UNIVERSITI PUTRA MALAYSIA

OUTLIERS IDENTIFICATION AND ROBUST ESTIMATION METHOD IN ANALYSIS OF CROSSED GAGE REPEATABILITY AND REPRODUCIBILITY, RANDOM EFFECT MODEL

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By

AHMAD AZIZI BIN SAUPI

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Master of Science

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DEDICATION

To family & friends

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

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Chair : Prof. Habshah binti Midi, PhD
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Measurement system analysis (MSA) is a rigorous assessment of measurement systems that is crucial in a manufacturing process. Under MSA, measurement accuracy and precision are observed. Measurement accuracy comprises of biasness and linearity of a gage while measurement precision focus on two types of variations which are part to part variation and gage variation. Part variation is the variability due to different items or units being measured while gage variation is due to measurement systems that consists of repeatability and reproducibility (R&R). This thesis will focus on crossed Gage R&R, random effect model. Repeatability is the variation in the measurement system which is due to measurement device while reproducibility is the variation in the measurement system which is caused by differences between operators who record the measurements. The Gage R&R study employs Analysis of Variance (ANOVA) technique to analyse the variation associated with each component, subsequently further analysis is done to determine whether or not measurement system precision can be acceptable.

Nonetheless, many are not aware that outliers have an adverse effect on the measurement system accuracy and precision. Hence, the effect of outliers on the measurement system analysis, crossed Gage R&R random effect model is analysed. The results clearly show that the measurement system accuracy and precision are badly affected by outliers which provide misleading results to the Gage R&R analysis and estimation. Therefore, the existence of outliers must be identified and rectified to provide an accurate analysis of Gage R&R.

The classical standardized residual (CSR) is the widely used method to identify outliers in the analysis of variance model. However, this method is not very

successful in detecting outliers since the CSR is based on sample mean in its computation of residuals and mean squares errors. Hence, robust standardized residual (RSR) is formulated by incorporating median in the calculation of residuals and mean squares errors. The findings show that the RSR is very successful in identifying outliers with no masking effect and smaller rate of swamping.

This thesis also addresses the problems of parameters estimation in the crossed Gage R&R, random effect model when outliers are present in a data set. The classical analysis of variance (ANOVA) method is the commonly used method to estimate the parameters of the model. The shortcoming of using the classical ANOVA is that the computation of each source of variation is based on sample mean which is easily affected by outliers. In order to give an accurate and efficient estimation, the effect of outliers should be reduced. Thus, an improvised ANOVA is developed by incorporating a weighting scheme such that outlying observations will be assigned a weight less than 1 while good observations are set a value equal to 1. The results of the study signify that the improvised ANOVA is more efficient than the classical ANOVA.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia
sebagai memenuhi keperluan untuk ijazah Master Sains

KAEDAH PENGESANAN TITIK TERPENCIL DAN ANGGARAN TEGUH DALAM ANALISIS TERSILANG KEBOLEHULANGAN DAN KEBOLEHASILAN TOLOK, MODEL KESAN RAWAK

