Research on key problems of electronic product production process based on hypothesis testing and integer programming

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Abstract. In the fierce competition pattern of modern electronic product manufacturing industry, quality control and production decision optimization are the key to improve the economic benefits and market competitiveness of enterprises. In this paper, a set of solutions based on hypothesis testing and integer programming is proposed for the evaluation and reception of spare parts in the production process of electronic products, production decision optimization and other issues. First of all, this paper uses the hypothesis test method to establish a sampling detection model, and realizes the specific sampling detection scheme with as few detection times as possible in the face of the problem of different reliability detection under the total condition of the defective rate of 0.1. Secondly, aiming at the multi-stage decision-making problem in the production process, this paper establishes an integer programming model and combines the Monte Carlo simulation algorithm to optimize the production decision. The model constructed in this study can provide theoretical reference and technical support for the production quality control and decision optimization of electronic products.

Keywords: Electronic product manufacturing, Production decision, Hypothesis testing, Integer programming, Monte Carlo simulation.

1. Introduction

In the modern electronic product manufacturing industry, quality control and production decision optimization are the key to improve the efficiency and competitiveness of enterprises. With the improvement of consumers' requirements for product quality, enterprises need to optimize production decisions and control costs while ensuring quality. It is very important to design an optimal detection scheme that saves sampling cost on the basis of confidence. Based on the sample test results, enterprises can flexibly adjust the production process and save resources. In addition, for the production process of multi-parts and multi-processes, optimizing resource allocation and ensuring product quality through phased decision planning is an important way to achieve efficient production.

In previous studies, scholars have extensively explored the quality inspection and decision optimization in the production process. Qiao Jing proposed the testing steps in the early stage of product production based on hypothesis testing [1]. Zheng Yongle used hypothesis testing to evaluate the failure efficiency of aircraft parts, which improved the evaluation efficiency and confidence [2]. Jiao Xianjun verified the reliability of coal mine safety measures through hypothesis testing [3]. Although hypothesis testing is widely used in quality inspection, there is still room for research in optimizing sampling schemes and reducing costs. As an important branch of linear programming [4], integer programming shows strong resource allocation ability in multi-stage production decision making, but it still needs further research when dealing with circular structure decision making process.

The innovation of this paper is the comprehensive use of hypothesis testing and integer programming. Aiming at the problem of spare parts evaluation and multi-stage decision optimization in the production of electronic products, an efficient sampling detection scheme is designed to optimize the allocation of production resources, realize the balance between quality and cost-effectiveness, and provide practical solutions for electronic product manufacturing enterprises.

2. Materials and methods

2.1. Data acquisition

The data in this paper are from the website www.mcm.edu.cn, including the production situation and production cost encountered by an enterprise.

2.2. Research problems and solutions

2.2.1. Design of sampling inspection scheme for spare parts based on hypothesis testing

Problem: A supplier claims that the defective rate of a batch of parts (Part 1 or part 2) will not exceed a certain nominal value. The enterprise intends to adopt sampling testing method to decide whether to accept the parts purchased from the supplier, and the testing cost shall be borne by the enterprise itself. The nominal value is known to be 10%, and there are two real cases:

(1) If the defective rate of spare parts exceeds the nominal value with 95% confidence, the batch of spare parts will be rejected;

(2) Under 90% reliability, it is determined that the defective rate of spare parts does not exceed the nominal value, and this batch of spare parts is received.

Solution: Hypothesis testing is to propose a hypothesis on a certain feature of the population, and make a decision to reject or not reject the original hypothesis based on the small probability event principle by using the information provided by the sample [5]. Judging whether the defective rate of parts meets the production requirements is a unilateral test problem in hypothesis testing. By setting the null hypothesis, Z-test was adopted based on the characteristics of large samples [6], and the range of standardized statistics was determined according to the confidence, so as to deduce the minimum sampling size under a fixed sample size.

