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ELECTRONIC PRODUCT ASSEMBLY DECIS-ION BASED ON THE DUAL PERSPECTIVES OF QUALITY AND COST

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Abstract: This paper aims to solve the problem of quality and cost control in the process of electronic product assembly. Through the cost-benefit analysis of each link in the assembly process, the mathematical model is constructed and the optimal decision-making scheme is proposed. The model comprehensively considers the defective rate of parts and finished products, detection cost, assembly cost, market price and other factors, aiming to achieve the best balance between product quality assurance and cost saving. Firstly, two sampling schemes are designed and compared, and a more economic binomial distribution scheme is recommended. Then according to the actual situation encountered in production, the cost and benefit of detecting spare parts, finished products and disassembling unqualified finished products are analyzed, and the optimal decision scheme is obtained after comparing the experimental data. In addition, taking two processes and eight spare parts as examples, three decision-making schemes are proposed to meet different needs. The experimental results can provide decision support for product assembly, help reduce costs, improve product quality and enhance market competitiveness.
Keywords: Simple random sampling; Cost-benefit theory; Decision tree algorithm; Central limit theorem; Product assembly decisions

1 INTRODUCTION

With the rapid development of science and technology, electronic products have become an indispensable part of people's lives, from smart phones to smart homes, the demand and market size of electronic products are continuing to grow. The assembly industry of electronic products is in a critical period of transformation and upgrading, and has huge market potential. For the problems related to product assembly, Zhu Haihua et al. studied the time prediction method based on the complete set of product assembly materials [1], Zhang Jin et al. proposed a risk early warning method for product assembly technical problems [2], and Shen Jitong et al. studied the planning and decision-making problem of material supply mode [3].
In this paper, we study the decision-making problems in the production process of an electronic product in a certain enterprise. The company purchases different kinds of spare parts (spare parts 1 to spare parts 8), and the finished products assembled into different types of spare parts are different. In the assembled finished product, as long as one of the spare parts is unqualified, the finished product must be unqualified; If the spare parts are qualified, the assembled finished product may not be qualified. For unqualified finished products, you can choose to scrap them, or disassemble them, the dismantling process will not cause damage to the spare parts, but the dismantling cost is required (data source: 2024 Higher Education Society Cup National College Students Mathematical Contest in Modeling[4]).
In view of the above process, the relevant mathematical model is established, and the following problems are solved: under the condition that the defective rate of a batch of spare parts does not exceed a certain nominal value, the sampling detection method is used to decide whether to accept this batch of spare parts. According to the two different reliability requirements, a sampling detection scheme with as few detection times as possible was designed, and specific detection results and decision-making schemes were given. Knowing the defective rate of two kinds of spare parts and finished products, we make decisions at all stages of the production process of the enterprise, including whether to test the spare parts, whether to test each finished product that has been assembled, and whether to disassemble the unqualified finished products that have been detected. According to the cost-effectiveness theory, the cost and profit under different decision-making schemes are analyzed, and the specific decision-making schemes and index results are also given for the situation of processes and spare parts. This paper analyzes the impact of sampling detection method on the decision-making scheme, weighs the potential risk loss caused by cost detection and non-detection, considers the market selling price, testing cost and the loss of replacing unqualified finished products, analyzes the dismantling cost and defective rate, and decides the dismantling or direct scrapping, and determines the optimal decision-making scheme according to the cost-benefit theory.

2 DESIGN A DETECTION PLAN BASED ON COST

2.1 Simple Random Sampling Testing

Based on the actual situation, this article makes the following assumptions:
(1) Assuming the sample size is large enough and the failure rate is not an extreme value;

(2) Assuming that the defect rates of spare part 1 and spare part 2 are independent of each other and do not affect each other's quality;
(3) Assuming that during each sampling test, the sample is randomly selected and the probability of each sample being selected is the same, ensuring that the sample is representative.

