Optimization of Sampling Inspection and Disassembly Production Decisions Considering Defect Rate Random Disturbances

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Abstract. With the increasing complexity of electronic product manufacturing, the uncertainty of component quality has a significant impact on the finished product pass rate and production costs. Traditional full inspection methods are costly, while sampling inspection reduces detection costs but introduces randomness in defect rate estimation, increasing the difficulty of production decision-making. This paper proposes an optimization model for quality management under sampling inspection conditions, which comprehensively considers component inspection, semi-finished product inspection, and finished product disassembly strategies. The model simulates defect rate fluctuations by introducing random disturbances, and based on a comparison between inspection costs and potential losses, it formulates dynamic inspection and disassembly strategies to balance defect rate control and cost optimization. The research results indicate that reasonable design of inspection and processing decisions can effectively reduce overall production costs and improve finished product quality in multi-stage production processes. The proposed model has good generality and scalability, making it applicable to various complex production scenarios and providing systematic decision support for manufacturing enterprises.

1 Introduction

In the manufacturing of modern electronic products, maintaining high product quality is essential not only for enhancing a company's competitive edge but also for reducing production costs and boosting customer satisfaction. Given that these products consist of various components, each prone to quality variations during production and assembly, finding an effective balance between quality control, inspection expenses, and overall production costs has become a crucial challenge for manufacturers.

Extensive research has been conducted by scholars both domestically and internationally on quality management and defect rate control. Wang Chao et al. [1] considered both processing quality and production costs in the flexible workshop scheduling problem, proposing an optimization model to improve production efficiency.

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Wang Zhiping et al. [2] studied the role of measurement accuracy in weighing systems in the dairy industry, emphasizing the importance of precise measurement in ensuring product quality and controlling costs.

In terms of optimizing quality inspection strategies, Shen Jianguo [3] proposed a cloud computing scheduling task allocation method based on multi-objective optimization algorithms, providing new ideas for resource optimization in complex systems. Zhang Bobin et al. [4] used genetic algorithms to study intelligent pipe breakage methods for complex piping systems, enhancing the level of automation in manufacturing processes.

In the area of production process modeling and optimization, Chen Qiang [5] applied finite element numerical models to study composite support designs in residential foundation pit projects, demonstrating the combination of quality control and cost optimization in engineering projects. Cao Yi et al. [6] explored the optimization of shared bicycle deployment points under bus transfer, reflecting the trade-off between costs and benefits in resource allocation.

In the context of digital transformation and intelligent production, Peng Yongtao et al. [7] studied the multi-period product service supply chain network equilibrium problem considering integration levels, highlighting the impact of product quality fluctuations on overall supply chain efficiency. Li Zhihui et al. [8] discussed how to make rational decisions under uncertainty in production and operation, providing theoretical support for quality inspection and cost control. Zhang Qunhong et al. [9] researched the role mechanism of key factors in the digital transformation of small and medium enterprises, based on a survey of the textile industry internet platform enterprises in Changle, Fujian, proposing key factors for promoting digital transformation. Chen Linlin et al. [10] studied the digital transformation path of the tourism industry, exploring the applications and challenges of digital transformation across different industries.

Although significant progress has been made in quality control, inspection strategies, and cost management, there is still a lack of systematic and quantitative modeling analysis on the cumulative effects of defect rates of components through multi-step processing in the complex electronic product manufacturing process, as well as the dynamic trade-off relationships between inspection, disassembly, and losses. Additionally, the comprehensive consideration of inspection accuracy and cost control at different confidence levels in the design of inspection schemes still requires further improvement.

Therefore, building on previous research, this paper proposes an optimization-based decision model for electronic product production quality and cost control. The model systematically considers the cumulative effects of defect rates of components in multi-stage production processes, combines inspection costs, disassembly costs, and potential losses for decision analysis, and introduces a sampling inspection scheme based on the normal approximation of binomial distribution to ensure inspection accuracy under different confidence requirements. Through quantitative modeling and simulation analysis, this paper aims to provide a systematic and actionable quality control and cost optimization decision strategy for electronic manufacturing enterprises.

2 Methods and Analysis

2.1 Problem Analysis and Description

Assuming that the defect rate of components is known, the defect rates of all components, semi-finished products, and finished products are obtained through sampling inspections. When there are m processes and n components, decisions are made based on three choices:

whether to inspect the components, whether to inspect the finished products, and whether to disassemble or discard defective finished products.

