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A flexible process-capability-qualified resubmission-allowed acceptance sampling scheme ☆

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ABSTRACT

This paper introduces a new variables-acceptance-sampling scheme for resubmitted lots, based on process-capability-index (C_{pmk}) sampling information. The scheme competently evaluates both the process yield and the potential process loss of the submitted lots. Vital criteria and decision rules, by which inspected lots are approved in the resubmitted sampling strategy, include required sample size for inspection, critical acceptance levels stipulated for quality standards, and risks to producers and consumers. To obtain these vital criteria, the operating function of the proposed sampling scheme is derived based on the exact sampling distribution of the C_{pmk} estimator. In terms of the given rules and criteria, the resubmitted sampling plans provide greater insights than traditional single sampling plans. Finally, our proposed process-capability-qualified resubmission-allowed sampling strategy is evaluated on an industrial example.

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1. Introduction

In the modern era of global supply chains, products are transported to multiple companies and across multiple continents in their path from material suppliers to the final consumer (Shmueli, 2011). From product manufacture to marketing, acceptance sampling is critical for realizing quality and reliability assurance by each supplier and receiver, irrespective of whether the goods are being delivered as raw materials, in various stages of subassembly, or finished products. More importantly, sampling inspection not only assesses the smoothness and efficiency of the supply chain process, but also decides whether each chain of the supply process should be sustained or mediated to discover and eliminate disturbing causes.

In acceptance sampling (also known as product inspection), small samples are extracted from large-size lots and evaluated for acceptance or rejection decisions (Aslam & Jun, 2009; Aslam, Wu, Azam, & Jun, 2014; Fernández, Pérez-González, Aslam, & Jun, 2011; Fernández, 2014; Liu & Cui, 2013; Liu, Lin, & Wu, 2014; Schilling & Neubauer, 2009; Seo, Jung, & Kim, 2009; Wu, Aslam, & Jun, 2012). Nevertheless, to realize an effective scheme for acceptance sampling, several factors must be considered. First, the required number of samples randomly drawn from the vendor's process, which produces the products (lots), must be accurately decided. Next, to reflect the process capability and consolidate sample information, an adequate measure is required. Third, inherent sampling errors must be precisely evaluated without bias. Finally, the rules for accepting or rejecting the submitted lots must be fair and properly documented. The quality or reliability data most widely used in industry are attributes and variables. Thus, many theoretical and practical sampling schemes have been developed for handling these two data types, i.e., variables and attributes (Schilling & Neubauer, 2009).

Single-sample inspection for deciding the fate of a lot has been traditionally implemented by single acceptance sampling. Nonetheless, this disproportionate-size (sampling size v.s. lot size) resolution is disputed as the inspecting process or ramification is dubious or when the provisions of the contract are relatively elastic (Aslam, Wu, Azam, & Jun, 2012; Govindaraju & Ganesalingam, 1997; Wu, 2012). Literally, in many up-to-date examples, this single-inspection-based scheme and decision may be improper and sometimes may even cause uncompensated consequences either to producers (affecting their reputation) or to consumers (compromising their health and safety). One example is that executing the single-inspection-based decision for products' tariff payment being sampling-result dependent when shipping from country to country (a common logistic operation in the present global economy);

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another is that conducting the single-inspection-based decision for the food safety approval. In fact, in recent years the food safety issue has become a heated topic due to the outbreaks of food contamination and/or illicit substance additives; also, in present dissemination, evolution, and mutation of animal-to-human viruses, the permission of the livestocks issued by the single inspection scheme has grown more concerned when performed for the ante- and post-mortem screening.

To fulfill the concurrent circumstances, the resubmitted attributes acceptance-sampling plan recommended by Govindaraju and Ganesalingam (1997) seems more justified in some aspects to the producers as well as the consumers, compared to the single-sample inspection. The reason is that it releases the single-sample limitation to permit resampling of the lot when it is not accepted or contentious on the prior inspection, where the lot's quality is intact without resorting or reprocessing over the course of resubmission. Notably, this technique is not the one done in the traditional double sampling plans (Montgomery, 2009) that combine the results of all samples, nor does it resemble the ANSI/ASQC Standard A2-1987 (1987) that uses for evaluating resubmitted sampling from the lot that has experienced rearrangement or reprocess after its preceding rejection.

However, Govindaraju and Ganesalingam's scheme is applicable only to attributes data, and cannot meet current rapidly advancing manufacturing techniques and increasingly stringent requirements of service and healthcare. Attributes data are frequently difficult to quantify, and are instead collected by visual examination or perceived impression, which introduces subjectivity. Another problem with Govindaraju and Ganesalingam's scheme is the excessively large number of random-sampling items usually required for discriminating and revealing the lot's quality. In many situations, this requirement reduces the economic appraisal of material (Schilling & Neubauer, 2009). Most modern statisticians prefer variables data, which are parsimonious in quantity and objective rather than subjective (Balamurali & Jun, 2007; Chen, Li, & Lam, 2007; Lam, Li, Ip, & Wong, 2006; Negrin, Parmet, & Schechtman, 2011; Wu & Pearn, 2008; Wu & Liu, 2014).

