

A variation reduction allocation model for quality improvement to minimize investment and quality costs by considering suppliers' learning curve

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Abstract. Quality improvement must be performed in a company to maintain its product competitiveness in the market. The goal of such improvement is to increase the customer satisfaction and the profitability of the company. In current practice, a company needs several suppliers to provide the components in assembly process of a final product. Hence quality improvement of the final product must involve the suppliers. In this paper, an optimization model to allocate the variance reduction is developed. Variation reduction is an important term in quality improvement for both manufacturer and suppliers. To improve suppliers' components quality, the manufacturer must invest an amount of their financial resources in learning process of the suppliers. The objective function of the model is to minimize the total cost consists of investment cost, and quality costs for both internal and external quality costs. The Learning curve will determine how the employee of the suppliers will respond to the learning processes in reducing the variance of the component.

1. Introduction

In an intense competitive market, a manufacturing company must be able to survive by improving the product quality and reducing costs. Quality improvement is an important issue in manufacturing since it has a strong relationship with the customer satisfaction. The improvement will satisfy the customers and the satisfied customers will become loyal and repurchase the product and eventually generate the income for the company. In producing a product, a manufacturing company usually has several suppliers to supply many things such as raw materials, components, or any other supporting goods which broadly known as outsourcing. In the outsourcing activities, the suppliers must be involved in many improvement programs that carried by the manufacturer. The programs will strengthen the suppliers position and the manufacturer will take benefits in term of components quality improvement and cost reduction. Hence, the manufacturer's expenses in such programs must be regarded as investments to improve the supplier's capability in producing the components.

In real practice, a manufacturer has a quality standard for the purchased parts or components from the suppliers. The standard must be treated as dynamic since the manufacturer requires the suppliers to improve their component's quality or the quality cost will be high in both suppliers and manufacturer's sides. The quality costs can be divided into two categories: internal and external quality costs. Internal quality cost quantifies the loss due to the out of specification components or products which known as defect or rejection cost. External quality cost quantifies the loss of customers



which is usually measured using Taguchi loss function. In the Taguchi quality concept, the source of quality loss can be divided into two components: off target and variations. Hence in this concept, the quality improvement can be regarded as the process to reduce components/products off targets and variations. The off target component is relatively easier to be handled than the variations since there are many design parameters that can be adjusted to change the mean of response [1]. While for the variation, it is more complicated since the variation of the response is caused by both variations of the design parameters and noise factors. In the manufacturer-suppliers relation, the quality improvement can be established by the manufacturer by specifying the same percentage reduction in process variation to the suppliers [2]. Due to the different capabilities of the suppliers in quality improvement, this strategy may not be the most effective one. Hence, the manufacturer should allocate the variations to its suppliers according to their capabilities.

The knowledge of the suppliers in understanding the process problems and solving such problems will influence their capability in reducing the variances. This knowledge is acquired through learning process of the employees. Two learning processes are identified in [3]: conceptual and operational learning. The conceptual learning deals with the acquisition of know-why while the operational learning deals with the acquisitions of know-how. The learning can also be partitioned into two categories: autonomous and induced learning [4]. Autonomous learning stems from the production through the learning by doing by employees while the induced learning stems from the process improvement effort [5].

There are many researches have been conducted in quality improvement. For example, Sou and Chen [6] developed a model to improve the quality of car seat assembly. They considered several objective functions in the model such as production cost and quality investment. The quality investment was used to reduce the off target and variations of the assembly process. Plante [7] developed an optimization model to allocate the variations considering the existence of interactions among suppliers. Moskowitz, et al [2] developed a model to consider investments in learning by both suppliers and the manufacturer in reducing the variance to improve the quality. Erlebacher and Singh [8] discussed the variation reduction of the process time in synchronous assembly lines and related the reduction to the quality of a product. The aim of this research is to develop a simple optimization model to allocate the variation reduction of component variations at the suppliers side to minimize the investment and quality costs by considering suppliers' learning curve.

2. The Optimization Model

In this paper, we consider a system consists of a manufacturer and several suppliers. The manufacturer set the quality improvement through setting the variations reduction target that must be attained by the suppliers. The manufacturer invests some funds in the quality improvement and must allocate the investment to the suppliers based on their capability in attaining the variations reduction target. The objective function of the optimization model is to minimize a total cost which consists of investment cost, defect or rejection cost, and external quality cost which quantified using Taguchi quality loss. We assume that the quality inspection is done by the suppliers so only good components delivered to the manufacturer. The smaller the components variances, the smaller their quality cost due to the defect components. The external quality loss will not exist until the components are assembled into final product and used by the final users [9]. Two constraints are considered in this paper, the variations reduction target of the assembly which must be allocated to each suppliers and the available maximum investment funds that provided by the manufacturer to improve the components quality.