2.2.2. Optimal design of multi-stage production decision-making based on integer programming and Monte Carlo simulation

Problem: In order to produce a kind of best-selling electronic products, an enterprise needs to purchase two kinds of spare parts (spare parts 1 and spare parts 2) respectively, and assemble two spare parts into finished products in the enterprise. In the assembly of the finished product, as long as one of the parts is not qualified, the finished product is not qualified; if both parts are qualified, the assembled finished product is not necessarily qualified. For unqualified finished products, enterprises can choose to scrap or disassemble them. The disassembly process will not cause damage to spare parts, but it will cost disassembly costs.

Knowing the decisions to be made at each stage of the production process of an enterprise:

(1) whether the spare parts (spare parts 1 and / or spare parts 2) are detected, if the spare parts are not detected, the spare parts will directly enter the assembly process; otherwise, the detected unqualified parts will be discarded;

(2) The assembly of each finished product is tested, if not detected, the assembly of the finished product directly into the market; otherwise, only the qualified finished products will enter the market;

(3) whether the detected unqualified products are disassembled, if not disassembled, the unqualified products are discarded directly; otherwise, the steps (1) and (2) are repeated for the disassembled parts;

(4) For the unqualified products purchased by users, enterprises will exchange unconditionally, and produce a certain loss of exchange (such as logistics costs, corporate reputation, etc.). Repeat step (3) for returned nonconforming products.

The defective rate of spare parts and finished products and the various production situations faced by enterprises are shown in Table 1:

Table 1. The situation encountered by enterprises in production

Situation	Spare parts 1			Spare parts 2			Finished product				Unqualified finished product	
	F	P	T	F	P	T	F	A	T	M	E	D
1	10%	4	2	10%	18	3	10%	6	3	56	6	5
2	20%	4	2	20%	18	3	20%	6	3	56	6	5
3	10%	4	2	10%	18	3	10%	6	3	56	30	5
4	20%	4	1	20%	18	1	20%	6	2	56	30	5
5	10%	4	8	20%	18	1	10%	6	2	56	10	5
6	5%	4	2	5%	18	3	5%	6	3	56	10	40

Note: F represents the defective rate. P represents the unit price. T represents the test cost. A represents the assembly cost. M represents the market price. E represents the exchange loss. D represents the disassembly cost.

Solution: This paper simplifies four decisions, whether to detect spare parts 1, whether to detect spare parts 2, whether to detect finished products and whether to disassemble non-conforming products. The four decisions are recorded as decision variables for integer programming. The objective function is the maximum net profit, and the corresponding cost or profit is analyzed for each stage, which is represented by decision variables. Since parts 1 and 2 enter stage 1 after disassembly of unqualified products, the cycle is entered here. The condition of jumping out of the cycle is designed as the constraint condition, and the objective function is expressed as the sum of the profits of each N cycles. Since the loop part is involved, this study uses Monte Carlo simulation to optimize the loop part. Monte Carlo simulation method, also known as statistical simulation method, is a calculation method to solve the problem through random sampling and statistical simulation [7]. Therefore, under the framework of Monte Carlo simulation, the design profit function is called in the loop and can be solved.

3. Results and analysis

3.1. Construction of spare parts sampling detection model based on hypothesis testing

Aiming at the problem of sampling inspection of spare parts, this paper introduces a hypothesis test method to preliminarily estimate the sample size on the basis of controlling wrong decision-making and ensuring the validity of probability.

(1) Determine the hypothesis type and significance level.

Both Case 1 and Case 2 are one-sided tests of the overall proportion (nominal defective rate $p_0 = 10\%$), and the significance level can be understood as the probability of making a true error (the null hypothesis is actually true, but after estimating the population through the sample, the null hypothesis is rejected). For cases 1 and 2 with reliability of 95 % and 90 %, the significance levels are 0.05 and 0.1, respectively.

(2) Establish the null hypothesis and alternative hypothesis

For the two cases, different original assumptions and alternative assumptions should be set to meet the different decision-making needs of enterprises.

Case 1 focuses on risk control to ensure that parts with high defective rate are not received;

1) Case 1 The null hypothesis H_0: the actual defective rate of spare parts $\widehat{P} \geq P_0$.

2) Case 1 Alternative hypothesis H_1: the actual defective rate of spare parts $\widehat{P} < P_0$.

