Weighting analysis of pellet quality attributes using Multi Response Signal to Noise (MRSN) method

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Abstract. Quality of pellets, one form of animal feed, is not only measured by the nutritional content but also by its physical form. The physical strength of the pellet is determined from crushing and not easily moldy. Both quality characteristics are measured by reliability (pellet durability index) and resistance (water content percentage). In order to improve the quality of pellet, this study applied Multi Response Signal to Noise (MRSN) method. The weight of product quality attributes used will influence the method in determining the selected alternatives. To accommodate the weighting of dynamic product quality attributes, this study also ran weighting sensitivity analysis of product quality attributes. The results showed that the combination of factor level that produced the optimal pellet is A₂, B₁, C₁, D₁, E₁, F₁, G₂ or combination of production process run with vapor pressure 1.9 bar, temperature conditioner 80 ° C, 3.5mm pellet diameter mold, cooler temperature 30 ° C, time in cooler 2 minutes, roller distance 1.5 cm, mixing time 175 seconds. This optimum combination can increase PDI percentage by 2.132% and decrease difference to target of water content by 0.234%. The optimum factor level combination will change if the weight for % PDI rises to be more than 0.77228 or decreases to be less than 0.00561, or in other words, the optimum combination will not change if the weight for % PDI is in the range 0.00561 - 0.77228.

Keywords: Quality attributes, Taguchi, MRSN, sensitivity Analysis

1. Introduction

Animal feed products consist of various forms, such as pellet (granular), concentrate, mash (flour), and crumble (fine grains). Besides depending on the nutritional content, the quality of poultry feed in the form of pellet is also influenced by the physical form such as not easily destroyed and not easily moldy. These depend on reliability measured by level of pellet durability index (PDI) and pellet resistance measured by their water content. The pellet-making process that influences the physical quality of the pellet is the vapor pressure, the temperature of the conditioner, the diameter of the pellet mold, the cooler temperature, the time in the cooler, the diameter of the roller and the mixing time [1]. Currently, the company produces pellets by PDI percentage is 86.794% and water content percentage is 9.738%. In an effort to improve the quality of products, this study conducted experiment designed based Taguchi method to develop robust design product. The Taguchi design experiment was an improvement of conventional experimental design. This method was a design process to produce products not sensitive to interference factors or have robust performance [2]. Taguchi based studies had been applied in some different area such as clothing [3][4][5], chemical study [6][7], food [8] and tool development [9].
This research used Multi Response Signal to Noise (MRSN) to optimize the different combination among product quality attributes or response variables. This method was done based on weight of response variables. Sensitivity analysis was done to guide researchers to be objective and to accommodate the dynamic product quality attributes weighting.

2. Literature review

2.1 Quality concept
Quality is a very important aspect in the progress of the company. One of the company success factors is determined by its final product quality. Many experts define quality in different words, however, all of them refer quality as meeting the customer requirements. Qualified products and services are products and services that match what their customers need [10]. Therefore, companies need to know their customers and their needs and desires. Quality has many different definitions, and varies from conventional to more strategic. The conventional definition of quality usually describes the direct characteristics of a product such as performance, reliability, easy to use, esthetics, perception and so on. Moreover, the strategic definition of quality is meeting the needs of customers [11].

2.2 Quality control
Quality control is a measurement process undertaken during the design of a product or process. Quality control activities include in every phase of product research and development, production process design, and customer satisfaction. Quality control is aimed to achieve all targets of continuous improvement, accelerated inventions, quick problem solving, and cost-effectiveness in improving product quality. Quality control can be divided into 2 parts, namely off-line quality control and on-line quality control [12].

2.2.1 Off-Line Quality control
Offline quality (QC) control is related to activities of QC during product development and process design. Activities undertaken include: identification of customers and their expectations, designing products in accordance with consumer expectations, designing products consistently and economically profitable and developing clearly and fairly specific standards, procedures, and production equipment. Off-line quality control is divided into 3 stages [13][14][15].
Phase I: Concept Design, relating to generating ideas in product design and development activities, in which the idea is identified from the needs of consumers
Phase II: Parameter Design, to optimize the level of controlling factors to the effects caused by other factors so that the resulting product can be robust to noise. Therefore, parameter design is often referred to as Robust Design
Stage III: Tolerance Design, is the last step by making orthogonal matrix, loss function, and Analysis of Variance (ANOVA) to balance cost and quality of product.

2.2.2 On-Line Quality control
On-line quality control is QC activities to observe and control the quality in every production process.