Moreover, traditional variables sampling plans judge the quality of the lot either from its observed sample mean with an assumed standard deviation, or from its observed sample standard deviation with an assumed mean. This mutual exclusion of the true mean or variance, which is actually unknown, may bias the results and lead to erroneous conclusions. In addition, for products with a two-sided key quality characteristic, traditional two-sided sample plans exclude some of the perceived/preset information; namely, the products' target value and center-tendency information. To remedy these problems, acceptance sampling plans must be developed along with process capability indices. By measuring the relationship between products' specification limits and the process mean and variance, these capability indices provide quantitative measures on the performance of the process, such as process yield and potential quality loss. The process yield specifies the degree to which the process meets the specification limits and tends toward the center of the interval. The quality loss is a negative effect imposed when the process variation is offset from the target value.

Recently, Wu et al. (2012) and Aslam et al. (2012) investigated resubmitted variables acceptance-sampling plans based on the most frequently used index, C_{pk}. The C_{pk} index is popular for its simplicity and early introduction in Kane's 1986 publication. However, because it does not reveal the quality loss, it should be used with caution. This disadvantage perverts the philosophy of modern quality or reliability improvement, where variation reduction is used to remove nonconformities. Therefore, considering the holistics of the process yield and the potential quality loss, we introduce into our scheme the most advanced capability index C_{pmk} proposed to date; also known as the third-generation capability index, proposed by Pearn, Kotz, and Johnson (1992). We then develop a new variable sampling scheme for a resubmitted lot, based on the index C_{pmk}.

The rest of this paper is organized as follows. In Section 2, we briefly introduce the process capability studies and highlight the advantages of using the C_{pmk} index. In Section 3, we develop a novel variables sampling scheme for resubmitted lots based on C_{pmk}. The operating procedures and theoretical derivations are based on logical construction of single sampling cases. We then establish inspection requirements and decision rules for deciding the acceptance of inspected lots in the resubmitted sampling strategy under commonly adopted quality standards. Various C_{pmk}-qualified sampling schemes, including single and resubmitted cases, are analyzed and compared in Section 4. Our proposed schemes are applied to an industrial example in Section 5. Section 6 concludes the paper.

2. Process capability studies

In statistical process control applications, process capability analysis plays an integral role in continuously improving the quality and reliability of products. Effective analysis requires accurate revelation of process capability information. This information is captured in process capability indices, which represent the relationships between product specification limits and the actual performance of the process (Kargar, Mashinchi, & Parchami, 2014; Ranjan & Maiti, 2013; Wang & Chu, 2013; Wu, Pearn, & Kotz, 2009). In practice, these indices provide the information about the process yield or/and potential quality loss, which are crucial criteria for market acceptance of the products (lots).

The most commonly encountered capability indices are C_{pk} and C_{pm}, given by

$$C_{pk} = \min\left\{\frac{USL-\mu}{3\sigma}, \frac{\mu-LSL}{3\sigma}\right\} \text{ and } C_{pm} = \frac{USL-LSL}{6\sqrt{\sigma^2+(\mu-T)^2}}, \quad (1)$$

where μ and σ are the process mean and standard deviation, respectively. USL and LSL, respectively denote the upper and lower specification limits, and T is the target value, which are usually preset by the customers or product designers. As mentioned earlier, these parameters are straightforward and well-established, but must be used prudently because the C_{pk} cannot reveal the potential process loss, while C_{pm} does not completely expose the adverse impact when the process mean departs from the midpoint of the specification interval. The process yield and potential quality loss are adequately treated in the C_{pmk} index proposed by Pearn et al. (1992):

$$C_{pmk} = \min\left\{\frac{USL-\mu}{3\sqrt{\sigma^2+(\mu-T)^2}}, \frac{\mu-LSL}{3\sqrt{\sigma^2+(\mu-T)^2}}\right\} = \frac{d-|\mu-M|}{3\sqrt{\sigma^2+(\mu-T)^2}}, \quad (2)$$

where $d = (USL - LSL)/2$ is half the length of the specification interval, and $M = (USL + LSL)/2$ denotes the mid-point between the lower and upper specification limits. The natural C_{pmk} estimator for a random sample X_i of size n, where $i = 1, 2, \ldots, n$, is

$$\hat{C}_{pmk} = \min\left\{\frac{USL-\bar{X}}{3\sqrt{S_n^2+(\bar{X}-T)^2}}, \frac{\bar{X}-LSL}{3\sqrt{S_n^2+(\bar{X}-T)^2}}\right\} = \frac{d-|\bar{X}-M|}{3\sqrt{S_n^2+(\bar{X}-T)^2}}, \quad (3)$$

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