Case 2 focuses on efficiency improvement to ensure timely receipt and use of qualified spare parts.

1) Case 2 The null hypothesis H_0: the actual defective rate of spare parts $\widehat{P} \leq P_0$.

2) Case 2 Alternative hypothesis H_1: the actual defective rate of spare parts $\widehat{P} > P_0$.

(3) Determine standardized statistics

Spare parts sampling is a large sample size situation, that is, the sample size is at least 50 or more. In the context of this large sample size, each sampling process is simplified to include only two mutually exclusive (defective non-inferior) results. Therefore, the sampling results follow the principle of binomial distribution:

$$X \sim B\left(n, p_0\right) \tag{1}$$

where X and p represent the number of defective products in the sample and the probability of occurrence of defective products in a single sampling, respectively. In the case of large sample size, the binomial distribution can be further approximated as a normal distribution:

$$X \sim N\left(np_0, p_0(1-p_0)\right) \tag{2}$$

Using the Z-test commonly used in large sample size, the standardized statistic Z is given as follows:

$$Z = \frac{\hat{p} - p_0}{\sqrt{\frac{p_0\left(1-p_0\right)}{n}}} \tag{3}$$

The defect rate observed in the sample is:

$$\hat{p} = \frac{X}{n} \tag{4}$$

(4) Determine the rejection domain

According to the significance level, the standard normal distribution table is searched to determine the corresponding critical value. Because the case 1 and the case 2 are the left test and the right test of an overall proportion respectively, the rejection domain direction is different, as follows:

1) Case 1: If the rejection region is $Z > Z_{0.05}$ (critical value), and the standardized statistic Z falls into it, the null hypothesis H_0 of case 1 is rejected.

2) Case 2: If the rejection region is $Z < Z_{-0.1}$ (critical value), and the standardized statistic Z falls into it, the null hypothesis H_0 of case 2 is rejected.

According to the above hypothesis testing steps, in order to ensure that when the defective rate really exceeds (or does not reach) the nominal value, we have enough confidence to reject the null hypothesis, and can get the estimation value of the fixed sample size sampling:

$$n = \frac{\left(Z_\alpha\right)^2 p\left(1-p_0\right)}{E^2} \tag{5}$$

where Z_α represents the critical value of the one-sided test at the significance level α , and E represents the allowable estimation error (i.e., the maximum allowable error). Here, we set the value of E to be 0.02 according to the actual production situation. The estimated sample sizes for cases 1 and 2 can be calculated to be 609 and 369, respectively.

3.2. Construction of production decision optimization model based on integer programming and Monte Carlo simulation

The production process is divided into four stages, each of which involves a decision problem and can be expressed as a zero-one variable, as shown in Table 2.

The problem can be understood as a single objective programming, and the objective function is the maximum net cost $\max M$. Before starting the calculation, make some simple marks: $n_{1,2}, n$ are the number of spare parts 1, the number of spare parts 2, the number of finished products; a_1 and a_2 are the unit price of spare parts 1 and 2 respectively ; b_1 and b_2 are disassembly unit price and assembly cost ; $q_{1,2,3}$ are the unqualified rate of spare parts 1, spare parts 2, and finished products ; $c_{1,2,3,d}$ are the inspection cost of spare parts 1 and spare parts 2 and finished products and exchange loss of unqualified products ; the cost of purchasing spare parts is M_1, the cost of spare parts inspection is M_2, the cost of finished product inspection is M_3, the cost of finished product assembly is M_4, and the cost of disassembly is M_5. w is the market price of the finished product.