Oleh

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Analisis sistem ukuran (MSA) merupakan penilaian yang penting terhadap sistem ukuran dalam proses pembuatan. Ketepatan dan kejituan ukuran diberikan pemerhatian dalam analisis sistem ukuran. Ketepatan ukuran terdiri daripada kepincangan dan kelinearan tolok manakala kejituan ukuran memberikan penekanan kepada dua variasi yang terdiri daripada variasi bahagian yang diukur dan variasi tolok. Variasi bahagian adalah variasi yang disebabkan pelbagai item atau unit yang diukur manakala variasi yang disebabkan tolok terdiri daripada kebolehulangan dan kebolehasilan (R&R). Tesis ini akan memberi fokus kepada rekabentuk tersilang kebolehulangan dan kebolehasilan tolok bagi model kesan rawak. Kebolehulangan merupakan variasi dalam sistem pengukuran yang berpunca daripada pengukuran tolok manakala kebolehasilan adalah variasi dalam sistem pengukuran yang disebabkan oleh pengendali yang berbeza yang merekod ukuran. Kajian tolok R&R menggunakan teknik analisis varians (ANOVA) bagi menganalisis varians yang sepadan dengan setiap komponen, seterusnya analisis lanjut dilakukan bagi menentukan sama ada kejituan sistem pengukuran boleh diterima atau tidak. Walaubagaimanapun, ramai tidak menyedari bahawa titik terpencil mempunyai kesan buruk terhadap ketepatan dan kejituan sistem ukuran. Oleh itu, kesan titik terpencil terhadap analisis sistem ukuran bagi rekabentuk tersilang kebolehulangan dan kebolehasilan tolok bagi model kesan rawak telah dianalisis. Hasil analisis menunjukkan bahawa ketepatan dan kejituan sistem ukuran sangat terpengaruh oleh titik terpencil, memberikan keputusan yang mengelirukan terhadap penganggaran dan penganalisisan kebolehulangan dan kebolehasilan tolok. Oleh itu, kewujudan titik terpencil mestilah dikenalpasti dan dibetulkan untuk menghasilkan analisis yang tepat.

Reja piawai klasik (CSR) merupakan kaedah yang selalu diguna pakai untuk mengenalpasti titik terpencil dalam model analisis varians. Walaubagaimanapun, kaedah ini gagal untuk mengesan titik terpencil kerana menggunakan min dalam pengiraan reja dan min kuasa dua ralat. Oleh itu, reja piawai teguh (RSR) diformulasikan dengan melibatkan median dalam pengiraan reja dan min kuasa dua ralat. Hasil menunjukkan bahawa RSR berjaya mengenal pasti titik terpencil tanpa kesan litupan dengan kadar limpahan yang kecil.

Tesis ini juga mengetengahkan masalah anggaran parameter dalam rekabentuk tersilang tolok R&R, model kesan rawak apabila terdapat titik terpencil dalam set data. Kaedah analisis varians klasik (ANOVA) sering digunakan bagi menganggar parameter model. Kelemahan menggunakan ANOVA klasik ialah pengiraan setiap punca variasi berdasarkan min sampel mudah dipengaruhi oleh titik terpencil. Untuk memastikan ketepatan dan keberkesanan anggaran, kesan titik terpencil haruslah dikurangkan. Maka, penambahbaikan ANOVA dibangunkan dengan melibatkan skema pemberat dengan memberikan pemberat kurang daripada nilai 1 kepada titik terpencil manakala cerapan yang baik akan diberikan pemberat bersamaan 1. Dapatan kajian membuktikan bahawa penambahbaikan ANOVA lebih berkesan daripada ANOVA klasik.

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

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LIST OF ABBREVIATIONS

ANOVA	Analysis of Variance
CSR	Classical Standardized Residual
CUSUM	Cumulative Sum Control Chart
EWMA	Exponentially Weighted Moving Average Chart
GAGE R&R	Gage Repeatability and Reproducibility
LCL	Lower Control Limit
MSA	Measurement System Analysis
RSR	Robust Standardized Residual
SPC	Statistical Process Control
SQC	Statistical Quality Control
UCL	Upper Control Limit

