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Research on Production Process Quality Control Method Based on Sampling Inspection and Multi-Stage Optimization Decision-Making

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Abstract: In the production process of modern manufacturing, how to effectively control costs while ensuring product quality is key to enhancing a company's market competitiveness. This paper proposes a method based on sampling inspection optimization and staged decision analysis to address the inspection and decision-making issues of parts, semi-finished products, and finished products during the production process. Firstly, a sampling inspection scheme is designed with the goal of minimizing the number of inspections. Based on the normal approximation of the binomial distribution, the minimum sample size required under different conditions is determined at 95% and 90% confidence levels, optimizing the acceptance decision in the parts procurement phase. Secondly, a decision-making model for inspection and dismantling of parts, semi-finished products, and finished products at each production stage is established. By comparing the overall cost under different schemes, an optimal production control process is developed. Numerical simulation results indicate that the proposed method effectively reduces overall production costs while improving finished product quality and market response speed, providing both theoretical support and practical guidance for quality management and cost optimization in manufacturing enterprises.

Keywords: Sampling inspection, Staged decision-making, Normal approximation, Production optimization, Quality control.

1. Introduction

In modern manufacturing, product quality control and cost management are key factors for enhancing a company's market competitiveness and profitability. With the increasing complexity of product structures, particularly in industries such as machinery and electronics, companies must purchase various components and assemble them into finished products. The defect rate of parts directly affects the pass rate of the finished products and their market performance, thus impacting the company's profitability. Therefore, how to reasonably control costs, increase profits, and make scientific inspection decisions in production management has become a focal point for enterprises.

In recent years, domestic scholars have conducted extensive research on product quality control and inspection technology. Zhu Guowen discussed the application of product quality and inspection technology in mechanical inspection processes, emphasizing the importance of improving quality control methods to enhance enterprise economic benefits[1]. Wang Yuan pointed out that sampling inspection methods play a significant role in product quality inspection, and a reasonable sampling strategy can effectively control product quality[2]. Chen Ping analyzed the relationship between mechanical product quality control and sampling inspection, proposing suggestions for optimizing sampling inspection strategies[3]. Additionally, Shen Mengqi studied the problems in mechanical product quality management and proposed countermeasures, stressing the importance of quality management in the production process[4]. Cheng Kangrong, starting from the steel rolling production process, explored product quality control strategies and practices, proposing specific quality control measures[5].

In the food industry, Zhang Li and Zhang Xiaoru analyzed the problems in food inspection and testing and proposed countermeasures, emphasizing the role of quality control in food safety[6]. Liu Tao and Liu Xia discussed the application of quality management methods in military enterprises, proposing strategies to enhance product quality and reliability[7]. Li Dan studied the use of big data to establish hazard control measures in the food industry, highlighting the application of data analysis in quality control[8]. Xu Xiaohui and others explored key points in the quality control of food inspection and testing organizations, suggesting ways to optimize quality control processes[9]. Wang Chaoyang analyzed the importance of quality control from the perspective of the design and processing of conventional mechanical products[10].

In summary, this paper aims to propose decision-making schemes suitable for different production stages through mathematical modeling. By considering factors such as inspection costs, assembly costs, replacement losses, and disassembly fees, the paper seeks to optimize the overall production process of enterprises. The paper will analyze a production scenario, design a sampling scheme with minimal inspection times, and provide defect rate assessment results for parts at different confidence levels, thereby offering theoretical support and practical guidance for decision-making at each production stage.

2. Sampling Inspection Method and Model Analysis

To determine the defect rate of parts, enterprises adopt a sampling inspection method, using hypothesis testing analysis. The null hypothesis is assumed as follows: $\mathbf{H_0}: \mathbf{p} \leq \mathbf{p_0}$,The alternative hypothesis is as follows: $\mathbf{H_1}: \mathbf{p} > \mathbf{p_0}$,Where $\mathbf{p_0} = \mathbf{10\%}$ is the nominal value. By using the normal approximation to the binomial distribution, the number of defective parts $\mathbf{X}$ follows a normal distribution:

$$X \sim N\left(np_0, np_o(1-p_0)\right) \quad (1)$$

The standardized statisticZis given by:

$$Z = \frac{\hat{p} - p_0}{\sqrt{\frac{p_0 - (1-p_0)}{n}}} \quad (2)$$

According to the requirements for95% and 90%confidence levels, different sample sizes were determined: for95%confidence,with $Z = 1.645$,the sample size $n \geq 98$;for90%confidence,with $Z = 1.28$,the sample size $n \geq 60$.The sample size calculation derivation is as follows:

$$n \geq \left(\frac{Z^2 \times p_0(1-p_0)}{\varepsilon^2}\right) \quad (3)$$

Where ε is the acceptable margin of error.