2.3 Experimental design
The experimental design is a design of any task that aims to describe or explain the variation of information under conditions that are hypothesized to reflect the variation. Each step/action of the experiment is completely defined so that related or required information for the issue studied can be collected [16]. Two experimental designs are known, namely the conventional experimental design and the Taguchi experimental design. The Taguchi method was first introduced by Dr. Genichi Taguchi. The purpose of the Taguchi experiment is to design how to minimize the deviation of quality characteristics from its target value. In the Taguchi method, a matrix (called orthogonal array) is used to determine the minimum number of experiments that can provide as much information as possible of
all factors affecting the parameters. The most important step of using orthogonal array lies in the selection of the level combinations of the input variables for each experiment [14]. Taguchi’s philosophy of quality consists of three concepts [13][17][18]:

1. Quality should be designed into the product and not just check it. The best quality is achieved by minimizing the deviation from the target.
2. The product must be designed so that it is robust against environmental factors that cannot be controlled.
3. The cost of quality should be measured as a deviation function of a certain standard and losses must be measured across the entire system.

Based on the data responses, Taguchi can be divided into two, namely Taguchi single response and Taguchi multi response. Taguchi single response has only one response variable so the result can be directly obtained optimal combination of the response variable. Taguchi multi responses has more than one response variables (at least two response variables), and if each response variable has different factor levels combination then multi attributes decision making process is required to obtain an optimal combination of factors to improve the quality of each response variable. One of methods that can be used to solve multi-response Taguchi problems is MRSN (Multi Response Signal to Noise) method [19]. The steps of using Multi Response Signal to Noise Ratio (MRSN) are as follows [20]:

1. Calculate quality loss (Lij) for each trial. For quality characteristics:

   \[ L_{ij} = k \frac{1}{n_i} \sum_{k=1}^{n_i} \frac{1}{y_{ijk}^2} \quad \text{Bigger the better} \]

   \[ L_{ij} = k \frac{1}{n_i} \sum_{k=1}^{n_i} (y_{ijk} - m)^2 \quad \text{Nominal the best} \]

   \[ L_{ij} = k \frac{1}{n_i} \sum_{k=1}^{n_i} y_{ijk}^2 \quad \text{Smaller the best} \]

   Where: \( Y_{ijk} \) = data for i-th response, j-th trial, k-replication; \( m \) = target value

   \( n_i \) = replication for the i-th response; \( k \) = coefficient of quality loss

   \( Lij \) = loss function for the i-th response in the j-th trial.

2. Determine Multi Response Signal to Noise Ratio (MRSN).

   a. Specifies the maximum quality loss for each response.

   \[ L_i^* = \max \{ L_{i1}, L_{i2}, ..., L_{ij} \} \]

   b. Normalize quality loss (Cij) per experiment.

   \[ C_{ij} = \frac{L_{ij}}{L_i^*} \]

   c. Calculate the total normalized quality loss (TNQL) per experiment:

   \[ TNQL_i = \sum_{i=1}^{m} w_i C_{ij} \]

   Where: \( w_i \) = the weight of the normalization of the i-th response

   d. Calculates the MRSN ratio of each experiment.

   \[ MRSN_j = -10\log(TNQL_j) \]

3. Determine the optimal combination of factor levels based on the largest MRSN value.

### 3. Research methods

The research was conducted on a factory that produced pellet. In general, this study was aimed to find out the factors that significantly affected the quality of pellets and the combination of factor levels that would produce the best quality pellets. Two response variables are selected: (1) the pellet reliability level measured by pellet durability index and (2) the pellet resistance measured by its moisture content. A good quality pellet is shown by the higher pellet durability index and water content of 10%.
4. Results and discussion

4.1 Experimental Planning

Some steps of the experimental planning phase include [5]:

1. Selection of product quality characteristics
   This stage is to determine the product quality characteristics and the objective function optimized. In this study, the dependent variable is the pellet durability index (% PDI) with the larger the better (LTB) objective function and the pellet resistance measured by its water content, with the nominal-the-better (NTB) objective function.

