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VALIDATION OF THE GRADER'S ABILITY USING MEASUREMENT SYSTEM ANALYSIS

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ABSTRACT

Quality control is one of the important thing for the company in maintaining consistency of product quality. Time always becomes a technical problem that often occur in quality control process while we are measuring quality characteristics with specific device. So, it can make the analysis and decision be late because it is not in accordance with the operational needs. Upgrading or adding a number of specific devices is not a wise solution because the impact is significant increase in the cost of quality. More efficient way for the company to reduce the quality cost is to develop human resource with particular sensory sensitivity to be a Grader. On the one hand the using of human labor as Grader is a practical solution in order to reduce the cost of quality, but on the other hand would cause a problem of trust between suppliers and companies (as customers). Grader often considered subjectively in providing an assessment of the characteristics of quality for the materials supplied by the supplier. Some methods in MSA as Gage R&R and Gage Linearity and Bias Study will be applied to validate Grader's ability in assessing the quality characteristics. The results of the study showed that the gage R&R not only can validate the Grader's ability but also detect when needed improvement for the measurement system in assessing the quality characteristics.

Keywords: validation, grader, measurement system analysis, gage R and R, gage linearity, bias study.

1. INTRODUCTION

Grader has an important role as the guardian of the main gate in the quality control system. For companies, Graders can shorten the time of assessment of the quality and lower the cost of quality. However, the use of Graders may have an impact on the decline of the supplier trust to the company. Grader is often considered not to be objective in assessing the quality of goods. The decrease in the suppliers trust will affect for the long-term commitment to continue supplying material to the company (Indarjo, 2002). Grader's certification could be a solution, but not all of the Grader's skills are available to be certified. That is the basis of the importance of research to validate the Grader's ability. Wang and Drury (1989) began a study to evaluate the performance of the inspector through a series of tests on cognitive factors and performance measurements while conducting a series of inspection tasks are processed by the method of factor analysis and correlation analysis. The result of this research was the difference in the ability of each inspector in performing the inspection could be seen in more detail. In further developments, Montgomery (2009) introduced a spesific statistical test methods to measure and detect the components of the cause of error in measurement known as Measurement System Analysis (MSA). The methods in the MSA as Gage R&R and Gage Linearity and Bias Study will be used in this research to validate the Grader's ability in assessing the moisture content. Moisture content is one of the important quality characteristics in the trade of commodity products such as copra. The results will be analyzed and used as a basis for improvement of measurement systems as well as evidence of the Grader's ability in assessing the quality characteristics.

2. GAGE R&R (ANOVA METHOD)

Two-way ANOVA was used in this research because there were two factors, Grader (Inspector) as the fixed factor and the class of copra (Parts) as the random factor. Based on Tsai 's (1989) ANOVA model is shown as follows:

$$y_{ijl} = \mu + P_i + O_j + \left(PO\right)_{ij} + \varepsilon_{ijl} \qquad \begin{Bmatrix} i = 1,2,...,n \\ j = 1,2,...,p \\ l = 1,2,...,k \end{Bmatrix} \tag{1}$$

Where μ is the measurement mean, O_i is the effect of the i-th level of the Graders factor, P_j is the effect of the j-th level of the class of copra factor, $(OP)_{ij}$ is the effect of interaction between O_i and P_j, and $\mathcal{E}_{ijk}$ is the random error. ANOVA table will be obtained as follows:

Table-1. Two-factor ANOVA table.

Source of variability	Sum of square	Degrees of freedom	Mean of square	Expected mean square
Parts	SS_P	$n_p = n-1$	MS_P	$E(MS_P) = \sigma_R^2 + k\sigma_{PO}^2 + pk\sigma_P^2$
Inspector	SS_O	$n_o = p-1$	MS_O	$E(MS_O) = \sigma_R^2 + k\sigma_{PO}^2 + nk\sigma_O^2$
Parts*Inspector	SS_{PO}	$n_{po} = (n-1)(p-1)$	MS_{PO}	$E(MS_{PO}) = \sigma_R^2 + k\sigma_{PO}^2$
Error	SS_R	$n_R = np(k-1)$	MS_R	$E(MS_R) = \sigma_R^2$
Total	SS_T	$npk-1$		

3. GAGE R&R STUDY

Variability of the measurement process is written in Equation (3) and the total variance is written in Equation (2) by Montgomery (2009).