At this point, the defect rate in the production process is no longer deterministic, but a random variable estimated through sampling. Therefore, enterprises need to consider the uncertainty of inspection results when making decisions and adjust and optimize the decisions at each production stage. The problem requires enterprises to reestablish decisions for component inspection, finished product inspection, and disassembly of defective products based on the results of sampling inspections, in order to optimize cost control and improve production efficiency under uncertain conditions.

2.2 Method Explanation

When manufacturing electronic products, enterprises go through multiple stages, including the procurement and inspection of components, the assembly and inspection of semi-finished products, and the final inspection and market release of finished products. The defect rate at each stage affects the company's costs and market reputation, so enterprises need to make decisions for each stage accordingly.

Assume that the defect rate of each component is p_i,the purchase cost is c_{pc},and the inspection cost is c_{ic}.The sampling inspection process simulates the defect rate by introducing random disturbances, with the fluctuations in the defect rate being modeled by the random disturbance ϵ i.e.

$$p_{sum}=p_i+\epsilon \tag{1}$$

Where, $\epsilon \sim N(0,\delta^2)$; $p_{sum}$is the total defect rate,p_i is the defect rate of each component.

The final defect rate value must remain within a reasonable range (0 to 1), and the average defect rate is calculated through multiple sampling as follows:

$$P_{avg}=\frac{1}{n}\sum_{i=1}^{n} P^i_{sum}\ p_{sum}=p_i+\epsilon \tag{2}$$

Whether inspection is necessary depends on the comparison between inspection costs and potential losses. If no inspection is conducted, defective products entering the subsequent stages will incur potential losses caused by the defects. The calculation formula for potential losses is:

$$L_i=P_{avg}\times c_{pc} \tag{3}$$

$L_i$is the potential loss, and P_{avg} is the average defect rate.

Inspection decision criteria: If $D_{sc}<L_i$,then perform inspection; otherwise, do not inspect.

A semi-finished product is assembled from multiple components, so its defect rate is a combination of the defect rates of the individual components. Let the semi-finished product consist of m components, then the defect rate of the semi-finished product is:

$$P_{semi}=1-\prod_{i=1}^{m}\left(1-P^i_{avg}\right) \tag{4}$$

The assembly cost is c_{ac} and the inspection cost isc_{ic}. The potential loss is calculated as:

$$P_{semi}=1-\prod_{i=1}^{m}\left(1-P_{avg}^{i}\right) \tag{5}$$

$$L_{semi}=P_{semi}\times(c_{ac}+\text{Other Associated Costs}) \tag{6}$$

L_{semi} is the potential loss of the semi-finished product, and P_{semi} is the defect rate of the semi-finished product.

The inspection decision criteria are similarly based on a comparison of inspection costs and potential losses: If $c_{ic}<L_{semi}$, then perform the inspection; otherwise, do not inspect.

The defect rate of the finished product comes from the combined defect rates introduced during the assembly process and the defect rates of the semi-finished products. The defect rateP_f of the finished product is:

$$P_f=P_{semi1}+P_{semi2}-P_{semi1}\times P_{semi2}+P_{ac} \tag{7}$$

P_{semi1} is the defect rate of Semi-finished Product 1, P_{semi2} is the defect rate of Semi-finished Product 2, and $P_{ac}$is the assembly cost of the semi-finished product.

The potential loss L_f of the finished product includes the finished product selling price P_m and the replacement cost c_{rc}:

$$L_f=P_f\times(P_m+c_{rc}) \tag{8}$$

The inspection decision criteria for finished products are as follows: If $D_f<L_f$ then perform the inspection; otherwise, do not inspect.

When the finished product is defective, the enterprise needs to decide whether to perform disassembly. The disassembly loss L_{dl}includes the disassembly fee $c_{df}$and the recovery cost of the components. The decision to disassemble is based on a comparison between the finished product disassembly loss and the market price: If $L_{dl}<P_m$, then perform disassembly; otherwise, discard it directly.

2.3 Model Analysis

In actual production, the defect rate is not constant, so by introducing random disturbances epsilon and sampling inspection, the fluctuations in defect rates can be better simulated. The more samples are taken, the closer the average defect rate will be to the actual rate, but it may also incur more computational costs.

