Consumer's Risk in Zero-defect Sampling Inspection of Surveying and Mapping Products

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Abstract

Through theoretical analysis and empirical research, this study thoroughly examines the theoretical foundations and practical applications of zero-defect sampling inspection schemes, revealing significant differences between inspecting large lots as a whole versus splitting them into sub-lots in terms of consumer's risk control. The findings indicate that although the zero-defect sampling scheme (Ac=0) adopted in the GB/T 24356-2023 standard shifts quality control from "post-production spot checks" toward "in-process prevention", it exhibits notable deficiencies in controlling consumer's risk, resulting in an unacceptably high level of risk for consumers. Empirical analysis demonstrates that, for large lots with relatively poor quality, e.g., when the product's defect rate is 10%, the inspection plan (100, 10, 0) still carries a 33.3% probability of erroneously accepting the lot, which significantly exceeds the risk level typically acceptable to consumers and thus imposes excessive quality risk on them. Furthermore, the study reveals that inspecting small lots or subdividing large lots benefits producers, highlighting an imbalance in the current standard's risk allocation mechanism. These insights provide more reliable theoretical support and practical guidance for quality management of surveying and mapping products.

1 General Introduction

1.1 Research Background

The quality of surveying and mapping products serves as a crucial guarantee for the construction of national fundamental geographic information infrastructure. The scientific soundness and effectiveness of their quality control system directly affect the reliability and application value of surveying and mapping outcomes. In quality inspection activities, implementing scientifically rigorous and appropriate sampling inspection schemes is of vital importance, as it constitutes the core strategy for achieving an optimal balance among inspection cost, efficiency, and risk control (Yu, 2015). Since the founding of the People's Republic of China, quality inspection methods for surveying and mapping products have undergone a transition from simple proportional sampling to standardized sampling inspection schemes (Luo, 2017). However, with the continuous increase in batch sizes and quality requirements for surveying and mapping products, the limitations of current sampling methods have become increasingly apparent, particularly in terms of insufficient control over consumer's risk (Yong, 2013). The newly issued GB/T 24356-2023 Specifications for Quality Inspection and Acceptance of Surveying and Mapping Products has achieved a major innovation in quality control methodology by formally adopting a zero-defect sampling scheme (acceptance number *Ac=0*), aiming to improve the quality management level of surveying and mapping products through stricter acceptance criteria. However, given the practical application scenarios of surveying and mapping products characterized by large batch sizes, multiple elements and high precision requirements, the effectiveness, quantitative characteristics and applicable boundaries of this scheme in controlling consumer's risk have not yet been systematically analyzed theoretically or verified empirically, which makes it difficult to directly support the accurate implementation and optimization of the standard.

1.2 Research Content

Accordingly, this paper puts forward the core research hypothesis: in the zero-defect sampling scheme, lot quality level, batch size and sample size are the key factors affecting consumer's risk; there is a significant interaction among the three factors, consumer's risk shows a nonlinear variation pattern with the change of parameters, and the current standard does not specify a reasonable control interval for such risk in combination with the characteristics of surveying and mapping products.

Based on the above hypothesis, this paper defines the core research questions: to systematically explain the mathematical and theoretical basis of the zero-defect sampling scheme in controlling consumer's risk; to quantitatively reveal the internal relationship and dynamic variation pattern among batch size, sample size and consumer's risk under different quality levels; to scientifically evaluate the actual risk control effectiveness of the zero-defect sampling scheme specified in GB/T 24356-2023 in the inspection of surveying and mapping products.

Through theoretical derivation and numerical simulation, this study conducts in-depth analysis. The research results can provide solid theoretical support and targeted practical guidance for optimizing the quality inspection standards of surveying and mapping products, formulating scientific sampling schemes, and balancing inspection efficiency and risk control.