$$\sigma_{total}^2 = \sigma_{product}^2 + \sigma_{gage}^2 \quad (2)$$

$$\sigma_{gage}^2 = \sigma_{repeatability}^2 + \sigma_{reproducibility}^2 \quad (3)$$

Based on the expected mean square in Table-1, the variation can be obtained for each source of variation as follows:

$$\begin{aligned} \hat{\sigma}_R^2 &= MS_R \\ \hat{\sigma}_{PO}^2 &= \frac{(MS_{PO} - MS_R)}{k} \\ \hat{\sigma}_P^2 &= \frac{(MS_P - MS_{PO})}{pk} \\ \hat{\sigma}_O^2 &= \frac{(MS_O - MS_{PO})}{nk} \end{aligned} \quad (4)$$

So repeatability, reproducibility, and the variance of the gage can be formulated as follows:

$$\begin{aligned} \hat{\sigma}_{repeatability}^2 &= \hat{\sigma}_R^2 = MS_R \\ \hat{\sigma}_{reproducibility}^2 &= \hat{\sigma}_O^2 + \hat{\sigma}_{PO}^2 = \frac{(MS_O + (n-1)MS_{PO} - nMS_R)}{nk} \\ \hat{\sigma}_{gauge}^2 &= \hat{\sigma}_{repeatability}^2 + \hat{\sigma}_{reproducibility}^2 = \frac{(MS_O + (n-1)MS_{PO} + n(k-1)MS_R)}{nk} \end{aligned} \quad (5)$$

The value of precision to tolerate (P/T ratio) is used to see the performance of the measurement process that has been done.

$$\frac{P}{T} = \frac{6\hat{\sigma}_{gauge}}{USL - LSL} \quad (6)$$

The following are the terms that are used to draw conclusions according to The AIAG (Automotive Industry Action Group) by using percentage of variance study.

- If the percentage of total variance study gage R&R ≤ 10 %, it is considered the measurement system acceptable.
- If the percentage of total variance study gage R&R between 10% and 30%, it is still acceptable depending on the application or there are certain conditions that can be explained.
- If the percentage of total variance study gage R&R > 30% it is considered the measurement system unacceptable and must be improved.

According to Montgomery (2009), additional testing can be used to ensure whether the measurement system acceptable or not is the signal-to-noise ratio (SNR).

$$\rho_P = \frac{\sigma_P^2}{\sigma_{total}^2}$$
$$SNR = \sqrt{\frac{2\rho_P}{1-\rho_P}} \quad (8)$$

Measurement system will be accepted if the SNR is greater than 5.

4. GAGE LINEARITY AND BIAS

Linear tendency of the measurement process can be seen from the bias value. According to Joglekar (2003), bias measurement system is the difference between the reference values with the actual measurement results. Linearity measurements conducted to determine whether the results of measurements have the same accuracy for all Graders.

5. MEASUREMENT SYSTEM ANALYSIS FOR VALIDATING GRADER ABILITY

Object of this research is Graders who work in edible oil industry. Grader has the responsibility to assess the moisture content of copra as one of the critical quality characteristics. Copra was used as much as 54 copra. It consisted of 18 copra that had A class quality, 18 copra had B class quality, and 18 other copra which had C class in accordance with SNI 01-3946-1995 quality of copra.

Systematically, the stage of the research was as follows:

a) Arranged the experiment design for the sampling process.

b) Implemented the experiment.

c) Used gage R&R analysis (ANOVA) to determine the amount of variation caused by each Grader, class of copra, repeatability and reproducibility.

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d) Performed gage R and R bias and linearity analysis to determine bias from the assessment result of moisture content in different class of copra and to know the linear tendency of each Grader.

e) Used gage run chart analysis to determine the measurement stability from each Grader.

f) Concluded whether the Grader was already acceptable or not in assessing copra moisture content.

6. PRELIMINARY ANALYSIS

a. Gage R and R (Anova)

Gage R and R (ANOVA) were used to determine the variance that it was caused by each Grader, class of copra, repeatability, and reproducibility. The result can be seen in Table-2.

Table-2. Gage R and R (ANOVA) result.

Source	DF	SS	MS	F	P
kopra	2	1162.32	581.162	809.391	0.00
grader	2	5.42	2.712	3.776	0.12
kopra * grader	4	2.87	0.718	6.594	0.00
Repeatability	153	16.66	0.109		
Total	161	1187.28			

The analysis result in Table-2 indicates that the different class of copra and the interaction between the classes of copra with each Grader have significant effect in assessing moisture content. Because their p-value are smaller than the α-value (0.05). Graders' ability in assessing moisture content has been homogenous (similar). Because its p-value is greater than the α-value (0.05). Gage repeatability and reproducibility assessment of moisture content in copra can be seen in Table-3.

