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Supplier Evaluation and Selection using Revised Taguchi Loss Function

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Abstract: Assessing quality as one of the main criteria for supplier selection is so important. Literature review showed that in order to evaluate the quality of suppliers, some methods such as rate of rejects, quality certification, easy to repair, reliability and process capability indices are so common. These methods can assess just one aspect of an organization and are not appropriate tools for assessing the real quality of the product supplied by the supplier, while loss functions are suitable tools to evaluate the quality. To overcome this problem and because of features of revised Taguchi loss function, this study proposes the use of the revised Taguchi loss function for supplier evaluation and selection. After assessing the quality, using the expected value of the revised Taguchi loss function and integrating of this function with the cost of purchasing and transportation, a simple Linear Programming (LP) model will appear. A numerical example provides the explanation. This model is a very simple linear programming model with excellent estimation of quality, which integrates the quality of supplier, cost of purchasing and transportation costs.

Key words: Price, quality, supplier evaluation and selection, revised Taguchi loss functions, loss functions

INTRODUCTION

Nowadays companies hope to establish a longer-term working relationship with the suppliers and supplier selection is one of the main decisions in supply chain management. Since, there are many suppliers with many criteria, it is impossible to find the best way to evaluate and select the suppliers. Therefore, scholars have used different methods and variables in order to select the proper suppliers. Moreover, different scholars have used different criteria to evaluate the suppliers. Quality is one criterion, which has concerned in all studies. Quality can be evaluated with different methods such as rate of rejects, continuous improvement programs, quality of customer, support services, certifications, percentage of on time shipment, easy of repair, reliability, process capability indices and process yield. These factors and criteria cannot be a good representation of quality of products. On the other hand, process capability indices are suitable to measure the quality, but these indices cannot be presented by cost, so it is impossible to employ them in the objective function of a mathematical model of supplier selection. In order to overcome this problem, we propose usage of loss functions such as revised Taguchi function and a novel cost-based model with the integration of quality cost, purchasing cost and transportation costs. This new method evaluates quality precisely and interprets that to the loss. This model is useful for all organizations that want to select the proper supplier for their materials.

Quality is the main criteria for supplier selection concerned in all studies (Dickson, 1966). In order to assess the quality many factors and methods can be used. There are many literatures have accumulated on the subject of vendor evaluation, selection models and quality evaluation. In order to evaluate the quality most of these models have used rate of rejects (Qing and Xiao-Min, 2007; Sanayei *et al*., 2008; Kokangul and Susuz, 2009), while rate of rejects cannot present the quality precisely. In a recent study, Lee (2009) used process yield in order to evaluate the quality, while process yield is such as rate of reject and cannot evaluate the quality precisely.

Different scholars integrated different factors and criteria in order to evaluate the quality. Teng and Jaramillo (2005) integrated continuous improvement programs, quality of customer, support services, certifications and percentage on time shipment. In another study, Hou and Su (2007) defined a quality index with integration of technical and design level, easy of repair and reliability. Xia and Wu (2007) used just technical, design level and reliability in order to evaluate the quality. These factors such as rate of rejects just can evaluate one aspect of an organization and they cannot present the core quality level of products. For example if a supplier has a good

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Table 1: Literature review about the methods of assessing quality for supplier selection

ID	Article	Year	Rate of rejects	Continuous improvement programs	Quality of customer and support services	Certifications	Percentage on time shipment	Technical and design level	Easy of repair	Reliability	Capability of handling abnormal quality	Yield rate	Process capability indices	Loss functions
1	Tseng and Wu	1991											✓	
2	Chou	1994											✓	
3	Huang and Lee	1995											✓	
4	Pearn and Kotz	2006											✓	
5	Teng and Jaramillo	2005		✓	✓	✓	✓							
6	Liu and Hai	2005	✓	✓										
7	Pi and Low	2005												✓
8	Pearn and Kotz	2006											✓	
9	Linn *et al.*	2006											✓	
10	Qing and Xiao-Min	2007	✓											
11	Hou and Su	2007						✓	✓	✓				
12	Xia and Wu	2007	✓					✓		✓				
13	Hui-Ming	2007											✓	
14	Sanayei *et al.*	2008	✓											
15	Teeravaraprug	2008												✓
16	Kokangul and Susuz	2009	✓											
17	Lee	2009									✓	✓		

support service or a quality certification such as ISO 9000, it does not ensure the high quality of the products.