2 Practice of the Zero-Defect Concept

2.1 Origin of the Concept

The zero-defect sampling theory was introduced by Philip B. Crosby in the 1960s. Its core principle "First Time Right" (doing it right the first time) marked a paradigm shift in quality management from "post-facto inspection" to "preventive control". In 1965, Nicholas L. Squeglia developed the *C=0* sampling plan (*Ac=0*), also known as the "zero-defect acceptance criterion" which mandates that the entire lot be rejected if even a single defect is found in the sample. This concept was further reinforced in 1996 by the U.S. Department of Defense's MIL-STD-1916 standard, which emphasized ensuring quality through process control rather than final inspection (Nelson, 2023). Modern quality management systems such as IATF 16949 have explicitly incorporated "zero defects" as the acceptance criterion for attribute data, promoting its deep integration in high-reliability industries like automotive and aerospace, where it aligns theoretically with Six Sigma's "zero-defect" philosophy. The emergence of zero-defect sampling stems from two key drivers:

(1) Urgent demand for high reliability (Gojanovic, 2007): After World War II, sectors such as defense and aerospace demanded absolute reliability, rendering traditional AQL-based sampling plans- which tolerate a certain defect rate- inadequate.
(2) Evolution of quality management philosophy (Nakhaeinejad, 2021): Crosby's zero-defect philosophy was institutionalized through the *C=0* sampling scheme, imposing a rigid constraint on producers: any error leads to rejection of the entire batch, thereby heightening accountability and discipline in manufacturing.

2.2 Performance Characteristics

Both traditional and zero-defect sampling are grounded in probability and statistical principles, yet they differ fundamentally. Traditional sampling accepts a level of "tolerable defects" under controlled risk, whereas zero-defect sampling enforces stringent quality requirements to drive improvements in process capability (Miedema, 2024). Under the same *AQL*, the *C=0* plan typically reduces sample sizes by 8%-30% (Ling and Tu, 2013), offering both economic efficiency and operational simplicity only two possible outcomes: "accept all" or "reject all". Empirical studies show that transitioning from GB/T 2828 to a zero-defect model significantly lowers inspection costs and effectively reduces reliance on final inspection, thereby shifting quality control upstream to the production process.

2.3 Challenges of Zero-Defect Sampling

As an internationally recognized quality control tool, the zero-defect sampling scheme has achieved breakthrough application in China's surveying and mapping sector, marking a paradigm shift in quality management from experience driven practices to science-based decision making. According to the technical framework of GB/T 24356-2023, the zero-defect approach achieves its quality control objectives by setting the Acceptable Quality Limit (*AQL*) to zero. Its core mechanism the "accept if zero defects, reject if one or more" rule (*Ac=0*), shifts the focus of quality control from "post-production spot inspection" to "in-process prevention". This significantly enhances producers' sense of responsibility for quality and drives the industry toward a quality culture centered on "process reliability and zero-error outcomes". However, implementation of this scheme faces two key constraints:

(1) For small-lot production, the required sampling ratio is relatively high, which may lead to a sharp increase in inspection costs.
(2) It imposes nearly stringent technical demands on process stability and consistency, necessitating a robust and well established process control system as support. Therefore, the adoption of zero-defect sampling must be carefully evaluated by holistically considering multiple factors, including product

quality requirements, cost constraints, and risk tolerance to ensure balanced and effective deployment.

3 Consumer's Risk Analysis

3.1 Theoretical Foundation

3.1.1 Hypergeometric Distribution

When performing random sampling without replacement from a finite lot of N items containing D defective units, the probability of observing a certain number of defectives in the sample follows the hypergeometric distribution (Sheng, 2001). The probability $P(d)$ of finding exactly d defective items (where $0 \le d \le \min(D,n)$) in a sample of size n is given by Equation 1:

$$P(d) = \frac{C_D^d C_{N-D}^{n-d}}{C_N^n} \tag{1}$$

3.1.2 Binomial Distribution

When production is operating under normal conditions, the number of defective items D in a lot is relatively small compared to the lot size N, and thus can be considered negligible. Specifically, when $N \geqslant 10n$ and $n < D$ (or more precisely, when the sampling fraction is small), sampling without replacement can be approximated as sampling with replacement (Fan, 2005). Under these conditions, the binomial distribution (Equation 2) can be used as an approximation to the hypergeometric distribution for calculating $P(d)$.

$$P(d) \approx C_n^d p^d (1-p)^{n-d} \tag{2}$$

where $p=D/N$ is referred to as the defective rate.

