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Original Article

Outsourcing and vendor selection model based on Taguchi loss function

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Abstract

In today's fiercely competitive environment, there is an emergence of the extended enterprise of interdependent organizations. This leads to a steady increase in part and service outsourcing. The decisions relating to this topic are whether outsourcing is appropriate and which vendors should be selected. To make the decision, many attributes need to be considered—both cash and non-cash. Cash impacts can be measured directly where as non-cash impacts are hardly measured. This paper applies Taguchi loss function to measure the non-cash impacts. The non-cash impacts considered in this paper include quality, speed, dependability, and flexibility. A mathematical model is given based on both cash and non-cash impacts. A numerical example is given to illustrate the model. Finally, conclusions and discussions are given.

Keywords: outsourcing, supply chain management, Taguchi loss function

1. Introduction

In the industrialized world, outsourcing has played such an important role in businesses. Increasingly, companies are outsourcing portions of their business process—from IT to raw material to after sales service to logistics and transportation. According to the survey carried out by Accenture, 80% of the companies surveyed use some form of outsourcing and a majority of these companies are spending close to 45% of their total budget on outsourcing (Accenture Consulting, 2005). Examples of industries where outsourcing is a key feature of the organization include aircraft, cars, computers, mobile phones, audio/video systems, watches, clothes, and so on. Many organizations are now evaluating supply chain procurement and logistic activities as candidates for outsourcing (Cavinato and Kauffman, 1999).

The concept of outsourcing is based on the fundamental idea that companies should focus their efforts on their core competence. Therefore, most businesses subcontract out most of their activities to other companies; a process known as "outsourcing". Outsourcing has resulted in an increasingly competitive global marketplace. The definition of outsourcing is not as simple as procurement of activities because that definition can not capture the true strategic nature of this issue (Gilley *et al.*, 2004). Thus, outsourcing is not simply a purchasing decision and it can be viewed as a discontinuation of internal production and an initiation of procurement from outside suppliers. According to Linder (2004), outsourcing is defined as the acquisition of parts or services from an outside company if those parts or services are also provided internally, or if producing those parts or services internally is considered a routine industry practice. The provider of goods or services to a company is known as a "vendor". A problem then is not only making decision whether items would be outsourced but also which vendors should be selected. Vendor selection is a critical and time-consuming process, and selecting vendors who can consistently provide the quality and quantity of items can be an arduous task.

According to the theory of cost analysis, the most common reason of outsourcing is to decrease transaction costs or to increase benefits (Coase, 1937; Williamson, 1975;1979;1985;1991). Several studies have been conducted on the different aspects, however the impacts of outsourcing largely remain a puzzle. Bryce and Useem (1998) state that

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the overall financial impacts of outsourcing cannot be quantified. Many researchers and practitioners have attempted to measure the financial impacts. While the tangible impacts of outsourcing can be estimated by managers, the quantification of the intangible impacts of outsourcing remains a difficult task. Smith *et al.* (1998) used historical accounting information to measure the impacts of outsourcing. Garrod and Rees (1998) and Bharadwaj *et al.* (1999) also examined the relationship between outsourcing performance, giving little consideration to be intangible impacts. Akbar and Stark (2003) criticized these earlier attempts to quantify the impact of outsourcing because these studies neglected to examine the link between outsourcing and future profits. Future profit figures may serve as a useful quantifiable metric to estimate the intangible impacts of outsourcing.

Quinn (1992) and Bathelemy (2003) state that outsourcing provides companies with substantial intangible benefits, such as increased ability to adapt to varying business conditions, improved quality and productivity, increased speed to market, improved access to outside experience and expertise, etc. Bryce and Useem (1998) believed that estimating the value of outsourcing to a firm is nearly as elusive as measuring the mass of a neutrino. Therefore, Weidenbaum (2005) warned companies against succumbing to the "everybody is doing it" mentality, as they may encounter several unexpected costs and complications, and it is noted that nearly one half of outsourcing contracts are terminated, for a variety of reasons. Almeida (2007) gave a multi-criteria decision model for outsourcing contracts selection based on a utility function. The utility function includes the impacts on cost, delivery time, and dependability. However, Slack *et al.* (1995) stated that the performance objectives include quality, speed, dependability, flexibility, and cost and thus cost is no longer the only aspect to be taken into account regarding the decisions.

