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ORIGINAL ARTICLE

Economic design of multiple inspection plans via the expectation-maximization algorithm

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ABSTRACT

Because of inspection errors, expensive items such as computer chips are usually inspected more than once with the same testing device to further improve the quality of accepted items. Many researchers have considered various multiple inspection plans that minimize the expected total cost of inspection and misclassifications. We first propose a new Markovian inspection plan under which each item is tested repeatedly until we have a sufficient number of positive or negative test results. We then deal with the problem of estimating three model parameters: the type I and II errors of an automated test equipment and the fraction defective of incoming items. Because of computational difficulties in maximizing the likelihood of the three parameters, we propose the use of the expectation-maximization (*EM*) algorithm as an easy alternative. In a numerical analysis, we demonstrate the outstanding performance of our new inspection plan over previous ones.

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Product quality; Markov chain; expectation-maximization algorithm; inspection; reliability

1. Introduction

To improve the quality of items and products, inspection is widely used as one of the most effective tools in industry. Parts, materials, and final products are subjected to rigorous inspections in order to detect any non-conforming items or non-conformities. However, inspection errors are inevitable in most screening, testing, or auditing procedures (Chun, 2008b). Due to the inspection errors, conforming items may be rejected (i.e. type I error), or some non-conforming items may be accepted erroneously (i.e. type II error). That is why some complex items or products that require a high level of outgoing quality are inspected more than once independently.

Many researchers have proposed various multiple inspection plans to improve the outgoing quality of accepted items. Such a multiple inspection plan is variously known as a repetitive inspection (Quinino & Ho, 2004), repeated screening (Gasparini et al., 2004), a repetitive testing (Aslam et al., 2018; Greenberg & Stokes, 1995), repeat test (Christer, 1994), or repeat inspection (Duffuaa & Khan, 2008; Elshafei et al., 2006).

As an example of the repetitive inspection, let's consider the fabrication of an integrated circuit (IC) in semiconductor industry (Greenberg & Stokes, 1995). The fabrication of a chip is a multi-step sequence of photolithographic and chemical processing steps such as layering, patterning, doping, and heat treatment. During each step, electronic circuits are created gradually on a crystal silicon wafer. Before being shipped to the customer, functioning chips are subjected to a rigorous test at the final stage. During the wafer sort test, hundreds of different patterns of input are used to check if each chip is fabricated in accordance with design specifications.

In such a situation, some degree of inspection error is inevitable. Non-defective chips may fail the functionality test, and defective chips may pass the test erroneously. If the unit price of a chip is relatively higher than the inspection cost per unit, it is more cost-effective to test each chip multiple times. Then, how do we make the acceptance-rejection decision based on the number of positive and negative test results? How many times do we need to test each unit to assure a certain level of outgoing quality? The two types of planning are known as the posterior and prior planning of the repetitive inspection in Chun (2009).

Many researchers have proposed various types of multiple inspection plans that minimize the cost of inspection and misclassifications. The major contribution of the paper is to develop a new sequential inspection plan, in which each item is tested repeatedly until we have enough positive or negative test results. Thus, the total number of inspections is flexible and considered a discrete random variable. However, we can find the expected number of inspections and the proportion of items that are

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