This article adopts a simple random sampling detection method where the samples follow a beta distribution and a binomial distribution respectively. When the nominal value is 10%, consider whether to accept this batch of spare parts in the following two situations:
(1) Case 1: Does the defect rate of spare parts exceed the nominal value with a 95% confidence level (significance level of α_1 is 0.05);
(2) Case 2: Does the defect rate of spare parts exceed the nominal value with a 90% confidence level (significance level of α_2 is 0.1)

2.1.1 Design samples that follow a beta distribution

In simple random sampling, the probability of all samples being selected is equal. Firstly, establish the hypothesis:
Null hypothesis H_0:The defect rate of spare parts P shall not exceed the nominal value P_0, that is:

$$H_0\textbf{:}\ \ P \le P_0 \tag{1}$$

Alternative hypothesis H_1:The defect rate of spare parts P exceeds the nominal value P_0, that is:

$$H_1\textbf{:}\ \ P > P_0 \tag{2}$$

Next, assuming that the overall defect rate is the nominal value, both parts 1 and 2 are defective and labeled as 1, while non defective parts are labeled as 0. Considering the actual situation, that is, the probability of the defect rate being lower than the nominal value is high, and the probability of the defect rate being higher than the nominal value is low, it is considered that this situation conforms to the beta distribution. Generate a random sample based on the beta distribution within the [0,1] interval[5], calculate the number of defective products in the sample, and then calculate the cumulative probability that the number of defective products is equal to or greater than the observed value. If the calculated value p is less than the significance level α_1, the null hypothesis is rejected, that is, if the defect rate of the spare parts exceeds the nominal value, the batch of spare parts will be rejected; if the calculated value p is greater than the significance level α_2, the null hypothesis is accepted, that is, the defect rate of the spare parts does not exceed the nominal value, and this batch of spare parts is accepted.

This article uses MATLAB to generate a random sample multiple times, which contains different numbers of defective products. To avoid accidental results caused by fewer runs, the number of generated samples is increased for different total numbers of spare parts, and the distribution between the defect rate and the value of the sample p is calculated. Taking the total number of spare parts as an example, when the number of runs is 100, the probability of the calculated value p being less than the significance level is α_1 0.13; when the number of runs is 1000, the probability that the calculated value p is less than the significance level α_2 is 0.067. As the generation frequency continues to increase, the probability of the calculated value p being less than the significance level α_1 decreases. According to the principle of low probability, events with very low probability are unlikely to occur in a single experiment. If the value p is considered to be greater than the significance level α_1, the null hypothesis cannot be rejected, and the defect rate does not exceed the nominal value. Through multiple experimental verifications, as shown in the p-value distribution at 100 runs in Figure 1, it is believed that at two levels of significance, when the number of defective products exceeds 13, the spare parts should be rejected.

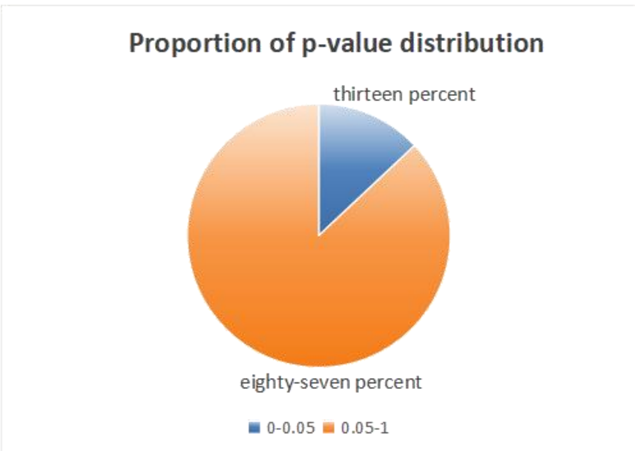

Figure 1 P-value Distribution at 100 Runs

2.1.2 The design sample follows a binomial distribution

For case one, at a significance level of 0.05, if the test results meet the following conditions, the spare parts will be rejected:

$$H_0: P \le P_0 \quad \text{VS} \quad H_1: P > P_0 \tag{3}$$

If the pass rate $\hat{p} \le P_0$, accept; otherwise, reject. For the rejection criteria in this situation, this is:

$$P(\hat{p} > P_0 | H_0) \le 0.05 \tag{4}$$

For case two, at a significance level of 0.1, if the test results meet the following conditions, the spare parts will be accepted:

$$H_0: P \ge P_0 \quad \text{VS} \quad H_1: P < P_0 \tag{5}$$

If the pass rate $\hat{p} < P_0$,accept; otherwise, reject. For the acceptiion criteria in this situation, this is:

$$P(\hat{p} < P_0 | H_1) \le 0.1 \tag{6}$$

Calculated from a nominal value P_0 of 0.1, with a 95% confidence level $n \ge \left(\frac{1.96\sqrt{0.1(1-0.1)}}{0.1} \right)^2 \approx 34$,is 34 sampling tests should be conducted. Let n be the threshold for rejection. Based on the binomial distribution $X \sim B(n,0.1)$ has $P(X > k) < 0.05$,use normal approximation to derive the relationship between the number of non-conforming parts k in the sample and the total number of parts n ($Z \approx 1.645$):

$k = 0.1n + 1.645\sqrt{0.09n}$,when n is taken as 100, if there are more than 14 defective products in the sample, they should be rejected.

At a 90% confidence level $n \ge \left(\frac{1.645\sqrt{0.1(1-0.1)}}{0.1} \right)^2 \approx 27$,is 27 sampling tests should be conducted. Similarly, according to the binomial distribution $P(X \le k) \ge 0.9$, the relationship between n and n is derived as follows($Z \approx 1.28$): $k = 0.1n + 1.28\sqrt{0.09n}$

When n is taken as 100, if there are more than 13 defective products in the sample, they should be rejected

The conclusion drawn from the comparison is that option two with fewer detection times should be chosen as the decision-making method to reduce detection costs.

3 MAKING DECISIONS BASED ON QUALITY

3.1 Model Establishment

Initialize whether to detect spare parts, semi-finished products, finished products, and whether to disassemble non-conforming products as 0-1 decision variables, and use a decision tree model to compare costs to obtain the optimal decision[6].

In the spare parts testing stage, each spare part has two options: testing and not testing. Choosing to test may increase costs, but it can ensure quality. Choosing not to test may result in unqualified spare parts entering the assembly process; During the assembly of finished products, only qualified spare parts can enter the assembly process to ensure the basic quality of the finished products; During the finished product testing phase, failure to conduct testing may result in unqualified products entering the market and affecting the reputation of the company;In the stage of handling non-conforming products purchased by users, the enterprise has the responsibility to handle the non-conforming products. Providing replacement services can improve customer satisfaction, but if replacement is not possible, the non-conforming products need to be reprocessed, which increases costs.

According to the production process, without testing spare parts 1 and 2, and without disassembling unqualified finished products, the quantity of finished products is m , and the total cost W_1 is:

$$W_1 = m*(x+y+z_1) \tag{7}$$

The defect rate P_1 is：

$$P_1 = (a+b-a*b+(1-a)*(1-b)*c) \tag{8}$$

If: (1) Consider whether to test spare part 1, the total cost W_2 is：

$$W_2 = \begin{cases} W_1 + m * z_2, \text{ Detect spare parts 1} \\ W_1, \text{Do not detect spare parts 1} \end{cases} \tag{9}$$

The defect rate P_2 is：

$$P_2 = P_1 * (b+c) / (a+b-a*b-(1-a)*(1-b)*c) \tag{10}$$

(2)Consider whether to test spare part 2, with a total cost of W_3 is:

$$W_3 = \begin{cases} W_1 + m * z_3, \text{ Detect spare parts 2} \\ W_1, \text{ Do not detect spare parts 2} \end{cases} \tag{11}$$

The defect rate P_3 is：

$$P_3 = P_1 * (a+c) / (b+c) \tag{12}$$

(3) Consider whether to test the finished product, with a total cost of W_4 is:

$$W_4 = \begin{cases} W_1 + m * z_4, \text{ Test finished products} \\ W_1, \text{ Do not test finished products} \end{cases} \tag{13}$$

