An Optimal Model for Quality Inspection Station Setting

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Abstract. The quality of products depends on the process of product processing, so controlling the quality of products during processing is an important measure to ensure the final quality of products. The article aims at the problem of setting up inspection stations in the manufacturing process correctly. Through the analysis of the total cost and total processing time, taking the minimum total production cost and total processing time as the objective function, the optimization setting model of quality inspection station is established, and the particle swarm optimization algorithm is used to solve the model to determine the location of the inspection station in the product processing process and quantity. The effectiveness of the model is verified through the production process of automobile crankshaft as an example.

1. Introduction
In the manufacturing process of mechanical products, due to the complexity of the manufacturing process, it is easy to lead to various quality problems. In order to prevent unqualified products produced in a certain process from continuing to be processed, a quality inspection station should be set up after the corresponding process to conduct product quality inspection. However, setting up a quality inspection station on the production line increases the cost and processing time. Therefore, it is necessary to set up a quality inspection station on the production line to ensure maximum product quality while investing the least cost [1]. At present, domestic and foreign scholars have done some research on quality inspection control strategy.

MC Mullen [2] used the sensitivity analysis method to configure the quality inspection station during the product process. Azadeh [3] studied the optimization of inspection strategy in continuous production process. A general model of quality inspection strategy was proposed by Liu [4], and the problem was solved by simulated annealing algorithm. Yinlu [5] and others established an economic analysis model based on the cost of setting up inspection stations in the process, and put forward suggestions on the quality control strategy of the production process.

In order to produce qualified products, it is usually necessary to set up inspection stations at the workstations; however, from an economic point of view, the installation of inspection stations will greatly increase the cost, which will be a great challenge for enterprises. To solve this problem, this paper establishes an optimal setting model of quality inspection stations, and designs a particle swarm optimization algorithm to solve them, so as to determine the location and quantity of inspection stations during product processing.
2. Problem Description
For the flow-line production of m stations, raw materials are processed successively from the first station. During the processing process, product quality problems may occur due to various reasons. Therefore, an inspection station is set up after the station to form a work unit with this station to conduct product quality inspections to ensure product quality.

![Flow-line Production](image)

**Fig 1.** Flow-line Production.

The establishment of inspection stations can largely ensure the quality of products, but it also increases the cost of manpower and material resources, and the increase in inspection time may affect the delivery time and other issues. Therefore, under the premise of ensuring the cost and cycle, it is necessary to reasonably establish the location and number of inspection stations.

3. Establishment an optimized model for quality inspection station
The processing cost, inspection cost, maintenance cost, rework cost, scrap cost and processing time, inspection time, maintenance time, rework time are considered when the inspection station is set or not. In order to minimize the total cost and total processing time, the optimization model of quality inspection station is established to determine the location and number of inspection stations. The modeling parameters are defined as follows:

- $N$: Number of products
- $m$: Number of work stations
- $S_i$: The $i$-th processing station $i = (1, 2 \ldots m)$
- $N_i$: Number of products entering station $S_i$
- $I_i$: The $i$-th test station located in the station $S_i$
- $P_i$: The unqualified rate of products of station $S_i$
- $P_{ai}$: The maintenance rate of unqualified products at station $S_i$
- $P_{bi}$: The scrap rate of unqualified products at station $S_i$
- $P_{ci}$: The rework rate of unqualified products at station $S_i$
- $E_i$: The fixed costs of setting up inspection stations
- $F_i$: The fixed costs of setting up IOT acquisition equipment
- $C_i$: Cost incurred when station $S_i$ has an inspection station
- $T_i$: Working hours when station $S_i$ has an inspection station
- $A_i$: Unit processing cost of station $S_i$
- $T_{Ai}$: Unit processing time of station $S_i$
- $B_i$: Unit inspection cost of inspection station $I_i$
- $T_{Bi}$: Unit inspection time of inspection station $I_i$
- $f_i$: Unit maintenance cost of inspection station $I_i$
- $T_{fi}$: Unit maintenance time of inspection station $I_i$
- $g_i$: Unit scrap cost of inspection station $I_i$
- $R_i$: Unit rework cost of inspection station $I_i$
- $T_{Ri}$: Unit rework time of inspection station $I_i$
- $\alpha_i$: Whether station $S_i$ sets the decision variable of inspection station
- $C$: Total cost of production line
- $T$: Total processing time of production line

