European Journal of Operational Research 246 (2015) 907–915

Contents lists available at ScienceDirect

European Journal of Operational Research

journal homepage: www.elsevier.com/locate/ejor

Decision Support

An optimal plan of zero-defect single-sampling by attributes for incoming inspections in assembly lines

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ARTICLE INFO

Article history:
Received 16 June 2014
Accepted 20 May 2015
Available online 29 May 2015

Keywords:
Quality management
Incoming inspection
Quality attributes
Acceptance sampling
Nonlinear integer programming

ABSTRACT

This paper proposes a nonlinear integer program for determining an optimal plan of zero-defect, single-sampling by attributes for incoming inspections in assembly lines. Individual parts coming to an assembly line differ in the non-conforming (NC) risk, NC severity, lot size, and inspection cost-effectiveness. The proposed optimization model is able to determine the inspection sample size for each of the parts in a resource constrained condition where a product's NC risk is not a linear combination of NC risks of the individual parts. This paper develops a three-step solution procedure that effectively reduces the solution time for larger size problems commonly seen in assembly lines. The proposed optimization model provides insightful implications for quality management. For example, it reveals the principle of sample size decisions for heterogeneous, dependent parts waiting for incoming inspections; as well as provides a tool for quantifying the expected return from investing additional inspection resources. The optimization model builds a foundation for extensions to advanced inspection sampling plans.

1. Introduction

Acceptance sampling is for sensing the quality of incoming material and outgoing products of a production system. The general procedure of acceptance sampling is to take a random sample from each lot and determine whether the lot will either be rejected or accepted based on the inspection result of the sample. A complete inspection is often not desirable when the inspection is expensive, time-consuming, or destructive. Therefore, acceptance sampling becomes a commonly used technique for quality management (Schilling & Neubauer, 2009). In incoming inspections, a manufacturer uses acceptance sampling to discriminate good lots of received material from bad lots, reducing the chance of bad lots entering the production system (Hamaker, 1958); sampling results are also provided by manufacturers to their suppliers as feedback on the quality of received lots, thus promoting healthy consumer–supplier relationships (Hill, 1960; Robinson & McNicholl, 1990).

During the past two decades, the use of zero-defect acceptance policy is growing. Under this policy a lot is accepted only if no defect has been identified in the inspected sample; that is, the maximum allowable number of defects is zero (Squeglia, 2008). The zero-defect policy emphasizes the non-existence of non-conformance and simplifies sampling plans, making the use of it easier for both suppliers and consumers. The zero-defect policy has been proved to be optimal in a variety of circumstances where quality control is very critical (Starbird, 1997). This policy has been implemented in the army (e.g., MIL-STD-1916) as well as in manufacturing and service industries (e.g., ISO/TS 16949). When the zero-defect acceptance policy is used, the quality control of a lot through incoming inspection solely relies on the selection of the sample size. This amplifies the importance of optimizing the sample size. Among existing approaches to addressing this problem, the economic modeling approach, which quantifies all quality-related cost components and aims at minimizing the total cost, demonstrates special advantages over the others. It supports the optimization of sample sizes; thus, it is more capable of revealing insightful implications for quality management.

The incoming inspection for assembly lines is a situation where the optimization of sample sizes is not a simple task for quality managers, particularly for inspecting quality attributes (due to the discrete nature of the decision). Nowadays many products are made of multiple parts; for example, an engine for a car includes hundreds of parts featured by different quality attributes. Some of the parts have complex designs with hundreds of quality features. These quality attributes are heterogeneous in that they usually differ in non-conforming (NC) rate, NC severity, and inspection complexity, necessitating the need for calibrating the sample size for each attribute. The interdependence of quality attributes further magnifies this need

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http://dx.doi.org/10.1016/j.ejor.2015.05.054

because certain relationships among them may make the cumulative error grow exponentially than linearly.

While it has been identified as a research need by industry practitioners, the above-mentioned problem has not been addressed in the literature. In an attempt to fill some of the existing gaps and to advance the use of zero-defect incoming inspections for complex conditions, this paper models and optimizes the zero-defect, single-sampling by attributes for inspecting incoming parts in an assembly line. Single-sampling is the most common and easiest plan for incoming inspections. The model and results of this paper build the foundation for other advanced sampling plans and for the integration of sampling plans across multiple decision levels.

The remainder of the paper is organized as follows. The relevant literature is briefly discussed in the next section, followed by the optimization model for sample size decisions. Section 4 presents the solution approach and important features of an optimal sampling plan, with mathematical derivations provided in the appendices. A real example is solved and discussed in Section 5. Conclusions and important extensions of the paper are discussed at the end, in Section 6.

2. The literature

Recently, the use of “accept on zero” as a policy of acceptance inspection has been growing. With this policy a lot is accepted only if no defect is identified in the inspected sample. Squeglia (2008) provided detailed discussions on the zero-defect policy. This policy emphasizes the non-existence of non-conforming products and simplifies the sampling plan, making the use of it easier for both suppliers and consumers. The military standard MIL-STD-1916, which replaced the popular standard MIL-STD-105E in 1996, is based on zero-defect acceptance sampling policy. The zero-defect policy is also used by manufacturing and service industries (e.g., ISO/TS 16949). The study by Starbird (1997) showed that a manufacturer who uses the zero-defect policy in the incoming inspection is most likely to motivate suppliers to deliver zero defects. Furthermore, when the manufacturer’s consumers use 100 percent inspection or zero-defect policy for their acceptance sampling inspections, the zero-defect policy is also optimal for the manufacturer to inspect the outgoing products. Although quality control is extremely important to certain manufacturers, the zero-defect policy has not received sufficient attention in the research literature.

