Research on Effectiveness Evaluation Method of Product Quality Improvement Plan Based on Actor Analysis Method

Wu Qian¹,a, Wang Chaowei², Pei Fei³,b*, Xu Yingcheng¹ and Lu Xiaowei¹

¹China National Institute of Standardization, Beijing, China, ²China Ship Develop and Design Center, Wuhan, China ³China standard promoting quality science and technology (beijing) co., ltd, Beijing, China

Corresponding author: aустбwuqian@163.com; bPeifei@cnis.ac.cn

Abstract. This paper divides the effectiveness evaluation index of product quality improvement programs into objective and quantifiable cost-based index such as equipment modification cost, personnel training cost, process upgrading cost, and other costs which is subjective unquantifiable index such as production level, quality and safety level, sales volume, and customer satisfaction. By introducing actor analysis method, the effectiveness evaluation model of product quality improvement plan based on actor analysis method is established. A toy manufacturer is used as an example in applying and analyzing the model and comprehensively evaluating the effectiveness of each proposed plan to verify the operability of the model. The method is scientific and reasonable, simple and easy to operate, can be widely spread in relevant enterprises, and can provide effective method guidance for enterprises in selecting the optimal plan and avoiding unnecessary losses.

1. Introduction
With the rapid development of economic globalization, market competition is becoming increasingly fierce. Only by continuously improving product quality can enterprises stand out in the fierce market competition [1]. Therefore, it has become the biggest challenge facing enterprises to make scientific and effective quality improvement plans. At present, scholars at home and abroad have carried out a series of researches on product quality improvement. They widely apply PDCA cycle, FTA, SPC, MSA and other methods in the Equationtion of product quality improvement plans [2]. For example, Wang Shuo (2019) [1], Zhou Jian (2019) [3], Su Shufeng (2014) [4], etc. use PDCA cycle as a tool for enterprise product quality management. Wu Yisha (2013) [5], Lin Hualin (2019) [6], etc. put forward the method of enterprise product quality improvement based on FMEA and FTA. And Yang Ping (2018) [7], Wu Huazhi (2017) [8], etc. apply SPC in the quality improvement plan of tobacco, elevator and other products.

However, a systematic analysis of numerous domestic and foreign literatures on quality improvement reveals the problem of insignificant input and output effects in the implementation of product quality improvement plan. The cause is the lack of a comprehensive, objective and scientific method for evaluating the effectiveness of the quality improvement plan. Therefore, how to transform the implicit management ideas of quality management and quality improvement into intuitive and explicit evaluation is the focus of study in this paper. Since the product quality improvement plan involves quantifiable cost and benefit indicators and subjective, unquantifiable descriptive evaluation
indicators, this paper introduces the actor analysis method combining subjective and objective evaluation to solve the problem in effectiveness evaluation of product quality improvement plan.

2. Effectiveness Evaluation Indicator of Quality Improvement Plan
The purpose of enterprises carrying out product quality improvement is to optimize the production capacity and improve the product quality and safety level through the improvement of equipment modification, personnel training, process upgrading, etc., so as to improve customer satisfaction, promote product sales and increase profits. The indicators such as equipment modification, personnel training and process upgrading are objective and quantifiable cost indicators. The smaller the indicator value, the better. While indicators like product production level, quality and safety level, customer satisfaction and sales volume are subjective and unquantifiable benefit indicators. The greater the indicator value, the better.

The evaluation of objective and quantifiable cost indicators is respectively expressed by the cost values of equipment modification, personnel training, process upgrading, etc. The evaluation of product production level, quality and safety level and sales volume is expressed subjectively in four levels, i.e. drop, unchanged, rise and sharp rise. The evaluation of customer satisfaction indicator is expressed subjectively in four levels, i.e. dissatisfied, satisfied, somewhat satisfied and very satisfied.