Table 2. Zero-one variable

Decisions to be made	Zero-one variable
whether to inspect part 1	When x_1 is 1, it means detection, and x_1 is 0, it means no detection
whether to inspect part 2	When x_2 is 1, it means detection, and x_2 is 0, it means no detection
whether to inspect the finished product	When x_3 is 1, it means detection, and x_3 is 0, it means no detection
whether to disassemble the non-conforming finished product	When x_4 is 1, it means disassembly, and x_4 is 0, it means no disassembly

Next, this study calculate the cost of the four stages and the cost of the cycle process:

Stage 1 (spare parts detection stage): spare parts produce two parts of the cost, one is the purchase cost, and the other is the detection cost, which can be expressed by zero-one variables x_1 and x_2. The expression is as follows:

$$M_1 = n_1a_1 + n_2a_2 \tag{6}$$

$$M_2 = x_1n_1c_1 + x_2n_2c_2 \tag{7}$$

Stage 2 (finished product inspection stage): the cost is assembled from parts 1 and parts 2 one by one. It can be seen that the number of finished products is equal to the small number of parts 1 and parts 2 at this time. Based on this, the finished product assembly cost and inspection cost are given as follows:

$$n = \min\{(1-x_1q_1)n_1, (1-x_2q_2)n_2\} \tag{8}$$

$$M_3 = x_3n_3 \tag{9}$$

$$M_4 = nb_2 \tag{10}$$

Stage 3 (disassembly stage of unqualified products): There are two sources of unqualified products, one is unqualified products eliminated by finished product testing, and the other is unqualified products returned without finished product testing ; in addition to the disassembly cost, the two also produce the unsold loss cost, the replacement cost after the replacement and the sales profit of the new finished product after the replacement (Note : the replacement of the past product must not be a defective product). The total cost generated at this stage is expressed as follows:

$$M_5 = x_3x_4q_3nb_1 + x_3\left(1-x_4\right)q_3nw + \left(1-x_3\right)\left(b_1 + w + c_{\mathrm{d}}\right)x_4q_3n + \left(1-x_3\right)\left(1-x_4\right)\left(w + cd\right)q_3n \tag{11}$$

Stage 4 (inflow market stage): Stage 4 only considers profits, and the losses caused by unqualified products are classified into stage 3. Then the detected and undetected qualified products in the market obtain the corresponding operating profits as follows:

$$W = \left(1-x_3\right)nw + x_3q_3nw \tag{12}$$

Due to the disassembly of non-conforming products, the corresponding spare parts 1 and spare parts 2 are generated. Then, back to stage 1 (part detection stage), a new detection cost is generated, which enters the cycle. In the i-th cycle, the corresponding total cost M_i and the corresponding total profit W_i are generated until one of the spare parts 1 or spare parts 2 is exhausted or the defective rate reaches a certain threshold. The objective function is:

$$\max M = \sum_{i=1}^{N} W_i - \sum_{i=1}^{N} M_i \tag{13}$$

The corresponding constraints are:

$$\begin{cases} x_{1,2,3,4} = 4 \\ n_1^{(i)} \geq 0 \\ n_2^{(i)} \geq 0 \end{cases} \tag{14}$$

3.2.1. Monte Carlo simulation algorithm of decision model

Monte Carlo simulation algorithm is a search algorithm for decision-making process. Its basic goal is to select an optimal action plan under a given state of the problem [8]. The algorithm uses the minimax principle, the ' selection-expansion-evaluation-reverse update ' iterative process, to perform online reasoning on the current state to improve its path strategy [9]. It can generate a large number of random samples according to the information of the basic random variables in the limit state equation. The richer the sample size, the more accurate the calculation results. This process is called random sampling [10].

The steps for Monte Carlo simulation of production process decisions are as follows:

Firstly, the state vectors a_1 and a_2 of spare parts 1 and 2 are initialized, and their lengths represent the number of spare parts respectively. Through the rand () function, the defective product (value 0) is randomly generated according to the defective rate, and the rest are qualified products (value 1). At the same time, the possible solutions are stored in a binary array X, which corresponds to the i-th possible case of the four zero-one variables $x_{1,2,3,4}$, a total of 16 kinds.

The objective function is defined as the moni function: input a_1, a_2 and decision variables. The length of the state vector a_1 and a_2 is multiplied by the corresponding purchase unit price to obtain the total cost required to purchase the accessories as $g_1 + g_2$. According to the values of $X(1)$ and $X(2)$, whether to detect the accessories is judged, and the detection cost $f_1 + f_2$ is calculated. After eliminating the defective products, a_1 and $a_2$are updated to be fully qualified.

