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Evaluating measurement and process capabilities by GR&R with four quality measures

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ABSTRACT

This paper proposes a procedure for assessing a measurement system and manufacturing process capabilities using Gage Repeatability and Reproducibility (GR&R) designed experiments with four quality measures. In this procedure, a GR&R study is conducted to obtain replicate measurements on units by several different operators. The gage and part variance components are then estimated by conducting analysis of variance (ANOVA) on the GR&R measurement observations. Finally, the acceptance and rejection criteria of the precision-to-tolerance ratio (*PTR*), signal-to-noise ratio (*SNR*), discrimination ratio (*DR*), and process capability index (C_p or C_{pk}), are employed to assess the measurement and process capabilities. Three previously studied case studies are provided for illustration; in all of which the procedure provided efficient capability assessments at minimal computational and statistical efforts. In conclusion, the procedure proposed in this research using GR&R designed experiments provides valuable procedure and helpful guidelines to quality and production managers in assessing the capabilities of a measurement system and manufacturing process, and deciding the needed actions for improving performance.

1. Introduction

Quality management efforts are often directed for zero defect production by reduction of variability. If a product is found nonconforming, it is usually claimed that the variability is attributed by process and thus improvement actions are implemented to enhance process capability. Unfortunately, such efforts may not necessarily result in improved process capability, because it is possible that the process is already capable enough, but there is no way of proving this due to inadequate measurement system. In addition, it may happen that the measurement system is already capable enough; however the measurement error is still unacceptable when compared to process variability. Therefore, investigating both the variabilities of a measurement system and a manufacturing process is necessary before taking future improvement actions. Practically, a measurement system does not always produce the exact dimension of the part, but it gives measurements that are deviated from the true value by some error. In any activity involving measurements, some of the observed variability will be due to variability in the product itself, σ_p^2, whereas the rest will be due to the measurement error or gage variability, σ_g^2. The variance of the total observed measurements can be expressed as [1]

$$\sigma_{\text{Total}}^2 = \sigma_p^2 + \sigma_g^2 \qquad (1)$$

In many measurement system analysis studies, the gage is usually used to obtain replicate measurements on units by several different operators. Hence, two components of σ_g^2 are frequently generated, including the repeatability and reproducibility. Repeatability, $\sigma_{\text{Repeatability}}^2$, represents the variation due to the gage itself when one operator uses the same gage to measure an identical quality characteristic of the same unit. Whereas, reproducibility, $\sigma_{\text{Reproducibility}}^2$, reflects the variation caused by different operators using

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the same gage to measure identical quality characteristic of the same unit. That is, the gage variance could be expressed as

$$\sigma_g^2 = \sigma^2_{\text{Reproducibility}} + \sigma^2_{\text{Repeatability}} \quad (2)$$

The study used to measure the components of σ_g^2 is usually called a Gage Repeatability and Reproducibility (GR&R) study, which aims at determining whether the variability of the measurement system is small relative to the variability of the monitored process. The GR&R studies have been widely conducted to assess the measurement systems in several industrial applications; such as an injected molded plastic part [2], thermal impedance on a power module for an induction motor starter [3], and paddle dissolution test of a pharmaceutical industry [4]. Further, the two-way random effects analysis of variance (ANOVA) model [5–7] is commonly used to analyze the GR&R study and estimate these variability components. Consequently, this research adopts the GR&R designed experiments followed by ANOVA to estimate variance components.

Evaluating a measurement system and manufacturing process capabilities is an important aspect of many quality and process improvement activities. The evaluation of the capability of a measurement is usually achieved by the use of appropriate quality measures, including the precision-to-tolerance ratio (*PTR*), signal-to-noise (*SNR*), and discrimination ratio (*DR*). On the other hand, the process capability is usually assessed using potential and actual process capability indices, C_p and C_{pk}, respectively. Several studies were conducted to evaluate measurement and process capabilities. Among them, Lin et al. [8] used Taguchi method to reduce the measurement variability, verified the improvement by conducting a GR&R study, and employed a process capability analysis to show the reduction effect on the product variability. Bordignon and Scagliarini [9] considered the problem of measurement error effects on the performance of process capability indices and presented the statistical analysis on the estimation of confidence intervals for C_p with data contaminated with measurement errors. Majeske et al. [10] utilized the *PTR*, C_p, and correlation in repeat measurements for evaluating measurement system and manufacturing processes between manufacturers and suppliers. Larsen [11] analyzed the measurement system in a production environment using GR&R study with confidence intervals and various test parameters, such as *PTR*, *SNR*, and C_{pk}. Hsu et al. [12] conducted a sensitivity analysis for the process capability index C_{pmk} in the presence of measurement error by considering a method for obtaining lower confidence bounds and critical values for the true process capability. Li and Al-Refaie [13] conducted two GR&R studies to improve wooden parts quality through enhancing the measurement system capability. The *PTR* and *SNR* were employed to assess the adequacy of measurement system.

Based on the above introduction, this paper proposes a procedure for assessing both the capabilities of a measurement system and manufacturing process utilizing GR&R designed experiments with four quality measures; including *PTR*, *SNR*, *DR*, and C_p or C_{pk}. ANOVA will be employed to estimate variance components. The quality measures will be then used to evaluate the capabilities of a measurement system and manufacturing process. Three real case studies are provided for illustration. The remaining of this paper is organized as follows. Section two introduces the measurement system and a manufacturing process quality measures. Section three introduces the main steps of the proposed approach. Section four provides three illustrative case studies. Section five summarizes conclusions.

2. Quality measures for capability assessment

This section introduces the quality measures usually used for assessing the capabilities of a measurement system and a manufacturing process.

2.1. Assessing measurement system capability

The quality measure usually used for assessing the measurement system is the *PTR* calculated as

$$PTR = \frac{6\sigma_g}{USL - LSL} = \frac{6\sigma_g}{T} \quad (3)$$

where *T* represents the tolerance, and *USL* and *LSL* are the upper and lower specification limits, respectively. A gage is then judged capable if the *PTR* is less or equal to 0.1, whereas a gage is incapable if the *PTR* is greater than 0.3 [14]. It can be noted that the *PTR* for fixed value of *T* depends only on σ_g.

Another quality measure for assessing the capability of a measurement system, which relates the signal, the part variation, to the noise, the measurement error, and considers both σ_p and σ_g, is the *SNR*, which is calculated using the following equation:

$$SNR = \frac{\sqrt{2}\sigma_p}{\sigma_g} \quad (4)$$

A *SNR* value of five or greater indicates that the gage is adequate, whereas a value of less than two indicates inadequate gage capability [15]. An alternative to *SNR* defined by Wheeler [16] is the *DR*, which is expressed as

$$DR = \sqrt{\frac{2\sigma_p^2}{\sigma_g^2} + 1} \quad (5)$$

Mader et al. [17] stated that a *DR* value of four or greater indicates an adequate measurement system, whereas a value of less than two indicates that the measurement system is inadequate.

2.2. Assessing the capability of a manufacturing process

Process capability indices represent a class of quality measures for assessing manufacturing processes, which describe the ability of a process to produce parts that meet a predetermined level of production tolerance. The potential process capability index, C_p, enjoys a broad base of acceptance in industry, and is widely used for checking the capability of production processes. The C_p simply measures the spread of the specifications relative to the six-sigma spread in the process, expressed as