On the other hand, some scholars have used process capability indices in order to evaluate the quality of suppliers. Tseng and Wu (1991) considered the problem of selecting the best manufacturing process from k available processes based on the precision capability index C_p and have proposed a Modified Likelihood Ratio (MLR) selection rule. Chou (1994) developed an approximate method for selecting a better supplier based on one-sided capability indices C_{pu} and C_{pl} when the sample sizes are the same, which deals with comparing two one-sided processes and selects a better one with higher process yield. Huang and Lee (1995) proposed a model for selection a subset of processes containing the best supplier from a given set of processes.

Process capability indices are appropriate and suitable indices in order to evaluate the quality, but presenting them as a cost are so complicated. Therefore, some scholars presented innovative qualitative methods with the integration of process capability indices and other factors. For instance, Linn *et al*. (2006) presented a chart called CPC chart for supplier selection problem. The CPC chart integrated the process capability and price information of multiple suppliers and presented them in a single chart. In another study, Hui-Ming (2007) established a chart consisted of supplier capability and price information called chart SCPIC. This chart focused on the case where the specification limits are symmetric about the target for evaluating supplier performance, which applied the process incapability index to measure supplier quality performance. As stated process capability indices cannot interpret quality as a cost and all of these integration methods are approximate innovative methods with the definition of ranges for process capability indices.

There are few studies about usage of loss functions to select the suppliers. In these studies, scholars just have used the concepts of loss functions (not the loss functions directly) in order to weight the criteria. For example, Pi and Low (2005) used Taguchi loss and assumed 3% defective products as the standard rate of rejects. In another study, Pi and Low (2005) continued their study and proposed an AHP method (Analytic Hierarchy Process) to select the final supplier. Teeravaraprug (2008) proposed a new model for outsourcing and vendor selection based on Taguchi loss function. In this study, Taguchi loss function was used to calculate the quality rate, but in this methodology Taguchi loss function was used just for weighting the different rates. Moreover, they employed rate of rejects in order to calculate the quality. Summary of main studies in this area is shown in Table 1.

NOTATIONS

Among the numerous methods that have been proposed for assessing the supplier, loss functions such as revised Taguchi loss function is considered one of the most effective techniques for identifying quality parts.

Since, mentioned methods are not appropriate methods for assessing the quality of suppliers, this study investigates on supplier selection based on using revised Taguchi loss function in order to integrate quality, price and shipment costs. Therefore, the objective of the proposed model is formed by using a loss function to interpret quality as a cost integrating with other factors such as transportation costs and price. The notations of this Linear Programming (LP) model are explained as follows:

$\bar{X}_{ij}$: The mean of sample from supplier i for product j
B : The coefficient of quality loss within the specification limits
B_j : The coefficient of quality loss for product j
K : The maximum value of quality loss
K_{ij} : The maximum value of quality loss of quality loss for product j of ith supplier
m_{ij} : The ordinary samples within L and U
n_{ij} : The sample size of product j from ith supplier
p_{ij} : The price of one unit of product j from ith supplier
Q_j : The quantity of the demand for product j
R_{ij} : The rate of ordinary products
σ : The process standard deviation
μ : The process average
S_{ij} : The standard deviation of sample from supplier j for product i
T : The target value of the specification
TC : The total quality cost
T_j : The target of process for jth product of ith supplier
X_{ij} : The order quantity for ith supplier for product j
Y : The quality characteristics
z : The number of all items (products)
u : The number of all suppliers
L : The lower limit for acceptable rang of a quality characteristic for point of ordinary loss
L_j : The lower limit for acceptable rang of a quality characteristic for point of ordinary loss for jth product
U : The upper limit for acceptable rang of a quality characteristic for point of ordinary loss
U_j : The upper limit for acceptable rang of a quality characteristic for point of ordinary loss for jth product
USL : The upper specification limit
LSL : The lower specification limit
H_{ij} : Transportation cost of product j from ith supplier
RTLF : Revised Taguchi loss function which provided by Ryan

PROPOSED MODEL

As mentioned, this study aims to propose an integrated model for supplier selection. For this purpose, we use revised Taguchi loss functions in order to evaluate the criteria. In this proposed model, all elements of the models interpret as cost. There are many criteria, which can be assumed to evaluate the supplier. In this study the most important criteria have been selected, are quality, price and transportation cost which will be integrated together as costs.