Finished product assembly and defective product treatment: multiply a_1 and a_2 by elements to generate a finished product state vector a_3, and any accessory is a defective product, the finished product is a defective product. Until one of the accessories is all involved in the combination, the calculation process should be further multiplied by the defective rate of the finished product, indicating the possible defective products in the assembly process, and finally the state variable a_3 represents the finished product. After the assembly of the finished product is successful, the remaining parts are assigned to a_{1}_last and a_{2}_last. Use the index to find the defective product in the finished product, that is, the element part equal to 0 in the a_3 vector. According to the value of $X(3)$ and $X(4)$, the classification is discussed : if $X(3) = 1$, the finished product is detected and the detection cost f_3 is calculated, and the income r is calculated after the defective product is eliminated; on the premise of testing the finished product, if $X(4) = 1$, the defective product is disassembled and the state of the accessories is updated, and the disassembly cost f_4 is calculated. If $X(3) = 0$,sell the finished product directly, calculate the income r and the defective loss f_5; on the premise of not testing the finished product, if $X(4) = 1$, disassemble and return the defective product and update the accessory status, calculate the cost required for disassembly and update f_4.

The net profit r can be obtained by comprehensive solution:

$$profit = r - \left(g_1 + g_2 + f_1 + f_2 + f_3 + f_4 + f_5\right) \tag{15}$$

and the state variables of the updated spare parts 1 and spare parts 2 can be obtained.

In the outer loop of iteration for each row in X, the moni function is called to calculate the profit $profit(i)$, and return the updated a_1 and a_2 values (i.e., a_1_last and a_2_last). Under the framework of Monte Carlo simulation, the code executes the optimization cycle:
(1) Random sampling: Randomly rearrange the state of accessories through the randperm function to simulate random sampling.
(2) Model evaluation: the moni function is called to obtain the net profit generated by the new cycle.
(3) Update and iteration: update the total profit, plus the profit generated by the new round of processes. Then, continue to loop to try more random permutations, and continuously accumulate profits until the exit conditions are met. The condition is set to:
(1) Exhausted accessories.
(2) The defective rate of accessories is close to 100 %, so it is not reasonable to assemble the finished product at this time.

3.2.2. The results of multi-stage production decision optimization model

Using the above Monte Carlo simulation algorithm, various parameter indexes given for different parameter indexes are substituted into the model. In order to make the results more general, the total number of spare parts is taken as 10000 in this study. The results are calculated by Matlab programming, as shown in table 3 below:

Table 3. Results

Case	Profit (yuan)	Decision plan ($\boldsymbol{x_1}, \boldsymbol{x_2}, \boldsymbol{x_3}, \boldsymbol{x_4}$)
Case1	1983408	(1,1,0,1)
Case2	117467	(1,1,0,1)
Case3	1738452	(1,1,0,1)
Case4	1293773	(1,1,1,1)
Case5	1234624	(0,0,1,1)
Case6	2447544	(0,0,0,1)

According to the general analysis, in the case of high defective rate, because the expected amount of loss caused by scheduling loss is much larger than the detection cost, enterprises should choose to detect spare parts, so as to achieve the highest net profit. In the case of a small actual defect rate, the benefits brought by the detection are not as good as the scheduling loss with a certain probability. At this time, the enterprise should choose not to detect and bear the scheduling loss, so as to achieve the highest net profit.

4. Conclusion

This paper proposes a set of solutions based on hypothesis testing and integer programming for parts evaluation and production decision optimization in electronic product production. Through the hypothesis test method, an efficient sampling detection model is constructed. Under the condition that the defective rate is controlled at 0.1 %, the minimum detection number scheme is provided for different reliability requirements. Enterprises should dynamically adjust several decisions on whether to detect according to the size of the defective rate, so as to achieve the highest net profit. At the same time, combined with integer programming and Monte Carlo simulation, the multi-stage production decision is optimized. The research provides theoretical support and technical solutions for quality control and production decision-making, helps enterprises improve efficiency, ensure quality, reduce costs, and provides strong support for the sustainable development of the electronic product manufacturing industry.

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