Model assumptions are as follows:
1. The unqualified products need to be repaired are repaired at the inspection station, and the qualified products enter the next station after repair.
(2) Products need to be reworked are returned to this station for rework. After rework, they are qualified products and go directly to the next station.
(3) Scrap products are directly separated from the production line.
(4) All machines on the production line can operate normally.
(5) The logistics time between stations is not considered, and the situation of stagnation and blockage is not considered during the processing.
(6) Assume that the unit cost and unit time of each product at each station are fixed.

The number of products entering the station $S_i$:

$$N_i = \prod_{j=i}^{j}[1 - \alpha_{j,i} P_{j-1}]$$

(1)

The cost incurred when station $S_i$ is not set up with inspection station:

$$C_i' = \prod_{j=i}^{j}[1 - \alpha_{j,i} P_{j-1}] A_i$$

(2)

The cost of setting the inspection station at work station $S_i$:

$$C_i = \prod_{j=i}^{j}[1 - \alpha_{j,i} P_{j-1}] (A_i + \alpha_i Y_i) + F_i + E_i$$

(3)

The time when the station $S_i$ does not set up the inspection station is:

$$T_i' = \prod_{j=i}^{j}[1 - \alpha_{j,i} P_{j-1}] T_{i-1}$$

(4)

The time when the station $S_i$ is set to the inspection station is:

$$T_i = \prod_{j=i}^{j}[1 - \alpha_{j,i} P_{j-1}] [T_{i-1} + \alpha_i (T_{i-1} + P_i T_{i-1} + P_i T_{i-1})]$$

(5)

Objective function:
Minimum total cost of production line

$$\min C = \sum_{i=1}^{m} \prod_{j=1}^{j}[1 - \alpha_{j,i} P_{j-1}] (A_i + \alpha_i Y_i) + F_i + E_i$$

(6)

Minimum total production line time

$$\min T = \sum_{i=1}^{m} \prod_{j=1}^{j}[1 - \alpha_{j,i} P_{j-1}] [T_{i-1} + \alpha_i (T_{i-1} + P_i T_{i-1} + P_i T_{i-1})]$$

(7)

Constraint condition:
(1) $Y_i$ is the sum of inspection cost, maintenance cost, scrap cost and rework cost incurred by the $i$-th station.

$$Y_i = B_i + P_i f_i + P_i g_i + P_i R_i \quad i = 1, 2, \ldots, m$$

(8)
(2) The products in process that just entered the production line are all qualified products, and the defective product rate is zero.

\[ P_{i(i-1)} = 0 \quad i = 1 \]  

(9)

(3) No quality inspection station is set before the first station.

4. Algorithm Design for the Setting of Quality Inspection Station

The Particle Swarm Algorithm (PSO) originated from the study of activities such as foraging and migration of birds in the real world. Due to its simple algorithm structure, few parameters and fast convergence speed, it has been widely used in different fields soon after being proposed [6]. In this paper, particle swarm algorithm is used to solve the optimization model of quality inspection station.

Encode whether each station on the assembly line is set as an inspection station. Use 1 to indicate that the station is equipped with an inspection station, and 0 to indicate that the station does not have an inspection station. Because it is a discrete problem, the position of the particle in space is limited to two states of 0 and 1. The position update of the particle in space will be calculated by the following formula.

In the formula, \( r_3 \) represents a random number between 0 and 1. The designed algorithm process is as follows.

Step1: Binary initialized particle swarm, set the acceleration constant and the maximum iteration factor, and randomly allocate the speed and position of the particles;

Step2: According to the fitness value of the two objectives in the population, the Pareto dominance level is calculated, and the external elite solutions are sorted according to the crowding distance;

Step3: Update the external solution set, delete particles exceed the external elite solution set, and generate a new external elite solution set;

Step4: Update the optimal position of the individual;

Step5: Select the global optimal position from the current external set, and some individuals are selected as the global optimal value according to the individual optimal value in the elite solution set;

Step6: Calculate random point \( r_3 \);

Step7: Update the velocity of particles to determine the value of particles in space is 0 or 1, and generating new particles;

Step8: Check whether all particles have been calculated, if not, go to Step6;

Step9: Check the end condition, if it is met, the output of the optimal value will be ended, if it is not met, go to Step2 and search again.