3.1.3 Acceptance Probability

Acceptance Probability is a core metric for evaluating the performance of a sampling inspection plan. Mathematically denoted as $L(p)$, it represents the probability that a lot with a specified defective rate p will be accepted under a given sampling scheme. For a single-sampling plan denoted by (N, n, Ac), the lot is accepted if the number of defectives d observed in the sample does not exceed the acceptance number Ac. The acceptance probability can thus be expressed as: $L(p)=P(d \leqslant Ac)$.

$$L(p) = \sum_{d=0}^{Ac} P(d \le Ac) = \sum_{d=0}^{Ac} \frac{C_D^d C_{N-D}^{n-d}}{C_N^n} \tag{3}$$

Accordingly, when $N>10n$ and $p<10\%$ (Xin, 2015), the binomial distribution can be used as a substitute for the hypergeometric distribution in calculations ((Equation 4).

$$L(p) = \sum_{d=0}^{Ac} C_n^d p^d (1-p)^{n-d} \tag{4}$$

3.1.4 The Operating Characteristic Curve

The curve defined by $L(p)$ is known as the Operating Characteristic Curve (*OC Curve*) of the sampling plan. It is a statistical tool that illustrates the relationship between the probability of lot acceptance and the lot's defective rate. First introduced by Walter A. Shewhart in the 1920s, the *OC Curve* constitutes a fundamental element of quality control theory. A typical *OC Curve* is shown in Figure 1.

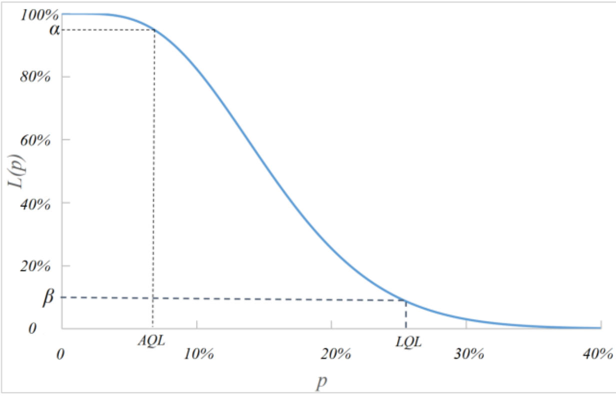

Figure 1. Schematic diagram of an *OC Curve*

The shape of the *OC Curve* is influenced by the parameters of the sampling plan, primarily as follows:

(1) With sample size n fixed and acceptance number *Ac* varied: Increasing *Ac* shifts the curve upward, indicating a more lenient sampling plan. Decreasing *Ac* shifts the curve downward, indicating a stricter sampling plan.

(2) With *Ac* fixed and sample size n varied: Increasing n shifts the curve downward, resulting in a stricter plan. Decreasing *n* shifts the curve upward, resulting in a more lenient plan.

(3) When both n and *Ac* change simultaneously: If *n* increases while *Ac* decreases, the plan becomes stricter. If *n* decreases while *Ac* increases, the plan becomes more lenient.

Therefore, the *OC Curve* holds significant practical value in quality control, primarily in the following aspects:

(1) Assessment of discriminatory power: The steepness of the curve reflects the ability of the sampling plan to distinguish between lots of different quality levels.

(2) Risk quantification: The producer's risk α and consumer's risk β can be quantified using the *OC Curve* to evaluate inspection risks.

(3) Optimization of sampling plans: By comparing *OC Curves* of different plans, an optimal sampling scheme can be selected based on desired performance criteria.