This paper considers the aspects stated by Slack *et al.* (1995), quality, speed, dependability, flexibility, and cost. Since quality, speed, dependability, and flexibility are non-cash impacts, they are difficult measure. This paper utilizes the concept of a well-known loss function, the Taguchi loss function, to measure those non-cash impacts called losses. The main objective of the selection process is then to minimize the summation of losses and cost. The losses are due to the performance objectives not meeting expectations, such as poor product quality, untimely delivery, an inability to adapt to changes, etc. The cost of an item is quantified as the price at which the vendor sells it. The losses and cost will be taken into account in the mathematical model of this paper. The mathematical model will be used to answer the questions of "if outsourcing is appropriate and 'which' vendors to outsource to, if outsourcing proves to be appropriate".

The structure of this paper is as follows. The next section shows the basic concept of Taguchi loss function. Then the concept of Taguchi loss function is applied to generate the loss and cost models in the Model Elements section. In this section, there are two subsections considering losses and costs. The loss models include the losses due to poor quality, untimely deliveries, the inability to meet demand, and the inability to adapt when required. Those losses are based on the following performance measures of Slack *et al.* (1995): quality, speed, dependability, and flexibility. The last performance measure of Slack *et al.* (1995) is cost, as shown in the last subsection. The expected values of losses and cost per item are given and are used in the Model Development section. To illustrate the use of the model, a numerical example is given. Finally, conclusions and discussions are provided.

2. The concept of Taguchi loss function

The loss function is a means to quantify, on a monetary scale, the loss incurred when a product or its production process deviates from the customer-desired value in terms of one or more key characteristics. This loss includes long-term losses related to poor reliability and the cost of warrantee, excess inventory, customer dissatisfaction, and eventually, loss of market share. Even though researchers attempt to construct many types of quality loss functions, there is a general consensus that the Taguchi loss function may be a better approximation for the measurement of customer dissatisfaction with product quality. Taguchi proposed three models of loss functions, which are 'smaller the better', 'bigger the better', and 'nominal the best'. In the 'smaller the better' model, the zero point is the assumed best target value. The 'larger the better' case assumes some larger value as the target. The loss functions are provided below, where L_{SB}, L_{BB}, and L_{NB} are the losses incurred in the 'smaller the better' case, 'bigger the better' case and 'nominal the best' case, respectively; k is a loss coefficient; t is a customer target value and the random value x represents the quality characteristic measurement.

Smaller the Better: $$L_{SB} = kx^2 \quad (1)$$

Bigger the Better $$L_{BB} = k(1/x^2) \quad (2)$$

Nominal the Best $$L_{NB} = k(x-t)^2 \quad (3)$$

The mathematical details of the loss function can be found in Cho and Leonard (1997), Phillips and Cho (1998; 2000), Kim and Cho (2000), and Teeravaraprug and Cho (2002); and Figure 1 shows the Taguchi loss function based on Eqs. (1-3).

3. Model elements

The elements of the models include losses and cost. Losses are non-cash impacts where as cost is an item cost or purchase cost. Generally, the losses and costs will differ depending on if a product or service is outsourced, and which vendor the item or product is outsourced to.