5. Case Analysis

Crankshaft is one of the most important parts in automobile engine, Therefore, taking crankshaft as the research object. According to the crankshaft processing technology, the process is divided into 14 operation units such as station 1-milling end face, drilling center hole, etc. Represented by \( S_i \) (\( i = 1 \ldots 14 \)), the processing procedure, process name and processing equipment used for the specific station are shown in Table 1.
Table 1. Crankshaft Machining Process.

| Station | Process | Process name | Type of Machine | Tool |
|---------|---------|--------------|-----------------|------|
| S1      | 1       | Milling end face and punch center hole | Special lathe |      |
| S2      | 2       | Machining the outer circle of the thrust journal | Numerical control lathe |      |
| S3      | 3       | Rough grinding thrust journal outer circle | Grinding machine |      |
| S4      | 4, 5    | Rough machining of spindle neck and both ends | Numerical control lathe |      |
| S5      | 6, 7    | Rough machining of connecting rod neck, machining oil hole | Numerical control lathe |      |
| S6      | 8       | Medium Cleaning | Cleaning machine |      |
| S7      | 9       | Heat Treatment | Special lathe |      |
| S8      | 10      | Straightening | Special lathe |      |
| S9      | 11, 12  | Thrust surface grinding, journal grinding | Special lathe |      |
| S10     | 13      | Machining of threaded holes at both ends, positioning pin holes | Machining Center |      |
| S11     | 14      | Milling keyway | Universal equipment |      |
| S12     | 15      | Dynamic balance | Special lathe |      |
| S13     | 16      | Flaw detection | Special lathe |      |
| S14     | 17      | Polishing | Special lathe |      |

According to the crankshaft processing technology, for each station in the manufacturing process, determine the type of quality defects that may occur in the crankshaft manufacturing process at this station, and analyze the possible consequences of each defect and the treatment methods that need to be taken. The results are shown in Table 2.

Table 2. Related Parameters of Crankshaft Machining Process.

| S | P_i | P_{ai} | P_{bi} | P_{ci} | E_i | F_i | A_i | T_{Aj} | B_i | T_{Bi} | f_i | T_{fi} | g_i | R_i | T_{Ri} | C_{pi} | T_{pi} |
|---|-----|--------|--------|--------|------|-----|-----|--------|-----|--------|-----|--------|-----|-----|--------|--------|--------|
| S1 | 0.015 | 0 | 0.01 | 0.005 | 70 | 26 | 18 | 8 | 3 | 3 | 3 | 2 | 12 | 6 | 6 | 7 | 12 |
| S2 | 0.007 | 0 | 0.004 | 0.003 | 68 | 23 | 15 | 6 | 2 | 3 | 3 | 2 | 8 | 4 | 5 | 10 | 13 |
| S3 | 0.002 | 0 | 0.001 | 0.001 | 72 | 18 | 17 | 5 | 2 | 2 | 4 | 1 | 11 | 5 | 4 | 8 | 10 |
| S4 | 0.005 | 0 | 0.002 | 0.003 | 65 | 28 | 14 | 6 | 4 | 3 | 2 | 1 | 6 | 7 | 4 | 7 | 12 |
| S10 | 0.006 | 0.001 | 0.002 | 0.003 | 75 | 25 | 16 | 9 | 4 | 3 | 2 | 9 | 6 | 6 | 12 | 11 |
| S6 | 0.008 | 0 | 0.003 | 0.005 | 80 | 22 | 18 | 7 | 3 | 3 | 4 | 1 | 10 | 7 | 3 | 9 | 14 |
| S7 | 0.003 | 0 | 0 | 0.003 | 70 | 26 | 17 | 8 | 4 | 3 | 3 | 1 | 10 | 6 | 3 | 7 | 10 |
| S8 | 0.009 | 0 | 0.003 | 0.006 | 60 | 24 | 18 | 7 | 4 | 3 | 2 | 2 | 11 | 7 | 4 | 6 | 11 |
| S9 | 0.003 | 0.002 | 0 | 0.001 | 50 | 16 | 13 | 6 | 2 | 2 | 2 | 1 | 4 | 2 | 3 | 8 | 13 |
| S10 | 0.002 | 0.001 | 0 | 0.001 | 65 | 22 | 16 | 7 | 4 | 3 | 3 | 2 | 8 | 5 | 6 | 10 | 12 |
| S11 | 0.001 | 0 | 0 | 0.001 | 70 | 24 | 18 | 5 | 4 | 2 | 4 | 1 | 9 | 8 | 9 | 13 | 15 |
| S12 | 0.003 | 0 | 0.002 | 0.001 | 75 | 26 | 17 | 6 | 3 | 3 | 5 | 2 | 10 | 9 | 11 | 9 | 14 |
| S13 | 0.004 | 0 | 0.003 | 0.001 | 78 | 23 | 19 | 5 | 4 | 2 | 5 | 2 | 9 | 8 | 9 | 10 | 11 |
| S14 | 0.003 | 0 | 0.002 | 0.001 | 76 | 24 | 20 | 6 | 3 | 1 | 6 | 2 | 8 | 9 | 13 | 11 | 12 |