3.2 Definition of the Two Types of Risk

Any statistical sampling plan entails certain risks. When the quality of the produced items meets the producer's specified Acceptable Quality Level (*AQL*), the lot should be accepted with a high probability (*1-α*, typically 95%) (Cai, Cheng and Zhang, 2019). Conversely, when the defect rate exceeds the limiting quality level (*LQL*), the lot should be rejected with a high probability (*1-β*, typically 90%). Clearly, the producer prefers a smaller producer's risk α, while the consumer prefers a smaller consumer's risk β. If the two parties cannot reach an agreement on acceptable levels of α and β, inspection cannot proceed effectively. Consequently, the central issue in designing an inspection scheme becomes how to determine mutually acceptable values for these two risks. Assuming no inspection errors, Equation (5) yields:

$$\begin{cases} \alpha = 1 - L(p_0) = 1 - \sum_{d=0}^{Ac} C_n^d (p_0)^d (1-p_0)^{n-d} \\ \beta = L(p_1) = \sum_{d=0}^{Ac} C_n^d (p_1)^d (1-p_1)^{n-d} \end{cases} \quad (5)$$

Where p_0=*AQL*, p_1=*LQL*.

3.3 Consumer's Risk Analysis

3.3.1 Sampling Plan

The GB/T 24356-2023 standard introduces a zero-defect sampling plan (*Ac=0*), which requires that no defective items be present in the sample. The zero-defect sampling plan is (*N, n, Ac*). Table 1 in the standard provides the correspondence between lot sizes and required sample sizes. Assuming no inspection errors, the producer's risk under this sampling scheme for surveying and mapping products is effectively zero. However, the plan exhibits significant shortcomings in controlling consumer's risk.

N	n	N	n
1~20	3	161~180	14
21~40	5	181~200	15
41~60	7	201~232	17
61~80	9	233~282	20
81~100	10	283~362	24
101~120	11	363~487	30
121~140	12	488~685	40
141~160	13	686~1000	56

Table 1. Sample size table from GB/T 24356-2023

3.3.2 Quality Level

The Surveying and mapping products are classified as general industrial goods, with a quality level of 3%. Some scholars also using *OC Curve* analysis, have recommended a Limiting Quality for GIS products with a defect rate ranging from 3% to 5% (Liu, 2000).

3.3.3 Consumer's Risk Associated with Random Non-Conforming Product

Select typical sampling plans from Table 1 and calculate the consumer's risk β for lots containing Non-Conforming Product (*NCP*= 1, 2, 5, 10, 20). Table 2 shows the results, Figure 2 illustrates the corresponding relationship graph.

(*N, n, Ac*)	*NCP*				
	1	2	5	10	20
(20, 3, 0)	85.0%	71.5%	39.9%	10.5%	0%
(40, 5, 0)	87.5%	76.2%	49.3%	21.7%	2.3%
(60, 7, 0)	88.3%	77.8%	52.5%	25.9%	4.8%
(80, 9, 0)	88.8%	78.6%	54.2%	28.0%	6.3%
(100, 10, 0)	90.0%	80.9%	58.4%	33.0%	9.5%
(120, 11, 0)	90.8%	82.4%	61.3%	36.7%	12.2%
(140, 12, 0)	91.4%	83.5%	63.5%	39.5%	14.4%
(160, 13, 0)	91.9%	84.3%	65.1%	41.8%	16.3%
(180, 14, 0)	92.2%	85.0%	66.4%	43.5%	17.9%
(200, 15, 0)	92.5%	85.5%	67.4%	45.0%	19.3%
(232, 17, 0)	92.7%	85.8%	68.1%	46.0%	20.3%
(282, 20, 0)	92.9%	86.2%	69.0%	47.3%	21.7%
(362, 24, 0)	93.4%	87.1%	70.8%	49.9%	24.3%
(487, 30, 0)	93.8%	88.0%	72.7%	52.6%	27.3%
(685, 40, 0)	94.2%	88.6%	74.0%	54.6%	29.4%
(1000,56,0)	94.4%	89.1%	74.9%	56.0%	31.2%

Table 2. The relationship between consumer's risk β and *NCP*

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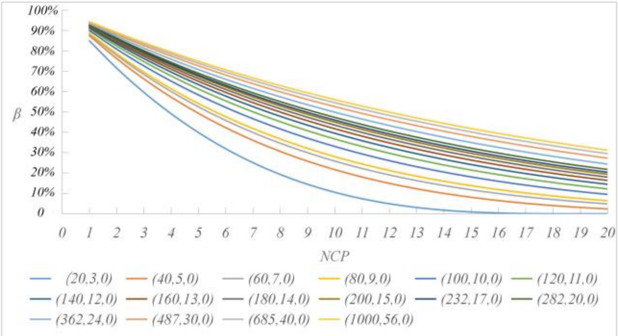