Therefore, considering the purpose of product quality improvement and the expression method of indicator evaluation, the effectiveness evaluation indicators are classified as Table 1:

| Primary indicator | Secondary indicator             | Expression method of indicator evaluation                                      |
|-------------------|--------------------------------|----------------------------------------------------------------------------------|
| Objective indicator | Equipment modification cost | Expressed by equipment modification cost value                                    |
|                   | Personnel training cost       | Expressed by personnel training cost value                                       |
|                   | Process upgrading cost        | Expressed by process upgrading cost value                                        |
|                   | Other costs                   | Expressed by cost values required for other improvements                          |
| Subjective indicator | Production level             | Expressed by production level drop, unchanged, rise and sharp rise                 |
|                   | Quality and safety level      | Expressed by quality and safety level drop, unchanged, rise and sharp rise         |
|                   | Sales volume                  | Expressed by sales volume drop, unchanged, rise and sharp rise                     |
|                   | Customer satisfaction         | Expressed by dissatisfied, satisfied, somewhat satisfied and very satisfied       |

3. Effectiveness Evaluation Model Based on Actor Analysis Method
The actor analysis method was originally used as a methodology for facility site selection and engineering experimental research. But it is now widely used in the fields of supply chain management, efficiency evaluation, professional title evaluation, etc. due to its use in comprehensive evaluation combining qualitative and quantitative evaluation of both subjective and objective factors [9, 10]. This paper introduces the method into the efficiency evaluation of product quality improvement plan to evaluate and optimize the plan to avoid various losses caused by plan defects, so as to achieve the purpose of saving costs and increasing benefits of enterprises.
3.1. Determination of Evaluation Indicators and Their weight

According to the above analysis, the evaluation indicators of product quality improvement plan include 4 objective indicators of equipment modification cost, personnel training cost, process upgrading cost and other costs, and 4 subjective indicators of production level, quality and safety level, customer satisfaction and sales volume.

The weight of evaluation indicator is a value that reflects the relative importance of objective and subjective indicators. It can be determined by experts grading method, AHP method, Delphi method, etc.

Definition 1: the weight value of objective factors is expressed by \( X \) and \( X \in [0,1] \), so the weight value of subjective factors can be expressed as: \( 1 - X \).

If \( X = 0.5 \), objective factors and subjective factors are equally important. If \( 0.5 < X \leq 1 \), objective factors are more important than subjective factors. If \( 0 \leq X < 0.5 \), subjective factors are more important than objective factors.

3.2. Determination of Objective Measure

For each product quality improvement plan, an objective measure \( \text{OM}_i \) can be found. The measure is affected by various objective evaluation indicators of proposed product quality improvement plans. The specific calculation Equation is as follows:

\[
\text{OM}_i = \left[ \frac{C_i \sum_{j=1}^{m} \frac{1}{C_{ij}}} {\sum_{j=1}^{J} C_{ij} \sum_{i=1}^{m} \frac{1}{C_{ij}}} \right]^{-1} \tag{1}
\]

Where,
- \( i \) represents the \( i^{th} \) proposed product quality improvement plan, \( i = 1, 2, 3, \ldots m \);
- \( j \) represents the \( j^{th} \) objective evaluation indicator, \( j = 1, 2, 3, \ldots J \);
- \( C_{ij} \) represents the cost of the \( j^{th} \) objective evaluation indicator of the \( i^{th} \) proposed product quality improvement plan;
- \( C_i \) represents the total cost of the \( i^{th} \) proposed product quality improvement plan,
- \( \text{OM}_i \) represents the objective measure of the \( i^{th} \) proposed product quality improvement plan, and the sum of the objective measures of all proposed product quality improvement plans is 1, i.e. \( \sum_{i=1}^{m} \text{OM}_i = 1 \), \( \text{OM}_i \in [0,1] \).

3.3. Determination of Subjective Rating Value

Since there is no quantized value for the subjective evaluation indicators of proposed product quality improvement plans, the forced-choice method is used as a comparison method to measure the advantages and disadvantages of each proposed plan. The forced-choice method is to make a pair comparison between one plan and the others, giving weight value 1 to the best and 0 to the inferior. Then, the subjective rating value \( S_{ik} \) of each proposed product quality improvement plan is calculated according to the ratio of the weight of the plan to the total weight. The specific calculation Equation is as follows:

\[
S_{ik} = \frac{W_{ik}}{W_k} = \frac{W_{ik}}{\sum_{i=1}^{m} W_{ik}} \tag{2}
\]