CHAPTER 1

INTRODUCTION

1.1 Background of the Study

Quality brings a different perspective to many people due to its universal value. Product that has high quality is affiliated as efficient and safe to be used. Montgomery (2009) defined quality as a product that fit to be used meanwhile Judi et al. (2011) stated that the definition of quality as a product manufactured without defects. Hence, a product must be controlled in terms of its quality to ensure that customer's needs can be fulfilled. Nonetheless, the variability that exists during the process prevents the process to produce a product that follows the specification. This can be emphasized on the definition from Montgomery (2009) that quality is inversely proportional to the variability. As a result, various statistical techniques of quality are being applied to ensure the manufacturing process provides the highest quality without producing defects at the end of the process. Motorola is the company that is responsible in establishing Six Sigma to respond on maintaining their quality and product performance. Six Sigma is considered as a statistical approach to control the defects reduction and variation, and process improvement that implies several statistical principals under the implementation (Snee, 2004). It is proven from the implementation that the company has significantly reduced defects on semiconductors and devices at 94% in the year 1987-1993 (Montgomery and Woodall, 2008). Their successful establishment has influenced another giant company such as Giant electric, American Express, Boeing, and Toshiba to participate in the implementations of Six Sigma towards producing products with low cost (Snee, 2004; Kwak and Anbari, 2006).

Product is claimed as good if there is no or less variability in the process. Nonetheless, to deliver a product without variation is impossible, need proper and adequate equipment and operators. In order to produce high-quality products, it must experience stable operating performance that can be achieved if there is no assignable cause. Assignable cause is defined as variability that is not a part of the process which is due to some certain reasons such as improperly handling machines, operator's errors and defective raw materials that affects the process performance (Montgomery, 2009; Srinivasu et al., 2011). Assignable cause must be eliminated throughout the process so that a stable process of quality improvement can be attained. Hence, a statistical technique namely Statistical Process Control (SPC) was introduced to identify any opportunity of having good process performance and as a tool to separate the effect of the assignable cause (Pzydek and Kellar, 2014). SPC is known as a powerful mechanism to ensure the process operates following the standard. In addition, two statistical properties observed are mean and variance. To ensure process is operating at optimum performance, the variance should be minimum meanwhile

the mean and target value should not be large whereby it should be closer to the actual value. Measurement system analysis and Gage R&R is the important method under SPC to analyse and ensure the product variability is not adversely large.

The successful implementation of Six Sigma is determined by the efficiency of five different components of problem-solving which are Define, Measure, Analyse, Improve and Control (DMAIC) (Pan, 2006; Montgomery, 2009). DMAIC is used for improving the existing process in terms of process variability (Snee, 2004). Amongst the five different steps, measurement phase is considered as the crucial part as it relates all the measurement activity that are important in quality system improvement. Due to their importance, the measurement itself must to be controlled in terms of effectiveness, precision, and accuracy from the actual value. It is because good quality of a product only can be achieved if proper and adequate measurement system involved in obtaining measurement (Pan, 2006). However, product with large variability is related to the measurement system inaccuracy. Measurement System Analysis (MSA) is required to assess all equipment and procedures regarding obtaining measurement to ensure that the data for product and process analysis is reliable for quality improvement (Cagnazzo et al., 2010). In addition, MSA is an important part of Six Sigma because 50% of the measurement system used to obtain measurement is substantial for quality improvement (Snee, 2004).

1.1.1 Measurement System Analysis

Automotive Industry Action Group (2010) defined measurement as a process of assigning numbers meanwhile value assigned is denoted as a measurement value. The measurement system is illustrated as the assortment of device, gage, standard, operation, and unit of measurement that is responsible to get the measurement on the parts. The measurement system is to deliver their function of producing output (Automotive Industry Action Group, 2010; Dhawale and Raut, 2013). Gage is the device or any equipment that is used to obtain the measurement. Under measurement, good measurement is judged as good when the observed measurement is closed to the actual values, whereby a good indicator to examine the efficiency of the measuring system (Montgomery, 2009). Nevertheless, the idea of getting quality measurement is always denied due to some measurement errors that was produced by several mistakes and measurement uncertainty (Pearn and Liao, 2007). Unfortunately, low-quality data is always due to the much variation existed in the data (Automotive Industry Action Group, 2010). Their presence will be subjected to SPC to be resolved (Senvar and Firat, 2010).