Figure 2. The relationship between consumer's risk β and *NCP*

With a random *NCP*, the consumer's risk exhibits the following characteristics:

(1) Consumer's risk decreases as product quality deteriorates, and increases as lot size grows. In practice, since the number of *NCP* remains constant, a larger lot size implies a lower *NCP* rate i.e., effectively higher quality.

(2) When there is only one *NCP* in the lot, the minimum consumer's risk is 85.0%, which is under the sampling plan (20,3,0). Conversely, the maximum consumer's risk is 94.4% under the plan (1000,56,0). As shown in Figure 2, for a fixed number of *NCP*, larger lot sizes are more favorable to the producer.

(3) Assuming a defective rate of p=5%, Table 2 indicates that the lot acceptance probabilities for sampling plans with lot sizes of 20, 40, 80, 160, 362, 1000 are 85.0%, 76.3%, 61.4%, 50.0%, 28.2%, 5.2%, respectively. Thus, when product quality is fixed, submitting lots in smaller batches is more advantageous to the producer.

(4) As reflected in Table 2, the sampling plans specified in GB/T 24356-2023 generally result in relatively high consumer's risk.

3.3.4 Consumer's Risk Associated with Limiting Quality Level

As the sampling plans listed in Table 1, the consumer's risk was calculated for limiting quality level (*LQL*=1%, 2%, 5%, 10%, 20%) across different lot sizes, the results are shown in Table 3. Figure 3 illustrates the corresponding relationship graph.

(*N, n, Ac*)	*LQL*				
	1%	2%	5%	10%	20%
(20, 3, 0)	-	-	85.0%	71.6%	49.1%
(40, 5, 0)	-	-	76.3%	57.3%	30.6%
(60, 7, 0)	-	88.3%	68.5%	45.9%	19.1%
(80, 9, 0)	-	88.7%	61.4%	36.7%	11.9%
(100,10,0)	90.0%	80.9%	58.4%	33.0%	9.5%
(120,11,0)	90.8%	82.4%	55.4%	29.7%	7.6%
(140,12,0)	91.4%	83.5%	52.6%	26.7%	6.1%
(160,13,0)	91.9%	77.4%	50.0%	24.0%	4.8%
(180,14,0)	92.2%	78.3%	47.4%	21.6%	3.8%
(200,15,0)	85.5%	73.0%	45.0%	19.4%	3.1%
(232,17,0)	85.9%	73.6%	42.5%	15.8%	2.0%
(282,20)	86.3%	69.0%	34.8%	11.4%	1.0%
(362,24,0)	81.4%	61.6%	28.2%	7.4%	0.4%
(487,30,0)	77.5%	56.1%	20.9%	4.0%	0.1%
(685,40,0)	69.6%	45.4%	12.3%	1.3%	0%
(1000,56,0)	56.0%	31.2%	5.2%	0.2%	0%

Table 3. The relationship between consumer's risk β and *LQL*

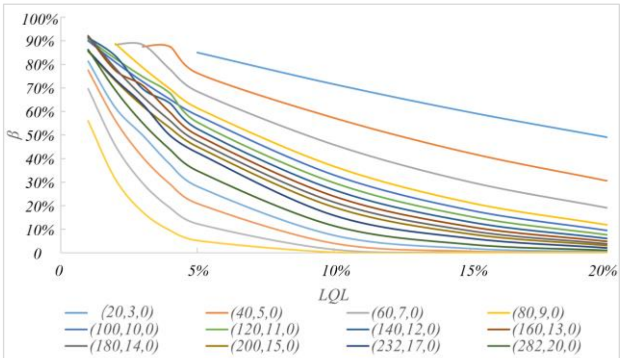

Figure 3. The relationship between consumer's risk β and *LQL*

Under stable quality conditions, the consumer's risk exhibits the following characteristics:

(1) Consumer's risk decreases as product quality deteriorates and also decreases as lot size increases.