When the zero-defect policy is used, sample size becomes the only decision to make. The determination of sample sizes for incoming inspections are often addressed in different ways, including: (i) applying standard sampling inspection tables such as Dodge and Romig Tables (Dodge & Romig, 1998) and Military Standards (e.g., MIL-STD-105E, 1989; MIL-STD-1916, 1996); (ii) using acceptance criteria such as acceptance quality level (AQL) and lot tolerance percent defective (LTPD) based on the supplier’s and producer’s risks (e.g., Collins, Jr., Case, and Bennett, 1973; Pearn and Wu, 2007); or (iii) developing an economic model to consider all quality-related costs (e.g., Case and Chen, 1985; Ferrell, Jr. and Chhoker, 2002; Horsnell, 1957; Shin and Lingayat, 1992; Wetherill and Chiu, 1975). Among these, the economic modeling approach provides the capability for optimizing sample sizes (Hamaker, 1958). It has been an important approach for decades (Wetherill & Chiu, 1975), being popularly used in the operations research literature.

The literature on the economic modeling approach is generally divided into two streams, with one focused on the sampling by variables and the other by attributes. The former is relatively well addressed for both the inspection of independent quality variables (e.g., Ferrell, Jr. and Chhoker, 2002; Fink and Margavio, 1994; Shin, Kongsuwon, and Cho, 2010; Tagaras, 1994) and that of multiple dependent quality variables over a single stage or multiple stages (e.g., Balamurali and Jun, 2007; Chan and Ibrahim, 2004; Drezner and Wesolowsky, 1995; Kapur and Cho, 1996; Moskowitz, Plante, and Duffy, 2001; Plante, 2002; Tang and Tang, 1989). Wetherill and Chiu (1975) reviewed the literature on acceptance sampling by attributes. Most of the work included in their review paper are economic models for inspecting only a single quality attribute. Schmidt and Bennett (1972) and Case, Schmidt, and Bennett (1975) modeled the optimization of multi-attribute acceptance sampling. Yet all the attributes were assumed independent in their studies. Moskowitz, Plante, Tang, and Ravindran (1984) developed a multi-attribute Bayesian acceptance sampling plan and, accordingly, designed a discrete search algorithm, based on a pattern search, to determine an optimal solution. The algorithm was shown to be efficient for up to three attributes. Tang, Plante, and Moskowitz (1986) extended the work of Moskowitz et al. by showing that interactions among attributes can impact an optimal inspection plan. Tang et al. developed a heuristic algorithm for solving the problem, which changes the sampling plan by just one attribute at a time (it is defined as a subproblem) until no improvement of the object function is possible. All of the testing problems in this paper considered only four attributes.

The discrete nature of sampling by attributes is one challenge facing the optimization of sampling plans. Discrete optimization such as nonlinear integer programming (NIP) has become a useful tool for addressing this issue. Ercan, Hassan, and Taulananda (1974) built an integer program (IP) to determine the sample size and the acceptance number for the incoming and outgoing inspections of a product, simultaneously. The product considered by Ercan et al. has a single quality attribute. Ravindran, Shin, Arthur, and Moskowitz (1986) developed two lexicographic nonlinear integer goal programming models to determine the optimal sample size and acceptance number for a product’s outgoing inspection. The goal of the decision is to determine the best trade-off between the average lot inspection quality and the average outgoing quality.

Nowadays, acceptance sampling decisions are no long considered in a standalone quality control scenario. In a broader range of operational settings, the decisions must be made jointly with other considerations. Tools of operations research have been shown to be effective in modeling and solving these complex problems. For instance, Seidel (1991) built a minimax problem to optimize the selections of sampling size and acceptance number when the prior information about the quality of incoming lots is incomplete. Modeling the risk of statistical classification error, Markowski and Markowski (2002) proposed alternative sampling plans that increase the lot acceptance number. Ben-Daya and Noman (2008) modeled the integration of inventory decision with inspection policies for buyers who face stochastic demand. Hsieh and Liu (2010) studied the quality investment by different parties in a serial supply chain and used noncooperative games to model the manufacturer’s inbound inspection policy and the supplier’s outbound inspection policy. Fernández, Pérez-González, Aslam, and Jun (2011) built an optimization model for designing group sampling plans with considerations of various constraints such as quality requirements by the producer and consumers. Although operations research tools would also be helpful for modeling and analyzing the problem presented in this paper, to our best knowledge no literature has made such an attempt.

3. The problem formulation

The acceptance policy of zero-defect, single-sampling by attributes for incoming inspections is the following. Inspectors will pick a random sample from the lot of each part without replacement. If no non-conforming (NC) item is found in the sample, the lot is accepted and sent to the inventory department. Otherwise, the entire lot is rejected. The sample size for each lot waiting for an incoming inspection is a decision to be made.

The inspection of M different parts coming into an assembly line can be formulated as an optimization problem that minimizes the