Based on the above derivation, the standard normal distribution curve is plotted as shown in Figure 1, with the 95% and 90% confidence intervals marked accordingly.

Standard Normal Distribution and Confidence Level Critical Values.

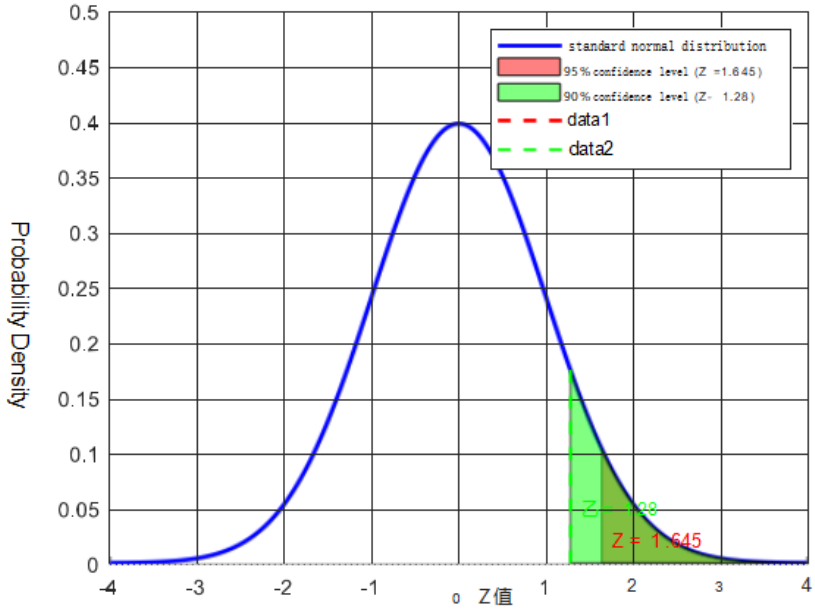


Figure 1: Illustration of the Standard Normal Distribution Curve and Confidence Interval.

After determining the defect rate, a multi-stage cost analysis is conducted, with the following cost parameters: purchase costs C_1, C_2 ,inspection costs D_1, D_2, D_P ,assembly cost A,disassembly cost T,market priceS,and trade lossL.The total cost calculation formula is as follows:

$$C_{total} = C_{purchase} + C_{inspection} + C_{assembly} + C_{replacement} + C_{disassembly} \quad (4)$$

Based on the comparison between inspection costs and potential losses, optimal decisions are made for different stages. If the cost of parts inspection is lower than the loss of finished products due to defects, parts inspection should be conducted. If the cost of finished product inspection is lower than the return and exchange losses incurred from not inspecting, finished product inspection should be carried out. If the disassembly cost is lower than the loss from direct disposal or remanufacturing, defective finished products should be disassembled.

By constructing a cost model, the costs associated with different inspection and handling strategies can be quantified, allowing for the selection of the production decision scheme with the lowest total cost. In practical applications, actual data can be used to determine the various cost and probability parameters, which are then substituted into the model for calculations, ultimately guiding enterprises in making reasonable inspection and production strategies, achieving the dual objectives of cost control and quality assurance.

3. Decision Model and Numerical Analysis

After determining the defect rate of parts through sampling inspection, enterprises need to make systematic decisions at multiple production stages to minimize total costs while ensuring the quality of finished products. For each stage, this paper establishes decision conditions and optimization criteria.

First, in the parts inspection stage, if the inspection cost of parts is lower than the potential loss caused by an increase in defective finished products due to not inspecting, it is recommended to conduct parts inspection. The inspection decision for part i is based on the following formula:

If $D_i < p_i \times L$, then perform inspection for part i.

Where $D_i$is the per-unit inspection cost of part i, $p_i$is the defect rate of part i, L is the per-unit market loss due to returns and exchanges of finished products.