Regarding to fierce worldwide competition, quality turned to the one of the main factors that will affect directly all decisions for supplier selection. Other main factors that always have been important are price (cost of purchasing) and transportation cost. Integration of these three criteria is the main proposed method that in this study will be clarified. In the other word, with the integration of these three elements as costs, a new element appears that is so clear and reasonable.

There are many ways to interpret the quality as a cost. Maybe calculation of rate of rejects and interpretation it as a cost is the simplest way. As mentioned in literature review, there are some qualitative methods such as certifications, continuous improvement programs, technical and design level, capability of handling abnormal quality, quality of customer and support services, easy of repair and reliability are considered. Qualitative factors and methods are able to interpret quality as a quantity, but hardly as a cost. On the other hand, there are quantitative factors such as rate of rejects, percentage on time shipment, process yield, process capability indices and loss functions. Except of loss functions, other quantitative factors are not suitable in order to interpret the quality as a cost.

Loss functions are reliable and applicable tools, which can interpret quality as cost. Loss functions have been widely used for several decades. These functions not only have used widely to predict the losses, but also for various purposes such as manufacturing and environmental risks decision-making (Kethley, 2008), quality engineering (Shu *et al*., 2005). There are different forms of loss functions such as squared error, absolute error, weighted and binary loss. Each of these forms tacitly assumes that the larger the error in estimating parameter values the larger the loss incurred (Leung and Spiring, 2004).

One of the most famous loss functions is Taguchi loss function. This function is a quadratic function which primarily has successfully applied in some topics of quality controls and then applied to other fields. The concept of Taguchi's quadratic quality loss function is based on measuring the cost of customers if the product quality is far away the target value. Therefore, Taguchi loss functions detect the customer's desire to produce products that are more homogeneous. Taguchi method in addition to traditional costs of re-work, scrap, warranty and services costs, assumes the cost of inhomogeneous. Taguchi loss function is as follows:

$$L(y) = B(y-T)^2 \tag{1}$$

where, L(y) is the loss associated with a particular value of quality character y. Note that B is the loss coefficient, whose value is constant and depends on the cost at the specification limits and the width of the specification.

Taguchi loss function is the most famous and applicable loss function that has been used vastly, but there are other loss functions such as Ryan (1989) proposed a loss function based on Taguchi loss function (revised Taguchi loss function). Since Taguchi loss function is infinite, sometimes the loss value is so high and unacceptable. Therefore, Rayan (1989) assumed a maximum loss for L(y) and then similar to Taguchi loss function, suggested a loss function that from a specific point (for example from specific limits) the value of loss is constant. In the other word, this function is bounded. Revised Taguchi loss function has defined as follows:

$$L(y) = \begin{cases} B(y-T)^2 & \text{if} \quad y-T \le \sqrt{\frac{K}{B}} \\ K & \text{if} \quad y-T > \sqrt{\frac{K}{B}} \end{cases} \tag{2}$$

where, K is the maximum value of quality loss, B represents the coefficient of quality loss within the specification limits and K consists of costs of bad reputation, rework and disposal.

In many manufacturing processes, it is unrealistic to assume the unbounded quality loss, even if the material, labor and other administrative costs are included. For instance, sometimes because of quality specification, which is so far from the USL or LSL, we have an unacceptable and unrealistic loss. Therefore, manufacturers cannot use the unbounded functions easily. Since revised Taguchi loss function (Ryan, 1989) is boundary, it is an appropriate function in order to interpret the quality as a cost.

Using revised Taguchi loss function to estimate the quality costs is so simple and the company only must estimate the maximum loss of a worst rejected product (K). Then regarding to Fig. 1 the function will interpret the amount of loss for all products.

In order to estimate the total loss of all products we need the expected value of revised Taguchi loss function.