2. Identification and selection of factors that may affect the quality of the resulting product. Factors involved in this experiment are vapor pressure, conditioner temperature, pellet diameter, cooler temperature, processing time in the cooler, roller spacing, mixing time, and labor age. The factor level used and the reasons for choosing the level are as follows [1]:
   a. Vapor pressure: 1.6 bars and 1.9 bars. The levels are selected because if the vapor pressures are less than 1.6 bars then the output is the water not the steam that can cause the engine jam and pellet easily crumbled and moldy. If the vapor pressure is higher than 1.9 bars then the steam will be too hot. It causes the pellet too dry so that it will be easily destroyed.
   b. Conditioner temperature: 80 ° C and 85 ° C, the level is selected because if the conditioner temperature is lower than 80 ° C, the pellet will not be ripe so that the pellet will be easily crumbled and moldy. If the conditioner temperature is higher than 85 ° C, the protein will be broken and the pellet will be easily destroyed.
   c. Pellet mold diameter: 3.5 mm and 4 mm, the levels are selected because if the diameter of pellet mold is less that 3.5 mm then the shape of pellet will be too small and it will not fit to the standard. If diameter is bigger than 4 mm then pellet will be easily destroyed because of too many the air cavities inside.
   d. Cooler temperature: 30 ° C and 35 ° C. The levels are selected because if the cooler temperature lower than 30 ° C then the pellet will be easily destroyed when split using a roller and if it is higher than 35 ° C then the pellet feed will be too hot so that it cannot be broken by the roller into crumble.
   e. Time in the cooler: 2 minutes and 3 minutes, the levels are selected because if the time in the cooler is longer than 2 minutes then the water content in the pellet will be too much. It will be easily moldy. If it is longer than 3 minutes then the pellet water content will be too small. It will cause the weight of the pellet become light so that the company will lose benefit.
   f. The distance between the rollers: 1.5 cm and 2 cm, The levels are selected because if the distance between rollers is less than 1.5 cm then the pellet will be shaped like a crumble (if granules) and if it is bigger than 2 cm, the pellet size well be too big/long. This cannot fit the standard and it will be easily broken.
   g. Mixing time: 180 seconds and 175 seconds, the levels are selected because if the mixing time is faster than 175 seconds, the mixing will be uneven and the pellet will be easily destroyed. If it is longer than 180 seconds the raw material will be too hot so that it can clot.
   h. Labor age: <40 years and> 40 years, the age difference of the workforce will affect the pellets produced due to different experiences and concentrations.

Based on initial evaluation, it is estimated that there is no interaction among factors.

3. Determination of Control Factor (Inner Array) and Noise Factor (Outer Array).
   Factors that allegedly affect the quality characteristics of the resulting product are divided into two factors, namely controllable factors and uncontrollable factors (noise). They can be seen in Table 1 and Table 2.
Table 1. Controllable factor

| No | Controlable Factor       | Code | Level 1   | Level 2   |
|----|--------------------------|------|-----------|-----------|
| 1  | Vapor pressure           | A    | 1.6 bar   | 1.9 bar   |
| 2  | Conditioner Temperature  | B    | 80°C      | 85°C      |
| 3  | Pellet Diameter Mold     | C    | 3.5 mm    | 4 mm      |
| 4  | Cooler Temperature       | D    | 30°C      | 35°C      |
| 5  | Cooling Duration         | E    | 2 minutes | 3 minutes |
| 6  | Distance Between Rollers | F    | 1.5 cm    | 2 cm      |
| 7  | Mixing Duration          | G    | 180 seconds | 175 seconds |

Table 2. Noise factor

| No | Noise Factor | Code | Level 1  | Level 2  |
|----|--------------|------|----------|----------|
| 1  | Labor ages   | H    | < 40 years | > 40 years |

4.2. Experiment Implementation
To identify pellet reliability and pellet resistance, this experiment uses L8 for inner arrays and L4 for outer arrays. The experiment result data are shown by Table 3 and Table 4.

4.3. Data Processing
To determine the combination of factor levels for getting the optimum pellet quality, there are some assumption tests as follows:

4.3.1 Normality Test
The normality test indicates that data (both PDI and Water content data) follow normal distribution. For PDI data, $\chi^2_{\text{calculation}}$ (5.61) is less than $\chi^2_{\text{table}}$ (7.81), and for water content data, $\chi^2_{\text{calculation}}$ (6.33) is less than $\chi^2_{\text{table}}$ (9.49). These mean that Ho is accepted.

4.3.2 Homogeneity Test
Barlett test shows that both data (PDI and water content data) are homogeneous. The tests accept Ho because $\chi^2_{\text{calculation}}$ is less than $\chi^2_{\text{table}}$. For PDI, $\chi^2_{\text{calculation}}$ (5.56) is less than $\chi^2_{\text{table}}$ (11.07) dan for water content, $\chi^2_{\text{calculation}}$ (8.18) is less than $\chi^2_{\text{table}}$ (11.07).

