toward S/N Ratio and sensitivity. Factors that has been included to the dispersion control factors were T-Die temperature zone 1, 3, 4, and 5, cylinder extruder temperature zone 3, 4, and 5, adaptor extruder temperature, line speed, and screw rotary. Factors that has been included to the

mean adjusted factors are T-die temperature zone 2, 6, and 7, cylinder extruder zone 2, and joint extruder temperature. Factors that have been included to the non significant factors are cylinder extruder temperature zone 1, and thickness of Litho paper.

- The combination of Taguchi parameter design method and Artificial Neural Network can generate a proposal of optimum setting design of operational condition from extrusion laminating process. Based on Taguchi prediction, this optimum setting design could resulted process output (gram) which was 1000 times bigger against noise factors and 37% closer to the mean target if being compared to the standard setting designed.

Suggestion for further research:

- It is suggested to conduct the normality test and residual test at historical data which will be the input for ANN model to prevent the existence of out layer data.
- It is suggested to gain further understanding and analysis toward the mathematical function or generic function of extrusion laminating process itself so that the determination of level can have an appropriate and logic technical function.
- It is suggested that employment of historical data which will be the input for ANN model is restricted only when the extrusion laminating process is in a normal condition.

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