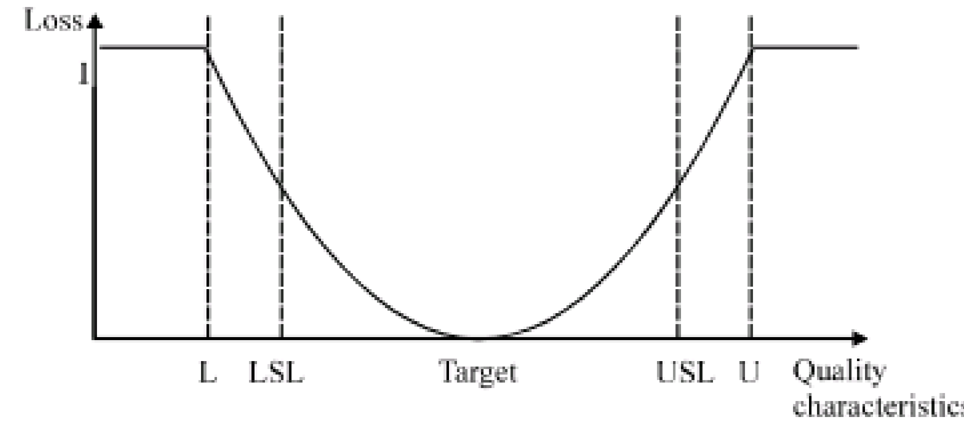

Fig. 1: Revised Taguchi loss function (RTLF) (Ryan, 1989)

The expected value of revised Taguchi loss function is calculated as follows:

$$E\left[L_{RTLF}(y)\right] = \int_{-\infty}^{\infty} L_{RTLF}(y)dF(y) = \int_{T-\sqrt{\frac{K'}{B}}}^{T+\sqrt{\frac{K'}{B}}} (y-T)^2 \times \frac{1}{\sqrt{2\pi}\sigma}\exp\left[-\frac{(y-\mu)^2}{2\sigma^2}\right]dy +$$
$$2\int_{T+\sqrt{\frac{K'}{B}}}^{\infty} K' \times \frac{1}{\sqrt{2\pi}\sigma}\exp\left[-\frac{(y-\mu)^2}{2\sigma^2}\right]dy = \left\{ -x\sigma^2 \times \frac{1}{\sqrt{2\pi}\sigma}\exp\left[-\frac{x^2}{2\sigma^2}\right]_{T-\sqrt{\frac{K'}{B}}-\mu}^{T+\sqrt{\frac{K'}{B}}-\mu} + \right.$$
$$\sigma^2 \times \left(\phi\left(\frac{T+\sqrt{\frac{K'}{B}}-\mu}{\sigma}\right) - \phi\left(\frac{T-\sqrt{\frac{K'}{B}}-\mu}{\sigma}\right) \right) + 2\sigma^2(\mu-T) \times \frac{1}{\sqrt{2\pi}\sigma}\exp\left[-\frac{x^2}{2\sigma^2}\right]_{T-\sqrt{\frac{K'}{B}}-\mu}^{T+\sqrt{\frac{K'}{B}}-\mu} +$$
$$\left.(\mu-T)^2 \times \frac{1}{\sqrt{2\pi}\sigma} \times \left(\phi\left(\frac{T+\sqrt{\frac{K'}{B}}-\mu}{\sigma}\right) - \phi\left(\frac{T-\sqrt{\frac{K'}{B}}-\mu}{\sigma}\right) \right)\right\} + 2K'\left(1-\phi\left(\frac{T+\sqrt{\frac{K'}{B}}-\mu}{\sigma}\right)\right) \tag{3}$$

Since, at first companies collect their samples from suppliers, we can employ X_{ij} (mean of sample) to estimate μ_j. Similarly S (standard deviation of sample) can be used in order to estimate the σ. Expected value of this function between L_j and U_j is as follows:

$$E\left[L_{RTLF}(y)\right] = \left\{ -xS_{ij}^2 \times \frac{1}{\sqrt{2\pi}S_{ij}}\exp\left[-\frac{x^2}{2S_{ij}^2}\right]_{T-\sqrt{\frac{K'}{B}}-\bar{X}_{ij}}^{T+\sqrt{\frac{K'}{B}}-\bar{X}_{ij}} + \right.$$
$$\sigma^2 \times \left(\phi\left(\frac{T+\sqrt{\frac{K'}{B}}-\bar{X}_{ij}}{S_{ij}}\right) - \phi\left(\frac{T-\sqrt{\frac{K'}{B}}-\bar{X}_{ij}}{S_{ij}}\right) \right) + 2S_{ij}^2(\bar{X}_{ij}-T) \times \frac{1}{\sqrt{2\pi}S_{ij}}\exp\left[-\frac{x^2}{2S_{ij}^2}\right]_{T-\sqrt{\frac{K'}{B}}-\bar{X}_{ij}}^{T+\sqrt{\frac{K'}{B}}-\bar{X}_{ij}} +$$
$$\left.(\bar{X}_{ij}-T)^2 \times \frac{1}{\sqrt{2\pi}S_{ij}} \times \left(\phi\left(\frac{T+\sqrt{\frac{K'}{B}}-\bar{X}_{ij}}{S_{ij}}\right) - \phi\left(\frac{T-\sqrt{\frac{K'}{B}}-\bar{X}_{ij}}{S_{ij}}\right) \right)\right\} + 2K'\left(1-\phi\left(\frac{T+\sqrt{\frac{K'}{B}}-\mu}{S_{ij}}\right)\right) \tag{4}$$