Quality control and improvement rely heavily on reliable data and therefore, Measurement System Analysis (MSA) is rigorous and significant to the analysis of quality of measurement in terms of information provided at the end of the phase. MSA is a basic requirement for the measurement taken and is reliable for the analysis based on SPC (Cagnazzo et al., 2010). Nonetheless, it is hard to

obtain a good measurement because the error and variability might arise despite well establish and standard procedure being followed (Senvar and Firat, 2010). Thus, MSA is being employed to manage the variability in order to keep them always within an acceptable range. Therefore, the observed variability under the measurement system is due to the part variation and measurement system itself (Burdick et al., 2003; Senvar and Firat, 2010). Part variation is the variability due to the item that are being measured (Montgomery, 2009). Therefore, the decomposition of several sources of variation using statistical methodology is aimed to see which variation contributed the most toward the measurement system (Larsen, 2003; Automotive Industry Action Group, 2010).

MSA study is to assess whether the measurement system is capable or not for further use in industrial and manufacturing. In accordance with the measurement phase in Six Sigma, all the activities regarding the measurement are conducted thoroughly as their potential to influence the quality improvement (Pan, 2006). Hence, their adequacy is checked following the quality standard, using Gage R&R technique to evaluate the adequacy of the measurement system according to some specific acceptance criteria. Measurement system adequacy is addressed through their accuracy and precision because it has responsibility in producing good and reliable data. Measurement accuracy referred to their measurement bias and linearity meanwhile measurement precision refers to gage repeatability and reproducibility (Majeske, 2012; Dhawale and Raut, 2013; Ha et al., 2017). Bias is referred as the difference of observed and true value meanwhile linearity is the change in bias over the normal operation range (Automotive Industry Action Group, 2010). If the measurement system demonstrated inadequacy, hence it needs some remedial measures such as a series of training on handling the types of equipment and machines.

1.1.2 Gage Repeatability and Reproducibility (R&R)

Gage Repeatability and Reproducibility (R&R) random effect model is an adequate technique to decide whether or not a measurement system is good for a process performance through assessing some specific criteria under measurement system acceptance (De Mast and Trip, 2005; Zanobini et al., 2016). According to Gurka et al. (2012), random effect model is defined by factors under Gage R&R, which is operators and parts are drawn from larger population. Two main variations were observed under Gage R&R variation; repeatability and reproducibility. Repeatability carries the meaning of capabilities of measuring equipment to provide constant observation of the sample. Meanwhile, reproducibility can be referred to as different operator measurements using different measuring equipment on the same sample (Tsai, 1988; Reilly, 2007; Automotive Industry Action Group, 2010).

The Analysis of Variance (ANOVA) approach is a statistical method being used to complete the analysis of Gage R&R to determine the source of variability in measurement system analysis (Montgomery, 2009). The variation due to repeatability and reproducibility is assessed through their variance estimation.

Another common method of estimating of repeatability and reproducibility is based on sample range to obtain the standard deviation (Burdick et al., 2003). However, ANOVA surpassed to range method, control chart, and other methods due to their good estimation of measurement capability (Burdick et al., 2003; Healy and Wallace, 2011).

1.2 Problem Statement and Purpose

The ANOVA technique that deploys experimental design has been widely applied in all applications related to measurement systems especially in validating the capability of the measurement system. Bhar et al. (2008) believed that the biggest fear of data being collected is their possibility of producing errors. The errors are usually due to bad observations known as outliers. An outlier is described as any of the observations that is inconsistent with the rest of the data (Bhar et al., 2008). Outliers are biased to the data being collected and responsible for providing inaccurate estimation (Iglewicz and Hoaglin, 1993). To add, ANOVA is one of the estimation techniques that are highly sensitive to outliers, and handling them is needed. Moreover, outliers affect the ANOVA through the value of the F-test and mean square as the ANOVA is not immune to bad observation since their estimates are based on sample mean (Iglewicz and Hoaglin, 1993). As such, outliers must be detected because their existence provides misleading and wrong conclusions if their presence are not being taken care of (Bhar et al., 2013).