(2) When *LQL* levels remain stable, submitting products in smaller batches is more favorable to the producer.

(3) Even when the *LQL* is below 5%, there remains a non-negligible probability of lot acceptance, indicating that the sampling plans specified in GB/T 24356-2023 generally entail relatively high consumer's risk.

3.4 Reliability of Inspection for Large Populations

3.4.1 Equivalence Between Full-Population and Sub-Lot

Suppose we have a stable-quality product population sampling plan for each sub-lot becomes (280,20,0). In contrast, the full-population sampling plan would be (560,40,0). The corresponding acceptance probabilities for these two approaches are presented in Table 4. Based on the data in Table 4, it can be calculated that although the probability of accepting the entire population under full-population inspection is lower than that under sub-lot inspection, it equals the square of the acceptance probability of a single sub-lot. In other words, when the total sample size remains the same, the overall probability of acceptance is mathematically equivalent between full-population and sub-lot sampling. However, splitting a large population into smaller sub-lots increases the acceptance probability for each individual sub-lot, thereby reducing the risk that the entire population will be rejected. Consequently, applying sub-lot inspection to a large population effectively constitutes a more lenient (i.e., relaxed) inspection scheme.

(N, n, Ac)	*p*				
	1%	2%	5%	10%	20%
(280, 20, 0)	81.8%	66.8%	35.8%	12.2%	1.2%
(560, 40, 0)	66.9%	44.6%	12.9%	1.5%	0%

Table 4. Rask β between full-population and sub-lot samples

3.4.2 Distortion in Inspection Results for Large Population

With the advancement of information and intelligent technologies, modern surveying and mapping products, such as LiDAR point clouds and real-scene 3D models are typically produced in large volumes. In such large population, the occurrence of a small number of defective items is statistically almost inevitable.

According to the zero-defect sampling plan specified in GB/T 24356-2023, conducting full-lot inspection on such large population will high probability lead to rejection. This indicates that the current sampling scheme exhibits a certain degree of ineffectiveness and fails to accurately reflect the true quality status of the product.

This phenomenon fundamentally stems from an inherent characteristic of zero-defect random sampling inspection. Under the requirement that the producer's risk be zero, the probability of accepting a lot containing a small number of defectives i.e., committing consumer's risk becomes unavoidably high. Consequently, to accurately assess product quality, it becomes necessary either to substantially increase the sample size or to adopt non-random inspection methods.

4 Conclusion

This study systematically analyzes the theoretical foundation and practical effectiveness of zero-defect sampling inspection schemes in quality control of surveying and mapping products, with a particular focus on how sampling plans influence consumer's risk under varying lot sizes and quality levels. The main findings are as follows:

(1) The zero-defect sampling scheme exhibits significant deficiencies in controlling consumer's risk. Although the GB/T 24356-2023 standard adopts a zero-defect approach to shift quality control from "post-production spot inspection" toward "in-process prevention", it demonstrates markedly inadequate capability in managing consumer's risk for large lots. Empirical results show that, for example, when the lot size is large and the quality level is low, e.g., with a defect rate of 10%, the sampling plan (100,10,0) still yields a 33.3% probability of erroneously accepting the lot. This error rate substantially exceeds the risk level typically acceptable to consumers, thereby imposing excessive quality risk on the user side.

(2) Lot size exerts a decisive influence on inspection stringency. The study finds that, under equal total sample sizes, full-lot inspection and sub-lot inspection are equivalent in terms of overall risk. However, full-lot inspection is more likely to reject lots containing defectives. This reveals a critical principle: inspecting in smaller batches or splitting large lots into sub-lots is more favorable to the producer. This pattern reflects the inherent trade-off between producer's risk and consumer's risk in sampling plan design and highlights an imbalance in the current standard's risk allocation mechanism.

This research uncovers the limitations of zero-defect sampling schemes in controlling consumer's risk and provides both theoretical support and practical guidance for improving China's quality inspection system for surveying and mapping products, thereby contributing to the safety and reliability of national spatial data infrastructure.

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