Assume that the number of crankshafts produced in a batch is N=1000. According to the optimization modeling process discussed above, the relevant parameter values of the crankshaft are brought into the
optimization setting model of the quality inspection station, and the algorithm is written by MATLAB, and the Pareto solution set is obtained after 500 iterations.

It can be seen when only one of the total cost or the total processing time is considered to be optimal, the other target will be affected. For example, when the total cost is optimal, the best result of the inspection station setting on the crankshaft production line is solved. The optimal solution is 11011101100000, that is, 7 quality inspection stations should be set up at the 1, 2, 4, 5, 6, 8, and 9 stations. When the total processing time is optimal, the result of the inspection station setting on the knuckle production line is solved. The optimal solution is 110101100011, that is, 8 quality inspection stations should be set up at stations 1, 2, 4, 6, 8, 9, 13, and 14. For the crankshaft machining problem, according to the different requirements of different periods, enterprise managers can choose the most suitable plan.

6. Conclusions
Aiming at the product quality inspection problems in assembly line production, this article analyzes the reasonable setting of quality control strategies, and how to set the number and location of inspection stations under the conditions of cost and production time. For assembly line processing, the minimum total cost of production line, the minimum total processing time as the objective function to establish the quality inspection station optimization model, using particle swarm optimization algorithm to solve. Take the production of automobile engine crankshaft as an example to conduct verification and analysis, and obtain the location and number of quality inspection stations on the crankshaft production line, verifying the validity of the model.

References
[1] Maleki H, Shabestari A A. A heuristic method against simulation for optimal allocation of inspection stations in manufacturing systems [J]. Simulation, 2018, 94(11): 1027-1040.
[2] Mc Mullen P R. A genetic algorithm for multiple inspections with multiple objectives. [J]. American Journal of Operations Research, 2013, 3(06): 463.
[3] Azadeh A, Sangari M S, Sangari E, et al. A particle swarm algorithm for optimising inspection policies in serial multistage production processes with uncertain inspection costs [J]. International Journal of Computer Integrated Manufacturing, 2015, 28(7):766-780.
[4] LIU C G, ZHOU Z Y, ZHAO X B. Optimization of quality control in production systems [J]. Journal of Tsinghua University (Science and Technology), 2000(05):54-57.
[5] LIN X, CUI T, Yang, B B. Method for establishing machining and inspection model of multistage machining processes of thin-walled blades [J]. Hangkong Xuebao, 2019, 40(11): 124-132.
[6] Zhang L B, Zhou C G, Ma M, et al. Solutions of multi-objective optimization problems based on particle swarm optimization [J]. Journal of Computer Research and Development, 2004(07): 249-254.