Table-3. Gage R&R for the result of moisture content assessment.

Source	VarComp	(% Contribution of VarComp)	StdDev (SD)	Study Var(6 * SD)	%Study Var (%SV)
Total Gage R&R	0.1797	1.64	0.42386	2.5431	12.82
Repeatability	0.1089	1	0.32999	1.98	9.98
Reproducibility	0.0708	0.65	0.266	1.596	8.05
grader	0.0369	0.34	0.19214	1.1528	5.81
grader*kopra	0.0338	0.31	0.18396	1.1037	5.56
Part-To-Part	10.749	98.36	3.27856	19.6714	99.17
Total Variation	10.9286	100	3.30585	19.8351	100
Number of Distinct Categories = 10					

The percent contribution of total variance component gage R&R in Table-3 is greater than 1%. It affects to the percent contribution variance component part to part to be 98.36. The percent study variance of total gage R&R is 12.82 %. This value is still in the range of 10%-30%, thus it can be said that the measurement system is still acceptable but there is a room for improvement.

b. Gage run chart

Gage run chart analysis was conducted to determine the stability/ consistency of moisture content assessment from each Grader on any class of copra. The results can be seen in Figure-1.

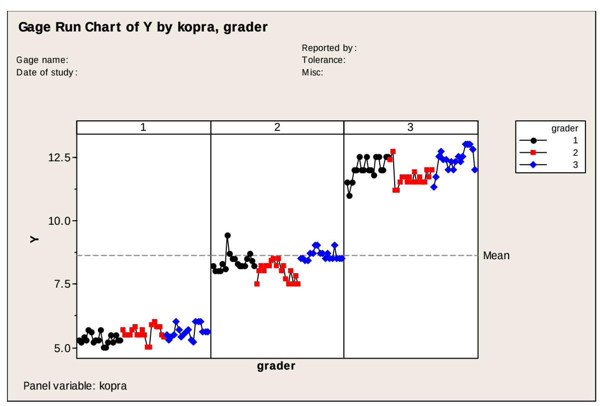

Figure-1. Gage run chart from the result of moisture content assessment.

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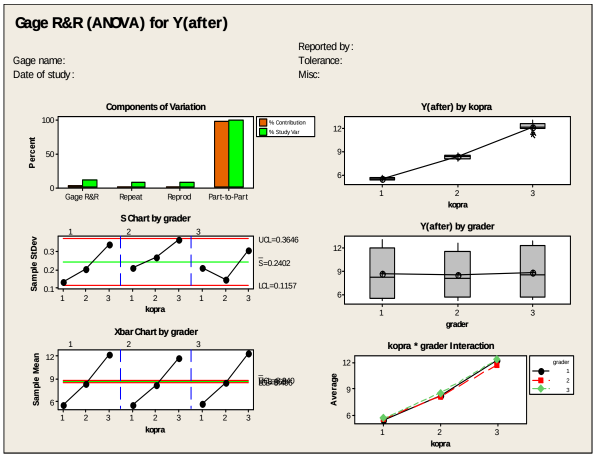

Figure-2. Gage R&R after training.

In Figure-1, can be seen the assessment consistency from each Grader on all classes of copra. For A class of copra, all of the Graders had been fairly consistent. Because the results of the assessment have a random pattern around the reference value, so that the results of the assessment is stable. It is different for B and C class of copra, the data pattern still have a high fluctuation, so that all of the Graders had not been consistent in assessing the moisture content for the B and C class of copra.

Although the moisture content measurements performed by each Grader had been acceptable, but it was still inconsistent and needed improvement. So, the Graders were given training. For training, Graders were given product samples and asked to assess the moisture content of the samples. After assessing the moisture content, Graders were asked to see the results of measurements by the moisture analyzer and analyzed the difference. This was done for three days for each Grader. It aims to increase the Graders' sensitivity and adjustments to the result of the moisture analyzer measurement. Further advanced analysis was conducted to see how effective the training method could change the Grader assessement behaviour.

7. AFTER TRAINING ANALYSIS

a. Gage R&R (Anova)

Gage R&R (ANOVA) was conducted to determine the variance caused by each Grader, class of copra, repeatability and reproducibility. The result can be seen in Table-4.

Table-4. Gage R&R (ANOVA) result.