Where,
- \( i \) represents the \( i^{th} \) proposed product quality improvement plan, \( i = 1, 2, 3, \ldots m \);
- \( k \) represents the \( k^{th} \) subjective evaluation indicator, \( K = 1, 2, 3, \ldots K \);
- \( W_{ik} \) represents the weight of the \( i^{th} \) proposed product quality improvement plan in the \( k^{th} \) subjective evaluation indicator;
- \( W_k \) represents the total weight value of the \( k^{th} \) subjective evaluation indicator,
- \( S_{ik} \) represents the subjective rating value of the \( i^{th} \) proposed product quality improvement plan in terms of the \( k^{th} \) indicator. The value varies from 0 to 1, and the closer to 1, the better the plan is. The sum of the subjective rating values of all proposed product quality improvement plans in terms of the \( k^{th} \) indicator is 1, i.e. \( \sum_{i=1}^{m} S_{ik} = 1 \), \( S_{ik} \in [0,1] \).
3.4. Determination of Subjective Measure
Since there are several subjective rating values for the proposed product quality improvement plan and the importance of each subjective evaluation indicator varies, each subjective evaluation indicator should be assigned with an importance index $I_k$. The assignment method of $I_k$ can be determined by using the forced-choice method, and $\sum_{k=1}^{K} I_k = 1$, $I_k \in [0,1]$. The subjective rating value of each evaluation indicator is multiplied by the importance index $I_k$ of the indicator to calculate the subjective measure $SM_i$ of each proposed product quality improvement plan. The calculation Equation is as follows:

$$SM_i = \sum_{k=1}^{K} I_k S_{ki}$$

(3)

Where,

- $i$ represents the $i^{th}$ proposed product quality improvement plan, $i=1, 2, 3, \ldots m$;
- $k$ represents the $k^{th}$ subjective evaluation indicator, $k=1, 2, 3, \ldots K$;
- $I_k$ represents the importance index of the $k^{th}$ subjective evaluation indicator;
- $W_k$ represents the total weight value of the $k^{th}$ subjective evaluation indicator;
- $S_{ki}$ represents the subjective rating value of the $i^{th}$ proposed product quality improvement plan in terms of the $k^{th}$ indicator.

3.5. Determination of Location Measure
The location measure $LM_i$ is the overall evaluation value of the proposed product quality improvement plan, and its calculation Equation is:

$$LM_i = X \times SM_i + (1 - X) OM_i$$

(4)

Where,

- $X$ represents the weight value of objective evaluation indicator;
- $(1-X)$ represents the weight value of subjective evaluation indicator;
- $SM_i$ represents the subjective measure of the $i^{th}$ proposed product quality improvement plan;
- $OM_i$ represents the objective measure of the $i^{th}$ proposed product quality improvement plan.

The larger the location measure is, the better the comprehensive evaluation result of the proposed product quality improvement plan is. The comprehensive evaluation result is represented by $LM_i^*$. The specific calculation method of $LM_i^*$ is as follows:

$$LM_i^* = \max\{LM_i|i = 1,2,3,4\}$$

(5)

4. Case Application

4.1. Case Background
A toy manufacturer makes three quality improvement plans for toy products in order to improve the competitiveness of products and promote the healthy development of the enterprise. Because the cost and benefit of each proposed plan are different, it is necessary to determine which plan is the best quality improvement plan by using the actor analysis method. The specific information is shown in Tables 2 and 3 below:

Table 2. Production Costs and Expenses of Each Proposed Toy Product Quality Improvement Plan

| Proposed plan                  | Objective evaluation indicator | Equipment modification | Personnel training | Process upgrading | Other costs |
|-------------------------------|--------------------------------|------------------------|-------------------|------------------|------------|
| Quality Improvement Plan I    |                                | 250                    | 181               | 75               | 17         |
| Quality Improvement Plan II   |                                | 230                    | 203               | 83               | 9          |
| Quality Improvement Plan III  |                                | 248                    | 190               | 91               | 22         |
### Table 3. Evaluation Indicator of Proposed Toy Product Quality Improvement Plan

| Proposed plan | Subjective evaluation indicator | Production level | Quality and safety level | Sales volume | Customer satisfaction |
|---------------|---------------------------------|------------------|--------------------------|--------------|-----------------------|
| Quality Improvement Plan I | | Unchanged | Sharp rise | Sharp rise | Very satisfied |
| Quality Improvement Plan II | | Rise | Rise | Rise | Satisfied |
| Quality Improvement Plan III | | Sharp rise | Unchanged | Rise | Neutral |

### 4.2. Case Solution

#### 4.2.1. Calculation of objective measure.

The objective measure $O_{M_i}$ of each proposed toy product quality improvement plan can be calculated according to Table 1 and Equation (1). The calculation results are: $O_{M_1} = 0.3395$, $O_{M_2} = 0.3382$, $O_{M_3} = 0.3223$.