Table 3: Pellet Durability Index (PDI) Data

| Controlable Factor | No  | Noise Factor (H) |
|--------------------|-----|------------------|
|                    | 1   | 1                |
|                    | 2   | 2                |
|                    | 2   | 2                |

| Tria Column Number | Experiment Result Data | Experiment Result Data |
|-------------------|------------------------|------------------------|
| 1                 | 88.4                   | 88.9                   |
| 2                 | 87.1                   | 87.0                   |
| 3                 | 85.4                   | 88.2                   |
| 4                 | 89.6                   | 88.7                   |
Table 3: Pellet Durability Index (PDI) Data (Cont.)

| Controlable Factor | Noise Factor (H) | Experiment Result Data | Experiment Result Data |
|--------------------|------------------|------------------------|------------------------|
|                    | A    | B    | C    | D    | E    | F    | G    | 1   | 1   | 2   | 2   |
| **Tria** | **Column Number** | **Replication** | **Replication** |
| 1          | 1 2 3 4 5 6 7   | 1 2 3 4 1 2 3 4 1 2 3 4 |
| 2          | 1 1 1 1 2 2 2 2 87.0 86.6 86.5 85.2 | 86.2 87.7 85.4 87.7 |
| 3          | 1 2 2 1 1 2 2 | 86.6 87.1 86.2 88.3 | 87.2 90.0 87.8 85.5 |
| 4          | 1 2 2 2 2 2 1 1 86.5 85.2 87.9 86.6 | 85.9 86.0 85.0 86.9 |
| 5          | 2 1 2 1 2 1 2 1 2 | 87.1 86.2 89.1 86.2 | 87.9 85.2 87.2 88.9 |
| 6          | 2 1 2 2 1 2 1 2 | 85.9 87.7 86.0 87.9 | 90.4 86.8 86.1 85.7 |
| 7          | 2 2 1 1 2 2 1 1 2 | 90.9 89.9 90.5 88.9 | 89.9 89.1 90.2 88.4 |
| 8          | 2 2 1 2 1 1 1 2 | 89.7 89.6 89.5 88.4 | 90.9 88.1 88.4 89.2 |

Table 4. Pallet water content data

| Controlable Factor | Noise Factor (H) | Experiment Result Data | Experiment Result Data |
|--------------------|------------------|------------------------|------------------------|
|                    | A    | B    | C    | D    | E    | F    | G    | 1   | 1   | 2   | 2   |
| **Tria** | **Column Number** | **Replication** | **Replication** |
| 1          | 1 2 3 4 5 6 7   | 1 2 3 4 1 2 3 4 1 2 3 4 |
| 2          | 1 1 1 1 1 1 1 1 | 9.6 9.8 10.0 9.5 | 9.7 9.8 9.8 9.6 |
| 3          | 1 1 1 1 1 1 2 2 | 10.6 9.9 10.4 10.3 | 11.0 10.0 10.2 10.4 |
| 4          | 1 2 2 1 1 2 2 | 10.0 9.7 9.5 10.0 | 9.7 9.8 9.6 9.9 |
| 5          | 1 2 2 2 2 1 1 | 10.7 10.2 10.6 11.0 | 10.8 11.0 10.9 10.6 |
| 6          | 2 1 2 1 2 1 2 1 | 10.4 10.5 10.3 10.2 | 10.2 10.4 10.0 9.4 |
| 7          | 2 1 2 2 1 2 1 2 | 10.3 9.9 10.1 10.8 | 10.4 10.6 10.6 10.4 |
| 8          | 2 1 2 2 1 2 1 2 | 9.9 10.1 9.6 9.7 | 10.0 9.5 9.8 10.0 |

4.4 Analysis of Variance (ANOVA)

ANOVA results (Table 5 and 6) indicates that the effect of factors A, B, C and D is significantly different. For reliability (PDI data), $F_{calculation}$ of factors A, B, C and D (respectively 18.30; 9.84; 20.69 and 6.64) is higher than $F_{table}$ (4.01). This means that $H_0$ for factor A, B, C and D are rejected. For resistance ($\%$ water content data), $F_{calculation}$ of pellets for factors A, D and F (respectively 4.38, 105.44 and 15.20) are bigger than $F_{table}$ (4.01). So, $H_0$ for factor A, D and F must be rejected.