where, S_{ij} is the standard deviation of the sample from supplier j for product i and similarly $\bar{X}_{ij}$ is the mean of sample from supplier j for product i. Now in order to calculate the cost of quality (loss), we suppose n samples which m of them are within L and U, called ordinary losses. Hence, n-m samples have extraordinary losses (y_j has been sorted from smallest to largest). The quality costs (losses) will be calculated by Eq. 5. By adding costs of purchasing and transportation, total costs of j^{th} product can be calculated as follows:

$$\text{Total cost of product j } (TC_j) = \text{Quality costs } (QC_j) + \text{Purchasing costs } (PC_j) + \text{Transportation costs } (TC_j) \quad (5)$$

$$\text{Total cost (TC)} = \sum_{j=1}^{z}\left\{\begin{array}{l}\text{Quality cost of one unit of part j+Purchasing cost+}\\ \text{Purchasing cost of one unit of part j + Transportation costs}\end{array}\right\}\times Q_j \quad (6)$$

$$=\sum_{j=1}^{z}\left(\begin{array}{l}\text{Average cost of one extraordinary part j +}\\ \text{Average cost of one ordinary part j+}\\ \text{Purchasing cost of one unit of part j+Transportation costs}\end{array}\right)\times Q_j \quad (7)$$

We suppose that there are z kinds of products to buy and m_{ij} is the sample size of product j from i^{th} supplier. We also suppose that we have u suppliers that can provide the products.

In order to create a linear programming model to select the best suppliers, rate of ordinary products that have the ordinary loss for each supplier must be calculated from samples.

$$R_{ij} = \frac{m_{ij}}{n_{ij}} \quad (8)$$

where, R_{ij} is the rate of ordinary products for product j of supplier i. Now the total cost of supplying all products is:

$$\text{MinTC} = \sum_{u}^{i=1}\sum_{z}^{j=1}\left(\left(\left(R_{ij}\left(EXP\left(RTLF_{ij}\right)\right)+\left(1-R_{ij}\right)\times K_j + p_{ij} + H_{ij}\right)\times X_{ij}\right) \quad (9)$$

where, p_{ij} is the price of one unit of product j and n_{ij} is sample size of product j from i^{th} supplier. From n_{ij}, m_{ij} are ordinary and remaining samples (n_{ij}- m_{ij}) have maximum losses. The variable X_{ij} represents the amount of purchasing of product j from i^{th} supplier. Equation 9 is the objective function and must be minimized and then the final model is as follow:

$$\text{MinTC} = \sum_{u}^{i=1}\sum_{z}^{j=1}\left(\left(\left(R_{ij}\left(EXP\left(RTLF_{ij}\right)\right)+\left(1-R_{ij}\right)\times K_j + p_{ij} + H_{ij}\right)\times X_{ij}\right)$$

Subject to:

$$\begin{array}{ll}\sum_{u}^{i=1} X_{ij} = Q_j & \text{for all j}\\ X_{ij} \le C_j & \text{for all i, j}\\ \forall X_{ij} \le 0 & \text{for all i, j}\end{array} \quad (10)$$

NUMERICAL EXAMPLE

Now in order to clarify and illustrate the usage of the mathematical model, this numerical example is given. The coefficients of loss functions in each organization must be generated by managers and the relevant experts. Table 2 shows the coefficients of loss functions, specification limits and other information such as quantity order for each product. Table 3 shows the supplier performances for each product.