Next, in the finished product inspection stage, if the inspection cost of the finished product is lower than the market loss caused by the defect rate of the finished product, then finished product inspection should be conducted. The decision criterion is:

If $D_p < P_p \times L$ then perform cost inspection.

Where $D_p$is the finished product inspection cost, and $P_p$is the defect rate of the finished product.

Again, in the stage of handling defective finished products,

if the disassembly cost of the finished product is lower than the loss caused by direct disposal and remanufacturing, then the decision is to disassemble the defective finished product, retain the usable parts, and reassemble them. The decision criterion is:

If $T < P_p \times L$,then choose to disassemble the defective finished product.

After considering both the inspection and disassembly strategies, enterprises can construct a decision tree to quantitatively compare the total costs across different paths, thereby selecting the production strategy with the lowest cost. By conducting numerical simulation analysis on typical scenarios, the results are shown in Table 1, which lists the optimal decision strategies corresponding to different production parameters.

Table 1: Numerical Simulation Analysis Results

Scenario Number	Potential Loss of Finished Products	Potential Loss of Part 1	Inspection Decision for Part 1	Inspection Loss for Part 2	Inspection Decision for Part 2	Finished Product Decision	Disassembly Decision
1	5.5680	1.9200	Do not inspect Part 1	1.9200	Do not inspect Part 2	Inspect Finished Product	Disassemble Defective Finished Product
2	9.8440	4.2800	Inspect Part 1	4.2800	Inspect Part 2	Inspect Finished Product	Disassemble Defective Finished Product
3	12.5280	4.3200	Inspect Part 1	4.3200	Inspect Part 2	Inspect Finished Product	Disassemble Defective Finished Product
4	16.5680	8.7200	Inspect Part 1	4.3600	Inspect Part2	Inspect Finished Product	Disassemble Defective Finished Product
5	9.5000	2.5000	Inspect Part 1	5.0000	Inspect Part2	Inspect Finished Product	Disassemble Defective Finished Product
6	6.3200	1.6000	Do not inspect Part 1	1.6000	Do not inspect Part 2	Inspect Finished Product	Disassemble Defective Finished Product

The numerical analysis results indicate that in cases of high defect rates and significant market return losses, prioritizing the inspection of parts and finished products, and disassembling defective items when necessary, can effectively reduce overall production costs. In contrast, in scenarios where inspection costs are high but defect risks are low, a direct assembly or sales strategy may be more economical.

Based on the above analysis, enterprises can flexibly adjust inspection and handling strategies according to actual production parameters, achieving optimal control of the production process.

4. Results Analysis

This study investigates cost minimization in production systems while maintaining product quality by optimizing sampling inspection schemes and developing a multi-stage production decision model. The proposed framework systematically evaluates inspection and reprocessing decisions across different production stages and their corresponding cost implications.

At the parts inspection stage, appropriate sampling sizes and inspection thresholds are determined to effectively identify defective components. This approach prevents nonconforming parts from entering subsequent assembly processes, thereby reducing the likelihood of rework, production disruptions, and customer returns.

At the finished product inspection stage, trade-offs between inspection costs and overall defect rates are quantitatively analyzed to ensure product reliability prior to market delivery. Furthermore, in the defective product handling stage, decision boundaries for disassembly and disposal are established to improve component reuse and reduce waste-related costs.

Numerical simulation results demonstrate that under conditions of high defect rates and substantial return losses, the joint implementation of parts inspection, finished product inspection, and disassembly strategies leads to a significant reduction in total production costs. In contrast, when defect rates are low and inspection costs are relatively high, simplified inspection strategies yield more cost-effective outcomes. The unified cost comparison and decision-making model developed in this study enables enterprises to select optimal production control strategies tailored to varying operational environments.

5. Conclusion

This paper proposes an integrated inspection and decision-making framework that enhances both economic efficiency and operational flexibility in production systems. By explicitly incorporating quality control, cost optimization, and defective product handling into a unified model, the proposed approach provides a robust theoretical foundation and practical guidance for manufacturing enterprises seeking to improve production quality management and risk control.

Future research may extend the model to account for uncertainty factors such as stochastic demand, variable defect rates, and supply chain disruptions. Incorporating these elements would further improve the robustness and real-world applicability of the proposed framework.

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