4.5. Signal to Noise Ratio (SNR) Analysis and Each Factor Effects

Signal to Noise Ratio (SNR) analysis is applied to identify the effect of each factor. This analysis is done based on some significantly influential factors which are found in the previous ANOVA, namely A, B, C, and D for pellet reliability and A, D, and E for pellet resistance. For the factors that are not
significantly influential, cost consideration is used to select the level factor for the combination. Because factor E, F and G do not have significant effect, so based on cost consideration (to select that is cheaper), the level factor E1, F1, and G2 are selected. Based on ANOVA and cost consideration, the best level factor combination for pellet reliability response variable is A2, B2, C1, D1, E1, F1, and G2. With the same analysis, the best level factor combination for resistance response variable is A1, B1, C1, D1, E1, F1, and G2.

### Table 5. ANOVA table for PDI

| Factor | Df | SS   | MS   | Fcal |
|--------|----|------|------|------|
| A      | 1  | 27.0530 | 27.0530 | 18.30 |
| B      | 1  | 14.5447 | 14.5447 | 9.84  |
| C      | 1  | 30.5947 | 30.5947 | 20.69 |
| D      | 1  | 9.8204  | 9.8204  | 6.64  |
| E      | 1  | 3.1996  | 3.1996  | 3.16  |
| F      | 1  | 0.0041  | 0.0041  | 0     |
| G      | 1  | 0.3496  | 0.3496  | 0.24  |
| Residual | 56 | 81.3169 | 1.4785 |
| Total  |    | 262.5600 | 81.3169 |

### Table 6. ANOVA table for water content

| Factor | Df | SS   | MS   | Fcal |
|--------|----|------|------|------|
| A      | 1  | 0.3025 | 0.3025 | 4.38  |
| B      | 1  | 0.1806 | 0.1806 | 2.61  |
| C      | 1  | 0.1806 | 0.1806 | 2.61  |
| D      | 1  | 7.2900 | 7.2900 | 105.44|
| E      | 1  | 0.2025 | 0.2025 | 2.93  |
| F      | 1  | 1.0506 | 1.0506 | 15.20 |
| G      | 1  | 0.1406 | 0.1406 | 2.03  |
| Residual | 56 | 3.8025 | 0.0691 |
| Total  |    | 15.20 | 0.2025 |

4.6 Determination of Optimal Condition Factor Level Using MRSN

Multi Responses Signal to Noise analysis is done because the optimal combination of factor level of each response variable is different. The reliability of pellets is relatively more important than pellet resistance and the linguistic term "High" and "Medium" is chosen. The relative importance level is shown by the “linguistic term table” and then it is converted into fuzzy numbers. The score of each response variable is determined based on the crips scores of fuzzy number table. The result shows that the score of pellet reliability is 0.750 and pellet resistance is 0.583. Based on the scores, the weight of each response is calculated, they are

Pellet reliability weight (W1) = 0.750 / (0.750 + 0.583) = 0.562641

Pellet resilience weight (W2) = 0.583 / (0.750 + 0.583) = 0.437359.

The loss function (k) for each %PDI = Rp. 13,366, ·, while the loss function (k) for each % water content = Rp. 22.050, ·. The best formulation is obtained from the selection of the greatest MRSN. The best combination is A2, B1, C1, D1, E1, F1, G2. This combination is able to increase 2.132% of % PDI (from 86.794% to 88.926%). This combination also can reduce the difference to the target of water content from 0.262% to 0.028% (or 0.234%).

4.7 Sensitivity Analysis

The optimum factor levels combination was obtained on the weight of reliability attribute of 0.562641 and the weight of the pellet resistance attribute 0.437359. The analysis of attribute weight change shows that the optimum factor-level combination is sensitive to weighting changes of both responses (pellet reliability and pellet resistance). The optimum combination of factor level will change if the pellet reliability weight rises to be more than 0.77228 or decreases to be less than 0.00561. In other words, if the weight change for pellet reliability is in between 0.00561 - 0.77228, the change will not be sensitive to the original decision.

5. Conclusion

Based on the analysis above, some conclusions of this study are:

1. The optimum combination of factor levels is A2, B1, C1, D1, E1, F1, G2 or the production process is run with a vapor pressure of 1.9 bar; temperature conditioner 80 °C; 3.5mm pellet molded diameter; cooler temperature 30 °C; time in cooler 2 minutes, roller distance 1.5 cm, mixing time 175 seconds.
2. The optimum combination can increase 2.132% of % PDI (from 86.794% to 88.926%). This result can reduce the difference to the target of water content from 0.262% to 0.028% (or 0.234%).

3. The optimum factor level combination will change if the weighting for pellet reliability rises to be more than 0.77228 or decreases to be less than 0.00561, or in other words if the weighting for pellet reliability is in the range 0.00561 - 0.77228, it will not be sensitive to the original decision.

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