Table 2: Specifications of products

Product ID	K_j	Q_j	L_j	LSL_j	T_j	USL_j	U_j	B_j
1	110	1300	114.0	120	123	126	132	0.9
2	260	3200	29.0	32	34	36	38	1.2
3	330	370	35.5	38	40	42	44	2.0

Table 3: Supplier's characteristic values and relative performances

i^{th} supplier	Product ID	$\bar{X}$	S	m_{ij}	n_{ij}	X_{max}	X_{min}	P_{ij}	C_{ij}	H_{ij}
1	1	123.6	3.1	117	120	134	116	11.1	2000	1.2
	2	34.1	1.5	120	120	35	32	17.9	5000	1.5
	3	40.0	3.0	111	120	46	31	40.1	200	2.0
2	1	124.2	3.2	111	120	135	112	11.1	3500	1.3
	2	34.8	1.9	114	120	41	29	18.2	2000	1.4
	3	40.0	1.2	119	120	44	34	39.1	650	2.1
3	1	123.9	5.1	101	120	136	111	11.1	1000	1.3
	2	33.5	1.4	116	120	39	29	18.3	2500	1.5
	3	40.0	1.4	115	120	42	35	40.1	500	1.9
4	1	122.8	2.5	117	120	130	113	10.6	1000	1.1
	2	33.1	2.0	110	120	36	28	18.8	1000	1.6
	3	40.0	1.4	114	120	41	34	40.3	1000	1.9

Regarding to information of Table 2 and 3 and Eq. 9 expected value of revised Taguchi loss function for each product and each supplier will be calculated and then with adding costs of purchasing and regarding to Eq. 10 relevant model is as follows:

$$\text{Min TC} = 23.7986X_{11} + 22.112X_{12} + 83.5X_{13} + 30.3736X_{21} + 37.445X_{22} + 46.806X_{23} + 50.1328X_{31} + 31.0302X_{32} + 59.5066X_{33} + 19.9694X_{41} + 47.3576X_{42} + 62.424X_{43}$$

Subject to:

$$\begin{array}{l}X11+X21+X31+X41 = 1300\\ X11+X21+X31+X41 = 3200\\ X11+X21+X31+X41 = 370\\ X11 \le 2000\\ X12 \le 5000\\ X13 \le 200\\ X21 \le 3500\\ X22 \le 2000\\ X23 \le 650\\ X31 \le 1000\\ X32 \le 2500\\ X33 \le 500\\ X41 \le 1000\\ X42 \le 1000\\ X43 \le 1000\\ \forall X_{ij} \ge 0 \qquad i = 1 \text{ to } 3,\ j = 1 \text{ to } 4\end{array}$$

Table 4: The result of Solver software package for numerical example

Variable	Answer
X_{11}	0
X_{12}	3200
X_{13}	0
X_{21}	1300
X_{22}	0
X_{23}	370
C_{31}	0
X_{32}	0
X_{33}	0
X_{41}	0
X_{42}	0
X_{43}	0

This is the linear programming model that must be solved to select the best supplier. In order to solve this model, SOLVER software package has been employed and the solutions have been listed in Table 4.

As shown in Table 4, product 1 from supplier 2, product 2 from supplier 1 and product 3 must be provided from supplier 2.

CONCLUSION AND FUTURE RESEARCH

In order to calculate the quality, some methods such as rate of rejects, quality certification, easy to repair, reliability and process capability indices are so common. These methods are assessing just one aspect of organizations and are not appropriate tools for assessing the real quality of the products supplied by supplier. For example having ISO 9000 can not ensure the high quality of products. To overcome this problem and because of features of the revised Taguchi loss function, this paper proposed the use of the revised Taguchi loss function for supplier selection. Then in this model, three criteria: quality, price and shipment costs were integrated and formed the objective of this model. In order to use revised Taguchi loss function, at first a sample must be collected from supplier and then regarding to the percentage of ordinary loss a linear programming model will be formed. This new model compared with other models has advantages such as:

- More simple operation research model (linear programming)
- Integration of quality loss, purchasing cost and transportation cost
- Better estimation of quality compared with old criteria such as rate of rejects
- The objective of the model is based on costs

This model is the basic model for the usage of loss functions for evaluation of quality. Regarding to the limitation of this study, further research can be done in the usage of other alternatives such as discount models, single item model and multiple items in this model. Moreover, an inventory management system can be considered in future research.

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