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Innovative Applications of O.R.

Six Sigma performance for non-normal processes

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ABSTRACT

Six Sigma is a widely used method to improve processes from various industry sectors. The target failure rate for Six Sigma projects is 3.4 parts per million or 2 parts per billion. In this paper, we show that when a process is exponential, attaining such performances may require a larger reduction in variation (i.e., greater quality-improvement effort). In addition, identifying whether the process data are of non-normal distribution is important to more accurately estimate the effort required to improve the process. A key finding of this study is that, for a low $k\sigma$ level, the amount of variation reduction required to improve an exponentially distributed process is less than that of a normally distributed process. On the other hand, for a higher $k\sigma$ level, the reverse scenario is the case. This study also analyzes processes following Gamma and Weibull distributions, and the results further support our concern that simply reporting the Sigma level as an indication of the quality of a product or process can be misleading. Two optimization models are developed to illustrate the effect of underestimating the quality-improvement effort on the optimal solution to minimize cost. In conclusion, the classical and widely used assumption of a normally distributed process may lead to implementation of quality-improvement strategies or the selection of Six Sigma projects that are based on erroneous solutions.

1. Introduction

Since its launch in the 1980s, Six Sigma has generated great expectations and hype in the business world, driven largely by reports of significant business gains, e.g., GE reported 11% revenue and 13% earnings increases from 1996 to 1998, AlliedSignal had savings of $1.5 billion in 1998, and Harry and Schroeder (1999) claimed "10% net income improvement, a 20% margin improvement, and a 10–30% capital reduction" for each Sigma improvement. These business gains were based on management and technical methods for improving processes with a theoretical aim of a failure rate of 3.4 parts per million (ppm) or 2 parts per billion (ppb), depending on certain assumptions. Important assumptions in Six Sigma are that the process is normal and its specifications are two-sided.

The assumption of normal distribution is generally appropriate for many technological manufacturing systems (e.g., machines, tools, and robots). Although not all manufacturing processes follow a normal distribution, this assumption remains widely used and recognized in the field of quality. Invariably, the normality test should be a first step in any approach using the normality assumption. However, for service or transaction systems, which have become increasingly predominant in various applications, even in manufacturing ones, the normality assumption comes into question. For example, in supply chain management and goods production systems, fill rates and the probability to meet specified customer service levels are not governed by normal distributions (Nourelfath, 2011). In addition, in project management where a project will more likely finish late, the normality assumption does not hold; in particular, this is the case when the number of activities is too small to assume a normal distribution based on the central limit theorem. Another example is the procurement process of oil and gas companies, where it was observed that cycle time data more closely resemble a Gamma distribution rather than a normal distribution.

Identified in a survey of the relevant literature, English and Taylor (1993) provide a good study on the robustness of the normality assumption when the distribution is not normal. Montgomery and Runger (2011) studied the error associated with non-normality in the estimation of defects in parts per million; the authors recommended applying transformational functions to the underlying non-normal variable until a normal transformed variable is found. A major drawback of this trial-and-error approach is the lack of physical meaning in the resulting transformed variable, rendering it unappealing to non-academic practitioners. Other researchers suggested fitting the appropriate distribution to the data and then calculating the

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parameters that would yield the desired parts per million (Somerville & Montgomery, 1996; Clements, 1989; Farnum, 1996; Rodriguez, 1992).

The main objective of this paper is to evaluate non-normally distributed data in Six Sigma performance methodology. Using the exponential distribution case, we first analyze the amount of variation reduction required to improve the process. The efforts required to achieve the performance goal of Six Sigma are then compared between the normal and exponentially distributed cases. Then, we generalize our study to processes using Gamma and Weibull distributions. Finally, two optimization models are developed: the goal of the first model is to find the optimal trade-off between quality-improvement program costs and costs incurred as a result of poor quality, and the second model addresses the optimal selection of process-improvement strategies. These optimization models analyze the impact of a poor estimation of quality-improvement effort on optimal solutions to minimize costs.

It is often the case in the professional and academic communities of quality to set 3.4 parts per million as the goal of Six Sigma without due consideration for the underlying process distribution. This could lead to erroneous estimation of the efforts and costs to achieve that goal when the process is not normal, as often is the case in service applications. The contribution of this research is that it provides guidelines to help managers to more accurately estimate the efforts required to achieve the performance goal of Six Sigma, and analyze the robustness of proposed quality optimization models under inaccurate probability distributions.

The remainder of this paper is organized as follows: Section 2 presents the relevant literature; Section 3 analyzes the Six Sigma performance methodology in exponential, Gamma and Weibull distribution processes; Section 4 presents two optimization models to illustrate the effect of inaccurate estimations of probability distributions; and Section 5 provides our concluding remarks.