#### 4.2.2. Calculation of subjective rating value.

The subjective rating values of each proposed toy product quality improvement plan in terms of different subjective evaluation indicators can be calculated according to Table 2 and Equation (2). The specific calculation results of the rating value in the four subjective evaluation indicators of production level, quality and safety level, sales volume and customer satisfaction are shown in tables 4-7 below.

### Table 4. Subjective Rating Value in Production Level

| Production level | Plan I | Plan II | Plan III | Weight | $S_{tp}$ |
|------------------|--------|---------|----------|--------|----------|
| Quality Improvement Plan I | /      | 0       | 0        | 0      | 0        |
| Quality Improvement Plan II | 1      | /       | 0        | 1      | 0.33     |
| Quality Improvement Plan III | 1      | 1       | /        | 2      | 0.67     |

### Table 5. Subjective Rating Value in Quality and Safety Level

| Quality and safety level | Plan I | Plan II | Plan III | Weight | $S_{tq}$ |
|--------------------------|--------|---------|----------|--------|----------|
| Quality Improvement Plan I | /      | 1       | 1        | 2      | 0.67     |
| Quality Improvement Plan II | 0      | /       | 1        | 1      | 0.33     |
| Quality Improvement Plan III | 0      | 0       | /        | 0      | 0        |

### Table 6. Subjective Rating Value in Sales Volume

| Sales volume | Plan I | Plan II | Plan III | Weight | $S_{ts}$ |
|--------------|--------|---------|----------|--------|----------|
| Quality Improvement Plan I | /      | 1       | 1        | 2      | 0.5      |
| Quality Improvement Plan II | 0      | /       | 1        | 1      | 0.25     |
| Quality Improvement Plan III | 0      | 1       | /        | 1      | 0.25     |

### Table 7. Subjective Rating Value in Customer Satisfaction

| Customer satisfaction | Plan I | Plan II | Plan III | Weight | $S_{tc}$ |
|-----------------------|--------|---------|----------|--------|----------|
| Quality Improvement Plan I | /      | 1       | 1        | 2      | 0.67     |
| Quality Improvement Plan II | 0      | /       | 1        | 1      | 0.33     |
| Quality Improvement Plan III | 0      | 0       | /        | 0      | 0        |

#### 4.2.3. Calculation of importance index of subjective evaluation indicator.

By asking the toy manufacturer's quality management department about its requirements and actual needs, it is known that the four subjective evaluation indicators are ranked by importance by the manufacturer as follows:
quality and safety level > customer satisfaction > production level = sales volume. The importance indices of the above four evaluation indicators are calculated by forced-choice method, as shown in Table 8:

| Subjective evaluation indicator | Production level | Quality and safety level | Sales volume | Customer satisfaction | Weight | \( I_k \) |
|---------------------------------|-----------------|--------------------------|--------------|-----------------------|--------|----------|
| Production level                | /               | 0                        | 1            | 0                     | 1      | 0.14     |
| Quality and safety level        | 1               | /                        | 1            | 1                     | 3      | 0.43     |
| Sales volume                    | 1               | 0                        | /            | 0                     | 1      | 0.14     |
| Customer satisfaction           | 1               | 0                        | 1            | /                     | 2      | 0.29     |

Table 8. Importance Index of Subjective Evaluation Indicators

According to tables 4-8, the rating values of each proposed toy product quality improvement plan in terms of different subjective evaluation indicators are shown in Table 9 below:

| Subjective evaluation indicator | Production level | Quality and safety level | Sales volume | Customer satisfaction | \( I_k \) |
|---------------------------------|-----------------|--------------------------|--------------|-----------------------|--------|
| Proposed plan                   |                 |                          |              |                       |        |
| Production level                | 0               | 0.33                     | 0.67         | 0                     | 0.14   |
| Quality and safety level        | 0.67            | 0.33                     | 0            | 0                     | 0.43   |
| Sales volume                    | 0.67            | 0.33                     | 0            | 0                     | 0.14   |
| Customer satisfaction           | 0.67            | 0.33                     | 0            | 0                     | 0.29   |

Table 9. Rating Value of Proposed Toy Product Quality Improvement Plans

4.2.4. Calculation of subjective measure. The subjective measure \( SM_i \) of each proposed toy product quality improvement plan can be calculated according to Table 8 and Equation (3). The calculation results are: \( SM_1 = 0.5762, SM_2 = 0.33, SM_3 = 0.0938 \).