Source	VarComp	(% Contribution of VarComp)	StdDev (SD)	Study Var(6 * SD)	%Study Var (%SV)
Total Gage R&R	0.1093	0.98	0.33062	1.9837	9.89
Repeatability	0.0636	0.57	0.25217	1.513	7.54
Reproducibility	0.0457	0.41	0.21383	1.283	6.4
grader	0.0222	0.2	0.14912	0.8947	4.46
grader*kopra	0.0235	0.21	0.15326	0.9195	4.58
Part-To-Part	11.0642	99.02	3.32629	19.9577	99.51
Total Variation	11.1735	100	3.34268	20.0561	100
Number of Distinct Categories = 14					

The percent contribution total variance component gage R&R in Table-4 is less than 1% that cause percent contribution variance component part to part to be 99.02. The percent study variance of total gage R&R is 9.89%. It is smaller than 10%, and the number of distinct categories is 14. This value is far greater than 5. Thus, it can be concluded that the measurement system has been acceptable. Graders have been already capable and consistent to assess the moisture content for each class of copra.

Visually, the variation can be seen in Figure-2 as follows:

In Figure-2, the Y (after) plot for all of the Graders shows that they could assess the moisture content well because the variance from all of the Graders were similar.

b. Gage linearity and bias

Gage linearity and bias analysis was conducted to determine bias from the result of moisture content assessment in different class of copra and to know the linear tendency of each Grader. Because the moisture content assessment carried out at three different times and had different reference value, then the gage linearity and bias analysis carried out respectively in accordance with the time of measurement. The analysis results can be seen in Figure-3.

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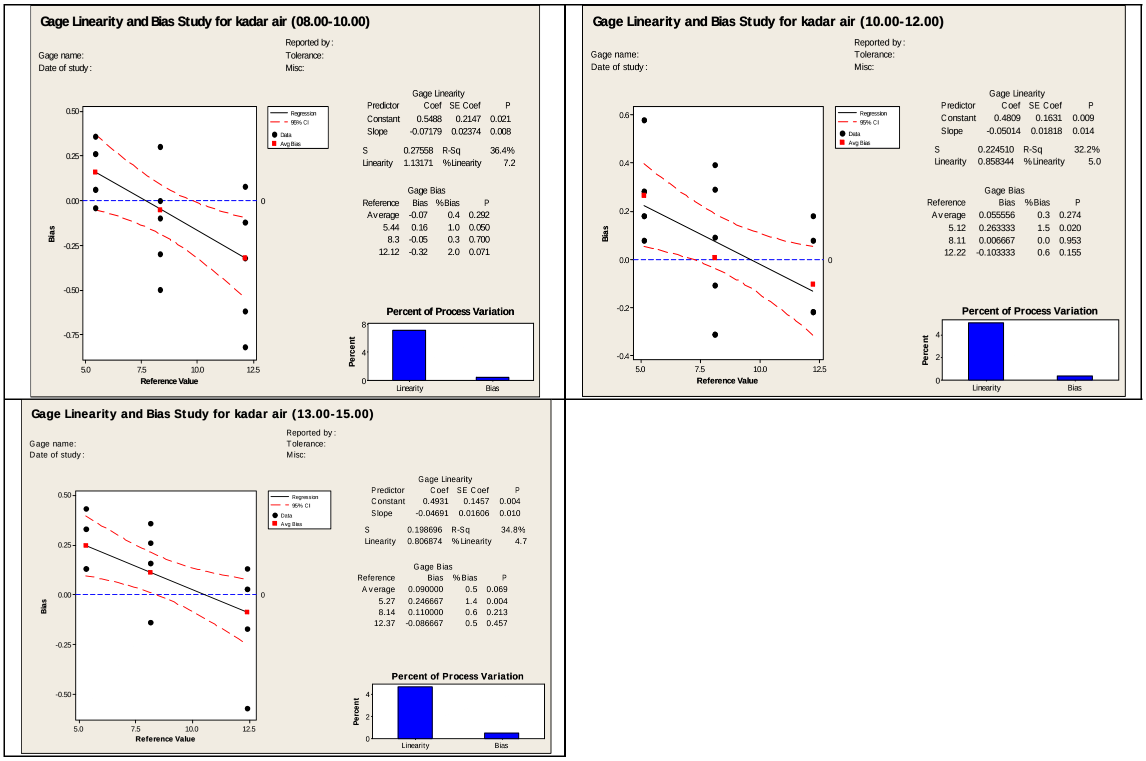

Figure-3. Gage linearity and bias.