The defect rate P_4 is：

$$P_4 = P_1 * (a+b-a*b) / (a+c) \tag{14}$$

(4) For non-conforming finished products, consider whether to disassemble them, with a total cost of W_5 is:

$$W_5 = \begin{cases} W_1 + q_2 + q_3 - 2*m*(a*x+b*y+c*x+c*y), \text{ Disassemble} \\ W_1 + q_2, \text{Do not disassemble} \end{cases} \tag{15}$$

The net profit margin P_5 is：

$$P_5 = m*(1-P_4)*q_1 - W_4 \tag{16}$$

(Among them, a , b and c respectively represent the damage rates of parts 1, 2, and 3, x represents the unit price of part 1, y represents the unit price of part 2, z_1 represents the assembly cost, z_2 and z_3 respectively represent the inspection cost of parts 1 and 2, z_4 represents the cost inspection cost, q_1 represents the market price, q_2 represents the exchange loss, and q_3 represents the dismantling cost).

3.2 Model Solving

Taking a defect rate of 10%, a purchase price of 12 yuan/piece, and a testing cost of 2 yuan/piece as an example.
(1)Root node (starting point), decision: whether to detect spare part 1; Option: Yes/No.
(2)The first level decision node
If you choose "Yes" to test spare part 1, the testing cost is 2 yuan per piece. Assuming that the defect rate after testing is 0, that is, all defective products are detected. Authentic product revenue is $90\% \times 12 = 10.8$ yuan, total cost is $12 + 2 = 14$ yuan, each spare part incurs a loss of $10.8 - 14 = -3.2$ yuan. Due to the zero defect rate after testing, the finished product is also genuine and does not require additional testing costs. The final profit is $10.8 - 3.2 = 7.6$ yuan.
If you choose 'No' to test spare part 1, there will be no testing cost, and the defect rate will remain unchanged at 10%.
(3)The second level decision node[7], decision: whether to detect spare part 2; Option: Yes/No.
If you choose "Yes" to test spare part 2, the testing cost is 2 yuan/piece, and the genuine product income is $90\% \times 12 = 10.8$ yuan The total cost is $12 + 2 = 14$ yuan. Each spare part incurs a loss of $10.8 - 14 = -3.2$ yuan.
If you choose "No" to test spare parts 2, there will be no testing cost, and the genuine product revenue will be $12 + 2 = 14$ yuan. The total cost is 12 yuan Each spare part has a profit of $10.8 - 14 = -3.2$ yuan.
(4)The third level decision node, decision: whether to detect the finished product; Option: Yes/No.
If you choose "Yes" to test the finished product: the testing cost is 2 yuan/piece, and the genuine product revenue is $90\% \times 12 = 10.8$ yuan The total cost is $12 + 2 = 14$ yuan Each finished product incurs a loss of $10.8 - 14 = -3.2$ yuan.
If you choose "No" to test the finished product: no testing cost, genuine product revenue of $90\% \times 12 = 10.8$ yuan, total cost of 12 yuan Each finished product incurs a loss of $10.8 - 14 = -3.2$ yuan. Due to not dismantling unqualified products, there are no additional costs or benefits.
Final decision

Inspect spare parts 1, do not inspect spare parts 2 and finished products, and do not disassemble non-conforming products The maximum profit obtained is 10.40 yuan.
For the case of m processes and n spare parts, use probability addition and multiplication rules to calculate the probability of each situation, and add them together to obtain the expression for the damage rate of d. Repeat the process of nesting the decision tree model mentioned above[8].
This decision tree model demonstrates[9] the calculation of expected profits at different decision points and how to maximize profits by selecting different detection strategies This includes whether to inspect spare parts, dismantle semi-finished or finished products, and whether to dismantle non-conforming products. It comprehensively analyzes the costs and profits under different decisions, making the decisions more systematic and scientific.