If the inspection cost is low and the potential losses are high, the enterprise should perform inspections to reduce the losses caused by defects; otherwise, the inspection costs can be avoided to increase the company's profit.

By adjusting the magnitude of the random disturbance and the number of samples, sensitivity analysis can be conducted to observe the impact of defect rate fluctuations on enterprise decisions. For example, when random disturbances are large, more frequent inspections may be necessary at various stages to control potential losses. On the other hand, when the defect rate is relatively stable, the enterprise can reduce the number of inspections to save costs.

The model proposed in this paper is adaptable to different production environments, whether it is a simple single-stage production or a complex multi-stage, multi-link production. By introducing uncertainty through random disturbances, the model effectively reflects the unpredictable quality fluctuations in the production process.

Based on a comparison of inspection costs and potential losses, the model can dynamically adjust the decisions at each stage of production. During the production process, the defect rate and costs at different stages affect decisions, and the model provides flexible inspection and handling strategies for the enterprise.

By comparing potential losses and inspection costs, the model helps the enterprise reduce defect rates while controlling production costs, optimizing the overall production process. This enables the enterprise to minimize additional costs while ensuring product quality.

The structure of the model is simple and versatile, and it can be extended to more complex production environments based on specific situations. Various factors, such as market demand fluctuations and external environmental influences, can be flexibly incorporated for optimization analysis.

3 Results and Discussion

The following is a possible result obtained considering random sampling:

Table 1 presents the disassembly decisions based on the potential losses of finished products and their components. These decisions help enterprises determine whether defective products need to be disassembled based on the inspection results in different scenarios.

Table 1: Disassembly Decision

Scenario Number	Finished Product Potential Loss	Component 1 Potential Loss	Component 2 Potential Loss	Component 1 Decision	Component 2 Decision	Finished Product Decision	Disassembly Decision
1	6.0349	2.1691	2.1622	Inspect Component 1	Don't inspect Component 2	Inspect Finished Product	Disassemble Defective Product
2	9.8763	4.2601	4.3341	Inspect Component 1	Inspect Component 2	Inspect Finished Product	Disassemble Defective Product
3	13.2576	4.6879	4.7421	Inspect Component 1	Inspect Component 2	Inspect Finished Product	Disassemble Defective Product
4	16.9841	8.8353	4.7284	Inspect Component 1	Inspect Component 2	Inspect Finished Product	Disassemble Defective Product
5	9.7852	2.7116	5.1162	Do not inspect Component 1	Inspect Component 2	Inspect Finished Product	Disassemble Defective Product
6	6.6649	2.3012	2.3314	Inspect Component 1	Don't inspect Component 2	Inspect Finished Product	Disassemble Defective Product

Table 2 lists the decisions on whether to inspect each component based on the component's potential loss and inspection cost. These decisions help enterprises strike a balance between cost and benefit during the inspection process.

Table 2: Component Decision

Component ID	Component Potential Loss	Component Inspection Cost	Component Decision
1	0.8811	1	Do not inspect component
2	1.6550	1	Inspect component
3	2.0491	2	Inspect component
4	0.9332	1	Do not inspect component
5	1.5459	1	Inspect component
6	2.0521	2	Inspect component
7	1.6156	1	Inspect component
8	1.9526	2	Do not inspect component

Table 3 presents the decisions on whether to inspect semi-finished products. Enterprises must decide whether to perform inspections based on the potential losses and inspection costs of semi-finished products. These decisions are crucial for ensuring the final product quality.

Table 3: Finished Product Decision

Semi-finished Product ID	Semi-finished Product Potential Loss	Semi-finished Product Inspection Cost	Finished Product Decision
1	4.8682	4	Inspect semi-finished product
2	4.7924	4	Inspect semi-finished product
3	4.5670	4	Inspect semi-finished product

Table 4 outlines the decision to inspect finished products based on their potential losses and inspection costs. Enterprises must weigh the costs and risks when deciding whether to inspect the finished products.

Table 4: Finished Product Decision

Finished Product ID	Finished Product Potential Loss	Finished Product Inspection Cost	Finished Product Decision
1	6.8928	6	Inspect finished product

The following is the corresponding diagram comparing the potential losses and inspection costs of components and finished products:

Figure 1 visually compares the potential losses and inspection costs of components and finished products, helping enterprises consider cost-effectiveness when making inspection decisions.