As stated before, the losses include the losses due to

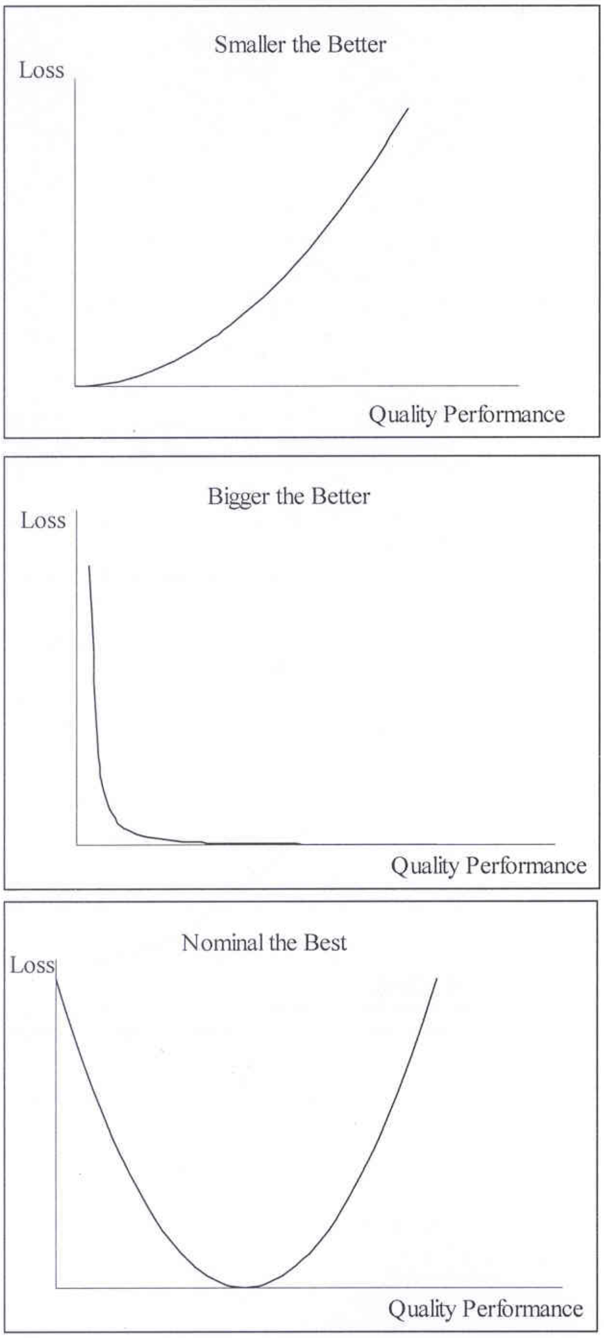

Figure 1. Taguchi loss function

poor quality, untimely deliveries, the inability to meet demand, and the inability to adapt when required in order to respond to the performance measures, i.e.: quality, speed, dependability, and flexibility. The cost, which is the last measure, will be discussed in the last subsection.

3.1 Loss of quality

In the long run, one of the most important factors affecting a business unit's competitive ability is the quality of its products. Material quality, part quality, and production quality are all aspects of product quality. In this paper, the focus is on part quality or the quality of the items being considered for outsourcing. Generally, the quality level is an inversely proportional to the defective rate. Note that p_m is the item defective rate for a product being made by the company and p_i is the defective rate when the product is outsourced to vendor *i*. A high quality level or a low defective rate is desirable. Therefore, the 'smaller the better' loss function, Eq.(1), can be applied to measure the loss of quality in this case. The loss in this matter can be measured as:

$$L_{Qm} = k_{Qm} p_m^{\ 2} \tag{4}$$

when items are produced by the company and

$$L_{Qi} = k_{Qo} p_i^{\ 2} \tag{5}$$

when items are outsourced to vendor *i*. Figure 2 shows the losses of quality.

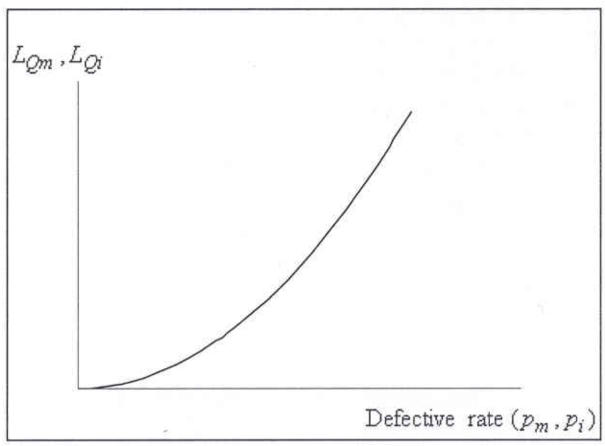

Figure 2. Losses due to having defective rate

Note that k_{Qm} and k_{Qo} are quality loss coefficients when items are produced by the company and when items are outsourced, respectively. This research assumes mass production. Therefore, based on the central limit theorem (CLT) stating that the sum of a large number of independent and identically-distributed random variables will be approximately normally distributed (i.e., following a Gaussian distribution, or bell-shaped curve), this research assumes the defective rate follows a normal distribution with mean μ_{pm} and variance σ^2_{pm} when items are produced by the company and with mean μ_{pi} and variance σ^2_{pi} when items are outsourced to vendor *i*.

The expected value of loss when items are produced by the company and that when items are outsourced to vendor *i* are

$$E[L_{Qm}] = k_{Qm}(\mu^2_{pm} + \sigma^2_{pm}) \tag{6}$$

and

$$E[L_{Qi}] = k_{Qo}(\mu^2_{pi} + \sigma^2_{pi}). \tag{7}$$

3.2 Loss of Speed

In service industries, a company's ability to deliver more quickly than its competitors may be critical. For example, a company that offers a repair service for computer-networking equipment in only 1 or 2 hours has a significant advantage over a competing firm that guarantees service only within 24 hours. Hence, the loss function that is appropriate in this case is the 'bigger the better' function as shown in Eq. (2).