4 PROVIDE THREE DECISION OPTIONS SUITABLE FOR DIFFERENT TYPES OF MANUFACTURERS BASED ON COST-BENEFIT THEORY

4.1 Risk Management

According to the cost-benefit theory[10], mark spare parts 1, 2, and 3 as A, B, and C respectively, semi finished product 1 is denoted as D and construct the following six decision-making schemes to explore different combinations of whether to inspect spare parts 1, spare parts 2, and finished products, as well as whether to disassemble unqualified finished products:
Plan 1: Do not detect A and B, do not dismantle non-conforming products; plan 2: detect A, do not detect B, do not dismantle non-conforming products; plan 3: do not detect A, detect B, do not dismantle non-conforming products; plan 4: detect A and B, do not disassemble non-conforming products; plan 5: detect A and B, disassemble non-conforming products; plan 6: do not test A and B, disassemble non-conforming finished products.
According to the strategy of minimizing costs and maximizing profits[11], that is, achieving cost minimization and profit maximization while ensuring product quality meets established standards. Cost identification includes inspection costs for spare parts, semi-finished products, and finished products, procurement costs for spare parts, assembly costs for semi-finished and finished products, dismantling costs for non-conforming products, and exchange losses for non-conforming products. Revenue recognition includes the revenue generated from the sale of finished products, as well as the recycling value of spare parts after dismantling of non-conforming finished products.
Fully consider risk factors in the decision-making process to avoid potential losses caused by decision-making errors. Identify eight possible combinations of situations for the damage of semi-finished product 1, as shown in Table 1, and use probability addition and multiplication rules to calculate the probability of each situation. The following is the expression for the damage rate of semi-finished product 1:

$$e = a + b + c - ab - ac - bc + abc + (1-a)(1-b)(1-c)d \tag{17}$$

Table 1 Damage Situation Combination

——	A	B	C	D
case1	damage	intact	intact	——
case2	intact	damage	intact	——
case3	intact	intact	damage	——
case4	damage	damage	intact	——
case5	damage	intact	damage	——
case6	intact	damage	damage	——
case7	damage	damage	damage	——
case8	intact	intact	intact	damage

Furthermore, by using the central limit theorem, the defect rate of the sample is approximated as the overall defect rate, thereby improving the confidence level of estimating the defect rate of spare parts and semi-finished products and effectively reducing decision risk[12].

4.2 Provide A Decision-Making Plan

Table 2 Possible Situations Encountered during Product Assembly Process

Spare parts	Defective rate	Purchase price	Testing cost	Partially Prepared Products	Defective rate	Assembly cost	Testing cost	Dismantling cost
1	10%	2	1	1	10%	8	4	6
2	10%	8	1	2	10%	8	4	6
3	10%	12	2	3	10%	8	4	6
4	10%	2	1	——	——	——	——	——
5	10%	8	1	finished product	10%	8	4	6

6	10%	12	2	——	——	——	——	——
7	10%	8	1	——	Market selling price		Exchange losses	
8	10%	12	2	finished product	200		40	

As shown in Table 2, the defect rate, purchase price, testing cost, assembly cost, testing cost, and disassembly cost of semi-finished parts, semi-finished products, and finished products are known. Among them, semi-finished product 1, semi-finished product 2, and semi-finished product 3 are respectively composed of spare parts 1, spare parts 2, spare parts 3 and 4, spare parts 5, spare parts 6 and 7, and spare parts 8. The finished product consists of semi-finished product 1, semi-finished product 2, and semi-finished product 3. Firstly, for semi-finished products, a decision tree model is used to determine the minimum cost of semi-finished products Secondly, for the finished product, provide a decision-making plan for the production process, as well as the basis and corresponding indicators for the decision[13].

4.2.1 Minimize the production cost of the enterprise

Under this decision-making plan, the plan with the lowest production cost for the enterprise is taken as the optimal decision-making plan[14]. At this point, if the finished product is not inspected or damaged, it needs to be disassembled, and the final cost per unit of finished product is calculated to be 133.4 yuan. If enterprises use this decision-making scheme, although they can obtain high profits, they also bear high risks, which is more suitable for enterprises with advanced production equipment and relatively controllable finished product damage rates. The specific decision variable records are shown in Table 3 (where "0" represents "no" and "1" represents "yes").