Unfortunately, many are not aware of the adverse effects of outliers on the analysis of Gage R&R study. They simply employ ANOVA to analyse the gage variations without taking into consideration the presence of outliers. Consequently, such analysis will be affected, thus the prediction and parameters estimation of the Gage R&R is inaccurate. Moreover, outliers have an adverse effect on the capability study and the quality enhancement also can be affected.

Therefore, a robust method which is less affected by outliers should be used. Before proceeding with the robust estimation technique, we first need to develop a method that able to correctly identify outlier in the crossed Gage R&R. The methods for outlier detection seems dynamically developed in robust regression. To the best of our knowledge, no research has been done for outlier detection and robust estimation in crossed Gage R&R study for the random effect model. Thus, the gap in the literature has motivated us to explore and propose an outlier identification method and robust estimation method in crossed Gage R&R random effect model. Nonetheless, in order to obtain a reliable estimation in the presence of outlier, robust estimation is being considered. Robust estimation attempts to reduce the effect of outliers in the data by down weight their effects (Wilcox, 2011). Hence, a robust ANOVA is needed to estimate the parameters of crossed Gage R&R study for the random effect model.

1.3 Research Objectives

The main aim of this research is firstly to investigate the effect of outliers for the crossed Gage R&R, random effect model. It is known that the analysis of the Gage R&R study in ANOVA is based on the classical estimator. This method is widely used in most applications without proper investigation of the existence of outliers in the data set. Hence, the objectives can be outlined as follows:

1. To analyse the effect of outliers on the measurement system analysis, crossed Gage R&R random effect model

2. To formulate diagnostic method of outlier detection for crossed Gage R&R random effect model

3. To develop a robust estimation method for the analysis of crossed Gage R&R random effect model.

1.4 Significance of the Study

Most sectors such as agriculture, health, manufacturing and industries adopt measurement system to ensure that the initiatives of quality enhancement of certain product and services become more efficient. By practicing the MSA help them to produce a product that meets customer's demand with more profits. In the absence of outliers, some process experienced an efficient operation that can reduce errors in measurement. When outliers are successfully identified using robust method, in returns it can help manufacturers to reduce the wastage, scrapped work, and time consumption. It is evident that outliers are responsible for an inefficient estimate if using classical statistical methods (Zhou and Zhu, 2003). As such, it is difficult for the manufacturers to deliver good products to satisfy customer's demand. This research focus on the use of robust statistical method which is expected to give good results even when outliers are present in the data. When outliers are properly taken care by using robust methods, the result and analysis will be more reliable. Hence, production cost, rework and scrapped work is expected to reduce and yet provide good product that could gain profit as much as possible (Subbulakshmi et al., 2017).

1.5 Scope and Limitation of the Study

To the best of our knowledge, no research has been done on the investigation of the effect of outliers on the crossed Gage R&R for random effect model. Moreover, no work has been done on the method of identification of outliers in the measurement system crossed Gage R&R for the random effect model. Hence, this motivated us to fill up the gap in the literature.

The measurement system is a popular method to analyse the variation that is due to measurement error in the measurement, since the possibilities of error being made is high in the data set. Through the technique of Gage R&R that is associated with factorial design, this method indicates that measurement can be acceptable or not for broad application through the analysis of repeatability and reproducibility, and part variation. Moreover, the ANOVA method can determine the sources of variation and identifies which source that contribute the most in the analysis.

Nonetheless, the presence of outliers might affect the performance of the gage analysis and this may give misleading conclusion. Since gage study is a method that is widely used in agriculture, manufacturing, and health, it is important to address the problem when outliers are present in the data set. The gage study considers operator and parts effects. This thesis will only provide the replication, k = 4. Practically, 4 is the maximum number of samples per replication as increasing more replication will increase the cost. However, the result is expected to be consistent.

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