In manufacturing industries, the meaning of speed may be the ability to deliver items when needed. The company desires having items when required-not prior and not after. Therefore, the proper loss function that can be applied in this case is the 'nominal the best' function. Eq. (3) provides a 'nominal the best' loss function in the symmetric case. That means when items are delivered either prior to or after the desired period, the losses are incurred equally—which is not true. Normally, when items are delivered prior to the desired period, the company would pay for inventory costs but when items are delivered after the desired period, it may affect the production runs and may lead to late product delivery. The loss incurred due to delivery prior to the desired period seems to be less than the loss incurred due to delivery after the desired period. The loss function is then asymmetric. An illustration of loss due to speed is shown in Figure 3.

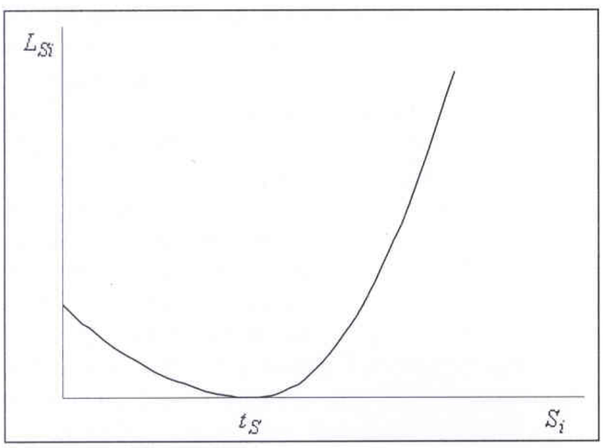

Figure 3. Losses due to not getting items on the time required

When items are produced by the company, the delivery period can be managed through a good planning system. Therefore in this situation, losses due to untimely deliveries can be prevented and the loss due to untimely deliveries will be incurred only when outsourcing items to a vendor.

Note that L_{Si} is the loss function due to speed for vendor i; k_{SL} and k_{SR} are the loss coefficients when delivering prior to and after the desired period respectively; S_i is the delivery period of vendor i and t_S is the desired period. The loss due to untimely delivery is shown as

$$L_{Si} = \begin{cases} k_{SL}(S_i - t_S)^2 & S_i \le t_S \\ k_{SR}(S_i - t_S)^2 & S_i > t_S \end{cases}, \tag{8}$$

when items are outsourced to vendor i and $k_{SL} < k_{SR}$. Assuming that is normally distributed with mean and variance, the expected value of is

$$\begin{aligned} E[L_{Si}] = {} & k_{SL}\left[\sigma_{Si}^2\left[\Phi\left(\frac{t_S-\mu_{Si}}{\sigma_{Si}}\right)-\left(\frac{t_S-\mu_{Si}}{\sigma_{Si}}\right)\phi\left(\frac{t_S-\mu_{Si}}{\sigma_{Si}}\right)\right]+\mu_{Si}^2\Phi\left(\frac{t_S-\mu_{Si}}{\sigma_{Si}}\right)\right. \\ & \left.-2\mu_{Si}\sigma_{Si}\phi\left(\frac{t_S-\mu_{Si}}{\sigma_{Si}}\right)-2t_S\left[\mu_{Si}\Phi\left(\frac{t_S-\mu_{Si}}{\sigma_{Si}}\right)-\sigma_{Si}\phi\left(\frac{t_S-\mu_{Si}}{\sigma_{Si}}\right)\right]+t_S^2\Phi\left(\frac{t_S-\mu_{Si}}{\sigma_{Si}}\right)\right] \\ & +k_{SR}\left[\sigma_{Si}^2\left[1-\Phi\left(\frac{t_S-\mu_S i}{\sigma_{Si}}\right)+\left(\frac{t_S-\mu_{Si}}{\sigma_{Si}}\right)\phi\left(\frac{t_S-\mu_{Si}}{\sigma_{Si}}\right)\right]+\mu_{Si}^2\left[1-\Phi\left(\frac{t_S-\mu_{Si}}{\sigma_{Si}}\right)\right]\right. \\ & +2\mu_{Si}\sigma_{Si}\phi\left(\frac{t_S-\mu_{Si}}{\sigma_{Si}}\right)-2t_{Si}\left[\mu_{Si}\left(1-\Phi\left(\frac{t_S-\mu_{Si}}{\sigma_{Si}}\right)\right)+\sigma_{Si}\phi\left(\frac{t_S-\mu_{Si}}{\sigma_{Si}}\right)\right] \\ & \left.+t_{Si}^2\left[1-\Phi\left(\frac{t_S-\mu_{Si}}{\sigma_{Si}}\right)\right]\right]. \end{aligned} \tag{9}$$

where F and f are cumulative and probability density functions of a normal distribution, respectively.