4.2.5. Calculation of location measure. Since the toy manufacturer attaches the same importance to the objective evaluation indicators and the subjective evaluation indicators, so \( X = 0.5 \). The location measure of each proposed toy product quality improvement plan can thus be calculated according to Equation (4). The calculation results are: \( LM_1 = 0.4579, LM_2 = 0.3341, LM_3 = 0.2080 \).

4.2.6. Decision on the best plan. According to Equation (5), \( LM_1^* = \max\{LM_i|i = 1,2,3\} = LM_1 \). The location measure of the proposed quality improvement plan I is the largest. This indicates that the comprehensive evaluation result of this toy product quality improvement plan is the best, and that the manufacturer's best toy product quality improvement plan is plan I.

5. Summary

Cost and benefit are eternal research topics for enterprise management. The effectiveness evaluation model of product quality improvement plan based on actor analysis method established in this paper can scientifically evaluate the effectiveness of quality improvement plan before the implementation and help choose the best plan for enterprises from many options. This avoids unnecessary losses and to a certain extent solves the problem of insignificant input and output effects during the implementation of the quality improvement plan. The research results of this paper are scientific and practical. They can provide a method support for enterprises in carrying out the effectiveness evaluation of product quality improvement plan and a basis for research of relevant institutions on the optimization of quality improvement plan.
Acknowledgements
We would like to acknowledge that this Study is supported and funded by the Market Supervision Technology Assurance Project under Grant No. 2020YJ043, the National Science Foundation of China under Grant No. 91646122, 91746202, the Basic Scientific Research Business Projects 552018Y-5927-2018.

References
[1] Wang Shuo. Supplier Quality Improvement Strategy Based on PDCA Method [J]. Internal Combustion Engine & Parts, 2019, 16: 220-221. (in Chinese)
[2] Jiao Chaofeng. The Research on the Quality Management Improvement of Hunan CPEV Battery Co., Ltd. [D]. Hunan: Hunan University, 2018. (in Chinese)
[3] Zhou Jian, Chen Hongjie. Discussion on Quality Improvement of Bus Duct Products for Buildings Through PDCA Method [J]. Intelligent City, 2019: 196-197. (in Chinese)
[4] Su Shufeng, Su Xianna. Comprehensive Evaluation of Internal Control Effectiveness Based on PDCA Cycle [J]. Accounting Research, 2014, 31 (10): 123-125. (in Chinese)
[5] Wu Yisha. Application Research of Automobile Company A Quality Improvement Based on FMEA and FTA Methods [D]. Guangdong: South China University of Technology, 2013. (in Chinese)
[6] Lin Hualin. Research on Quality Improvement of Type 1A EMU Vacuum Circuit Breaker of S Company [D]. Shandong: Qingdao University, 2019. (in Chinese)
[7] Yang Ping, Luo Sai, Zhu Jiang. Application Research of Tobacco Production Quality Management Based on SPC [J]. Information Technology and Informatization, 2018: 179-182. (in Chinese)
[8] Wu Huazhi, Wei Xiaojing. Application Research of Elevator Balance Cable Production Quality Improvement Based on SPC [J]. Modern Business Trade Industry, 2017: 185-187. (in Chinese)
[9] Wang Lixiu, Duan Xin, Gao Hongbo. The Applied Research of Plant Location Based on the AHP and Actor Analysis Method [J]. Journal of Huaiyun Institute of Technology, 2011, 20 (3): 84-88. (in Chinese)
[10] Liu Deqiang. Selection and Recruitment of Part-time Teachers in Higher Vocational Colleges Based on Actor Analysis Method [J]. Construction of Teachers' Team, 2011, 25: 78-80. (in Chinese)