Table 3 Optimal Decision Plan with Minimum Cost

——	Partially Prepared Products 1	——	Partially Prepared Products 2	——	Partially Prepared Products 3
Whether to detect spare parts 1	0	Whether to detect spare parts 4	0	Whether to detect spare parts 7	0
Whether to detect spare parts 2	0	Whether to detect spare parts 5	0	Whether to detect spare parts 8	0
Whether to detect spare parts 3	0	Whether to detect spare parts 6	0	——	——
Whether to detect semi-finished products 1	0	Whether to detect semi-finished products 2	0	Whether to detect semi-finished products 3	0
Damage rate	0.1	Damage rate	0.1	Damage rate	0.1
Whether to disassemble or not	0	Whether to disassemble or not	0	Whether to disassemble or not	1
cost(yuan)	26	cost(yuan)	26	cost(yuan)	26

4.2.2 Maximize the production cost of the enterprise

Under this decision scheme, the optimal decision scheme is the one that maximizes the production cost of the enterprise. At this time, the cost is not tested and needs to be dismantled after damage. The final calculated cost per unit of finished product is 173 yuan. If the enterprise uses this decision-making scheme, although it requires the least risk, the profit is the least. This scheme is more suitable for enterprises with fixed sales channels and stable production all year round[15]. The decision variable records are shown in Table 4 (where "0" represents "no" and "1" represents "yes").

Table 4 Optimal decision plan under maximum cost

——	Partially Prepared Products 1	Partially Prepared Products 2	Partially Prepared Products 3
Spare parts 1	1	1	1
Spare parts 2	1	1	1
Spare parts 3	1	1	1
Whether to test or not	1	1	1
Whether to disassemble or not	1	1	0
cost(yuan)	40	40	35

4.2.3 Take the median of enterprise production costs

Under this decision-making scheme, the optimal solution is to take the median of the production cost of the enterprise. At this time, if the finished product is not inspected or damaged, it needs to be disassembled. The final cost per unit of finished product is calculated to be 157.5 yuan. Compared to the above two decision-making schemes, this scheme has higher stability and is more suitable for the production of most enterprises. The decision variable records are shown in Table 5 (where "0" represents "no" and "1" represents "yes").

Table 5 Optimal Decision Plan for Taking the Median Cost

——	semi-finished product 1		——	semi-finished product 2		——	semi-finished product 3		
Whether to detect spare parts1	0	1	Whether to detect spare parts4	0	1	Whether to detect spare parts7	0	1	1
Whether to detect spare parts2	1	0	Whether to detect spare parts5	1	0	Whether to detect spare parts8	0	0	0
Whether to detect spare parts3	1	1	Whether to detect spare parts6	1	1	——	—	—	—
Whether to detect or not	1	1	Whether to detect or not	1	1	Whether to detect or not	1	1	1
Whether to disassemble or not	0	0	Whether to disassemble or not	0	0	Whether to disassemble or not	1	0	0
cost(yuan)	33		cost(yuan)	33		cost(yuan)	30.5		

5 CONCLUSION

In this paper, the decision-making problem of electronic product assembly from the dual perspectives of quality and cost is studied. Factors such as whether to detect and whether to disassemble are initialized as 0-1 decision variables, and flexibly adjusted and optimized according to the actual needs and conditions of different manufacturers. In view of the defective rate of spare parts, this paper designs a sampling detection scheme with samples obeying beta distribution and binomial distribution, and reduces the cost for enterprises by calculating and comparing the detection times and rejection standards of the two schemes. According to the assembly situation of each process and spare parts, the decision tree algorithm is used to analyze a variety of decision combinations, and three decision-making schemes suitable for different types of manufacturers are proposed. The model and solution established in this paper can provide decision support for product assembly, help reduce costs, improve product quality, and enhance market competitiveness, which has certain reference significance for the actual production and assembly of electronic products.Although the current research has made significant progress, we recognize that there is still much work to be done. Through continuous efforts and improvement, we hope to provide a more advanced, practical and reliable decision support system for electronic product assembly in future practice, and help the transformation, upgrading and sustainable development of the industry.

COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

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