To see whether there is bias measurement of moisture content of each class of copra with a specified reference value, it can be done hypothesis testing as follows:

H_0: $\mu = \Theta$ (there is no bias between the measurement results with the reference value)

H_1: $\mu \neq \Theta$ (there is bias between the measurement results with the reference value)

Based on Figure-3, the measurement at 08:00 to 10:00, 10:01 to 12:00, and 13:00 to 15:00 have p-value sequence as follows 0.292, 0,274, and 0.069. All of the p-values are greater than the α-value (0.05), which means that H_0 is accepted. So, it can be concluded that there is no significant bias (with the 0.5% error rate) between the assessment results with the reference value set on each class of copra in all of the experiment times.

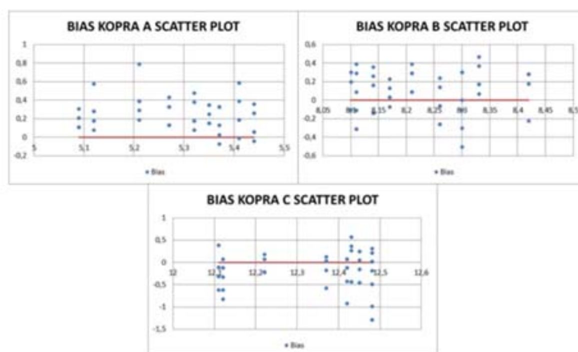

Figure-4. Scatter plot between reference value and bias value for any class of copra.

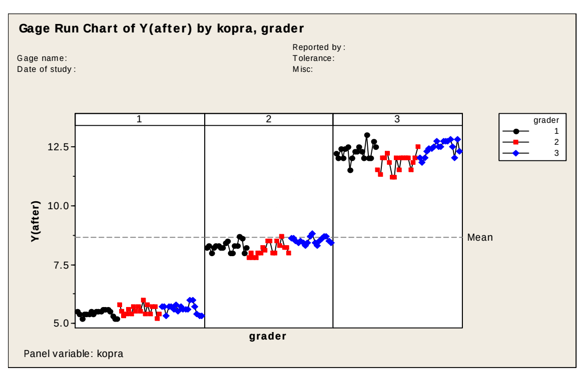

Figure-5. Gage run chart from the result of moisture content assessment.

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Furthermore, the linearity tendency of each Grader can be analyzed from a plot between the reference value with the bias value. Of the three times of assessment, the results of the A class copra bias tend to be a lot of positive bias (above the '0' line), which means that every Grader tends to be overestimated in determining moisture content. Another case in C class copra, the results tend to be a lot of negative bias (below the '0' line), which means that every Grader tends to be underestimated in determining the moisture content. So, it can be concluded that the greater reference value affect every Grader tends to make estimates below the reference value. This is caused the slope value on the regression equation for the third time measurement has a negative value. The detail can be seen in Figure-4.

c. Gage run chart

Gage run chart analysis was conducted to determine the assessments stability/ consistency of moisture content from each Grader on any class of copra, the results can be seen in Figure-5. It can be seen in Figure 5 that the assessments consistency of each Grader on any class of copra after training is more consistent and stable than the previous situation. For A and B class copra, all of the Graders are consistent. It is seen from the result of assessment have a random pattern around the reference value, so that the measurement has stable.

8. CONCLUSIONS

The conclusions from this research are:

a) Measurement system analysis methods as Gage R&R and Gage linearity and bias are suitable to validate the assessment of quality characteristic by Graders.

b) The results of the preliminary gage R&R study shows that different class of copra and the interaction between the class of copra with each Grader has a significant effect in assessing the moisture content.

c) The training has effect in increasing the Grader's ability in assessing moisture content. This is evidenced by the decrease in the percentage of variance study from 12.82% to 9.89%.

d) Gage linearity and bias showed that the fatigue factor does not affect the Grader's ability in assessing the moisture content. So, it proved from the experiments that conducted at 08:00 to 10:00, 10:01 to 12:00, and 13:00 to 15:00 have the same results. There is no bias between the assessment results with the reference value. So, the Graders have a good reliability.

e) Qualities of copra have effect for Graders in assessing the moisture content. Graders tend to be overestimated in assessing the A class quality of copra and Graders tend to be underestimated in assessing C class quality of copra. So, this is the reason why the equation of regression in Gage linearity and bias has a negative slope value.

f) Through gage run chart is known that all of the Graders' consistency became better after the training.

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