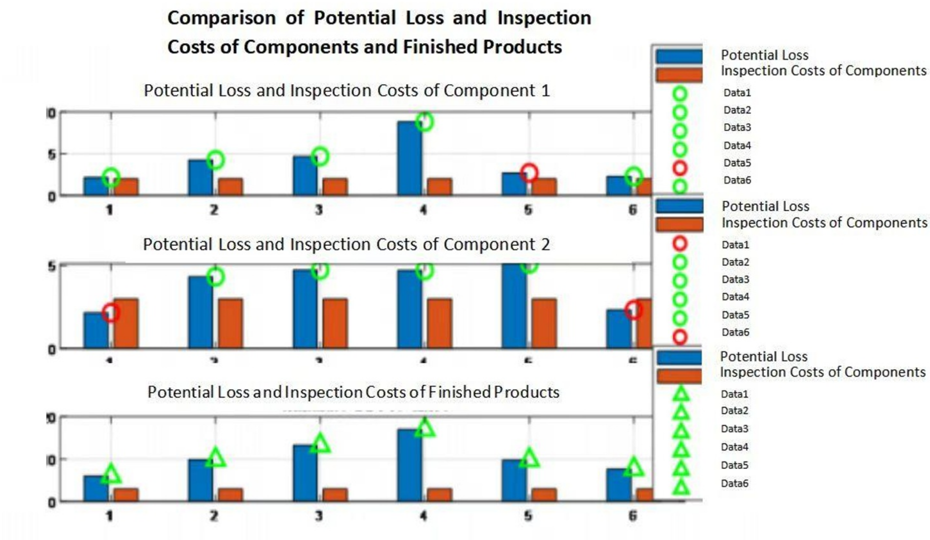

Fig 1. Comparison of Potential Loss and Inspection Costs of Components and Finished Products

The following is the corresponding diagram comparing the potential losses and inspection costs of components and semi-finished products during the production process:

Figure 2 compares the potential losses and inspection costs of components and semi-finished products, providing enterprises with a clearer perspective on whether inspections should be performed based on the economic impact.

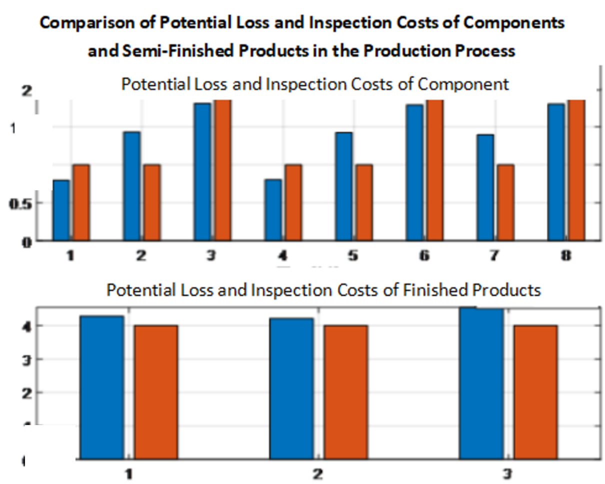

Fig 2. Comparison of Potential Loss and Inspection Costs of Components and Semi-Finished Products in the Production Process

These charts aim to compare the potential losses and inspection costs of each component and semi-finished product during the production process, assisting enterprises in making reasonable inspection decisions. Typically, when the potential loss exceeds the inspection cost, enterprises may be more inclined to inspect to reduce potential economic losses. On the other hand, when the inspection cost exceeds the potential loss, enterprises may choose not to inspect.

Through the above modeling and analysis, enterprises can dynamically adjust inspection strategies for each production stage based on actual conditions, thereby reducing defect rates while effectively controlling production costs.

4. Conclusion

The model proposed in this paper effectively optimizes quality control and cost management in multi-stage production processes, helping enterprises make reasonable inspection and disassembly decisions at different production stages. The model takes into account the random fluctuations in defect rates and explores the impact of uncertain factors such as market demand and equipment failures on production decisions. Furthermore, the model can also address cost fluctuations in actual production by introducing dynamic cost changes and can be extended to supply chain management to optimize raw material procurement and logistics. With these improvements, enterprises can achieve more efficient cost control and quality management in more complex production environments.Future research could improve this model by incorporating supply chain uncertainties, real-time defect prediction, sustainability factors, and advanced technologies like IoT and digital twins, while also addressing multi-echelon systems and human factors for greater resilience and adaptability in complex manufacturing environments.

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