2. Literature review

There are two main bodies of literature that are related to our research. The first is the literature of Six Sigma implementation in *service* systems that are more often characterized by non-normal distributions. The second concerns approaches to the evaluation of Six Sigma performance *without* assuming normal probability distributions. Next, we discuss each of these two research areas.

Several studies have been conducted in regard to implementation of the Six Sigma methodology in large manufacturing companies; nevertheless, as confirmed by many literature reviews, relatively few studies have reported the successful implementation of Six Sigma in service systems that, arguably, represent the life-blood of the modern economy (Aboelmaged, 2010; Stone, 2012). Behara, Fontenot, and Gresham (1995) presented a case study to illustrate how the concept of zero defects, as measured by Six Sigma, can be applied to the measurement of customer satisfaction and to examine the impact of customer expectations on the company's strategies for improving satisfaction. The information presented is based on actual studies conducted for a high-tech manufacturing company. Chakraborty and Chuan (2012) suggested that the implementation and impact of Six Sigma can be affected by contextual factors such as service types. The authors argued that management support and team member support are primary factors for success. Exploratory empirical evidence was provided through many case studies of organizations. They include a hospital, a public service organization, a consultancy service and a hotel. The major findings of the authors include an understanding about the suitability of Six Sigma implementation in service organizations. In addition, Chakraborty and Chuan (2013) highlighted that "top management commitment and involvement" are indeed important and critical factors for success, and the continuity of Six Sigma very much depends on these factors. The authors investigated the implementation of Six Sigma in service organizations through questionnaire surveys. They found that Six Sigma implementation in service organizations is limited across the globe. Service organizations in the USA and Europe are front-runners in implementation of Six Sigma, with Asian countries such as India and Singapore following behind. Their findings also showed that organizations from the healthcare and banking sectors have largely implemented the Six Sigma methodology, and other services, such as information technology, telecommunication services and transport services, are gradually incorporating Six Sigma. Antony, Antony, Kumar, and Cho (2007) presented some of the most common challenges, difficulties, common myths, and implementation issues in the application of Six Sigma in service industry settings. They also discussed the benefits of Six Sigma in service organizations and presented the results of a Six Sigma pilot survey in the UK. The results of their study showed that the majority of service organizations in the UK have been engaged in a Six Sigma initiative for just over three years. Management commitment and involvement, customer focus, linking Six Sigma to business strategy, organizational infrastructure, project management skills, and understanding of the Six Sigma methodology were identified as the most critical factors for the successful introduction, development and deployment of Six Sigma. Chakraborty and Leyer (2013) developed a framework that defined organizational conditions by which to implement Six Sigma in financial service companies. They showed that it is important to link Six Sigma to the strategic as well as the operational level. By analysing case studies of financial institutions in Thailand, Buavaraporn and Tannock (2013) formulated relationships between specific business process-improvement (BPI) initiatives and customer satisfaction. They developed a model based on service quality principles to explain the outcomes of BPI adoption at the operational level. In the context of Indian service companies, Talib, Rahman, and Qureshi (2013) empirically investigated the relationship between total quality management practices and quality performance.

Our analysis of the literature regarding Six Sigma performance *without* the normality assumption reveals that this assumption is usually "taken for granted" without a proper inquiry into whether this assumption has been fulfilled or not. Given that critical attributes may contain data sets that are non-normally distributed, Setijono (2010) presented a method of estimating left-side and right-side Sigma levels. In this method, to fulfil the assumption of normality, the primary data were "replicated" by first generating random numbers that followed a normal standard distribution and then re-calculating these random numbers with the mean, standard deviation, and the skewness of the primary data. Simulation technique was then applied to generate a larger amount of secondary data as the basis for estimating left-side and right-side Sigma levels. This method was applied in a Swedish house-building construction project. The calculated Sigma levels suggested that the developer's performance was still far below Six Sigma level of performance. Because most service quality data follow a non-normal distribution, Pan, Kuo, and Bretholt (2010) developed a new key performance index (KPI) and its interval estimation for measuring the service quality from customers' perceptions. Based on the non-normal process capability indices used in manufacturing industries, a new KPI suitable for measuring service quality was developed. In addition, the confidence interval of the proposed KPI was established using the bootstrapping method. The results showed that the new KPI allowed practicing managers to evaluate the actual service quality level delivered and to prioritize the possible improvement projects from customers' perspectives. Furthermore, compared with the traditional method of sample size determination, it was shown that a substantial amount of cost savings could be expected using the suggested sample sizes. Hsu, Pearn, and Wu (2008) considered the problem of determining the adjustments for process capability with mean shift when data follow a Gamma distribution. Using the adjusted process capability formula in Hsu et al. (2008), engineers were able to determine the