2.1. The Objective Functions

The first objective function in the optimization model is investment cost. This cost is used to reduce the variations of the components production in suppliers side. We follow the exponential function as in [6] to relate the variations reduction with the investments. The function can be expressed as in equation (1). In this equation, the resulted variation is expressed in term of the investment made by the

manufacturer, where σ_L^2 , σ_0^2 and b denote the lowest variance that can be attained by the suppliers, current variance, and investment coefficient respectively [10].

$$\sigma^2(I) = \sigma_L^2 + (\sigma_0^2 - \sigma_L^2) \exp(-bI), b > 0 \quad (1)$$

The second objective function is the loss due to the defective components. The defective components are any components in which the quality characteristics are outside the upper and lower specification limits. This loss can be expressed as in equation (2) where Q and V denote the production quantity and unit rejection cost respectively.

$$L_1 = QV \left(1 - \int_{USL}^{LSL} f(x) dx \right) \quad (2)$$

The third objective function is the Taguchi quality loss. Assuming that there are no off targets component of the quality loss, the objective function can be expressed as in equation (3). In that equation, the Taguchi quality loss is expressed as the multiplication of quality loss coefficient (k) and the sum of variances from the components in an assembly product.

$$L_2 = k \sum_{j=1}^J (\sigma_j^2) \quad (3)$$

2.2. The Constraints

There are several constraints considered in this paper. The first constraint is the total investment provided by the manufacturer to improve the quality through variation reduction allocation that may not exceed the maximum investment (I^{max}). This constraint is expressed in equation (4).

$$\sum_{j=1}^J I \leq I^{max} \quad (4)$$

The second constraint deals with the maximum variations reduction that must be attained by the suppliers. This constraint is used to ensure that each supplier contributes to the quality improvement through the variation reduction. This constraint is expressed in equation (5) in which σ_{assy}^2 denotes the variation reduction target that must be attained by the suppliers.

$$\sum_{j=1}^J \left(\frac{dy}{dx_j} \right)^2 \sigma_j^2 \leq \sigma_{assy}^2 \quad (5)$$

The third constraint concerns with the relation between the investments and learning rate. There are three learning rate functions which commonly used [2]: linear, quadratic, and exponential as expressed in equation (6), (7), and (8) respectively. In those equations, λ_j denotes the learning rate needed by the suppliers to attain the variation reduction.

$$I_j = h_j \lambda_j \quad (6)$$

$$I_j = w_j \lambda_j^2 \quad (7)$$

$$I_j = u_j (e^{\lambda_j} - 1) \quad (8)$$

3. Numerical Example

In this numerical example, we assume that a manufacturer has three suppliers to provide three different components for the manufacturer. The manufacturer will assembly 25000 units of a product. The out of specification components will be rejected in which the rejection costs of such components are \$1, \$1.5, and \$2 for components from Supplier A, B, and C respectively. The current variances of components from Supplier A, B, and C are 0.01, 0.098, and 0.0775 respectively, while the lowest

variance that can be attained by the supplier are 0.005, 0.003, and 0.0025 for Supplier A, B, and C respectively. The other parameters used in this paper are listed in table 1. The manufacturer provides a maximum investment of \$3500 to reduce the total variance of the assembly. The current assembly variance is 0.183 which equals to the sum of component's variance from each supplier. Through the investment, the manufacturer needs to improve the quality of the components by reducing the variance. The quality loss coefficient due to the assembly variance is assumed to be \$50.

Table 1. The model parameters for numerical example

Supplier	Variance		Variance Reduction Coefficient (b)	Investment Cost Coefficient (w)
	σ_0^2	σ_L^2		
Supplier A	0.010	0.0050	0.0035	850
Supplier B	0.098	0.0030	0.0025	3565
Supplier C	0.075	0.0025	0.0035	2475

The Crystal Ball software is used to solve the model. The results of the optimization is listed in table 2. From the table, we can see that the optimal total investment allocation for all suppliers is \$3,229.08 with \$430.78 defective cost and \$1,806.66 quality loss. The resulted total cost from the optimization is \$5,466.21. The variance of assembly will decrease from 0.183 to 0.0144.

Table 2. The optimization results

Supplier	Investment Allocation (\$)	Allocated Variance Reduction	Defect Cost (\$)
A	453.26	0.0060	249.18
B	1,632.54	0.0046	120.13
C	1,143.28	0.0038	61.17

From the investment allocation, we can find the learning rate that will be needed by the supplier to attain the variance target. Assuming the quadratic function as in equation (7) with investment cost coefficient in table 1, the learning rate is found to be 0.73, 0.68 and 0.68 for Supplier A, B, and C respectively. From the results of the optimization, the percentage of improvements in terms of components variance reductions are 40% by Supplier A, 95.4% by Supplier B, and 95% by Supplier C. Those reductions result in the assembly variance reduction by 92.2%.

4. Conclusions

In this paper, an optimization model was developed to find the optimal allocation of variance reduction by a manufacturer in order to improve the quality of an assembly. The quality improvement can be performed by investing some funds to the suppliers so they can improve their capabilities in producing the components. The improvement of components quality will eventually improve the quality of the final product. This paper related the variance reduction and investment allocation with the learning rate function which needed by the supplier to attain the variance reduction target set by the manufacturer. The model in this paper can be extended by partitioning the investment for both manufacturer and suppliers. The objective function can also be changed to return on investment so both manufacturer and suppliers will know the effectiveness of their investments in quality improvement.

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