3.3 Loss of Dependability

Dependability refers to the ability to supply items as promised. Dependability sometimes includes delivery due date, delivery accuracy, and delivery completeness. The above subsection has already considered the delivery period. Thus, this subsection emphasizes on only delivery accuracy and completeness. Similar to the speed, in the case that items are produced by the company, dependability can be managed with a good planning system. The loss is then incurred only when items are outsourced.

In this paper, completeness means a vendor delivers the correct items in the required amount. If the vendor delivers more items than required, the company may keep the remaining amount as inventory and accumulate inventory costs. On the contrary, if the vendor delivers fewer items than required, the shortage and its relevant costs may be incurred. Hence, the losses incurred when incorrect amount of item is delivered are asymmetric. Assume that k_{DL} and k_{DR} are the loss coefficients when fewer items than are required are delivered and when more items than are required are delivered, respectively. Since the shortage costs are generally greater than inventory costs, $k_{DL} > k_{DR}$. The loss function for dependability can be shown as.

$$L_{Di} = \begin{cases} k_{DL}(D_i - t_D)^2 & D_i \le t_D \\ k_{DR}(D_i - t_D)^2 & D_i > t_D \end{cases}, \tag{10}$$

where D_i and t_D are the delivery amount from vendor i and the required amount, respectively. Figure 4 shows the relationship between the losses and the delivery amount.

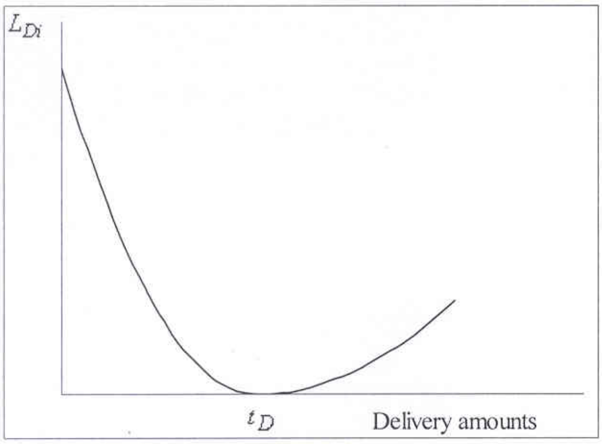

Figure 4. Losses due to not getting items on the required amount

Assuming that D_i is normally distributed with mean μ_{Di} and variance σ^2_{Di}, the expected value of L_{Di} is

$$\begin{aligned} E[L_{Di}] = k_{DL}\Bigg[& \sigma^2_{Di}\left[\Phi\left(\frac{t_D-\mu_{Di}}{\sigma_{Di}}\right)-\left(\frac{t_D-\mu_{Di}}{\sigma_{Di}}\right)\phi\left(\frac{t_D-\mu_{Di}}{\sigma_{Di}}\right)\right]+\mu^2_{Di}\Phi\left(\frac{t_D-\mu_{Di}}{\sigma_{Di}}\right) \\ & -2\mu_{Di}\sigma_{Di}\phi\left(\frac{t_D-\mu_{Di}}{\sigma_{Di}}\right)-2t_D\left[\mu_{Di}\Phi\left(\frac{t_D-\mu_{Di}}{\sigma_{Di}}\right)-\sigma_{Di}\phi\left(\frac{t_D-\mu_{Di}}{\sigma_{Di}}\right)\right] \\ & +t_D^2\Phi\left(\frac{t_D-\mu_{Di}}{\sigma_{Di}}\right)\Bigg]+k_{DR}\Bigg[\sigma^2_{Di}\left[1-\Phi\left(\frac{t_D-\mu_{Di}}{\sigma_{Di}}\right)+\left(\frac{t_D-\mu_{Di}}{\sigma_{Di}}\right)\phi\left(\frac{t_D-\mu_{Di}}{\sigma_{Di}}\right)\right] \\ & +\mu^2_{Di}\left[1-\Phi\left(\frac{t_D-\mu_{Di}}{\sigma_{Di}}\right)\right]+2\mu_{Di}\sigma_{Di}\phi\left(\frac{t_D-\mu_{Di}}{\sigma_{Di}}\right)-2t_{Di}\left[\mu_{Di}\left(1-\Phi\left(\frac{t_D-\mu_{Di}}{\sigma_{Di}}\right)\right)\right. \\ & \left.+\sigma_{Di}\phi\left(\frac{t_D-\mu_{Di}}{\sigma_{Di}}\right)\right]+t^2_{Di}\left[1-\Phi\left(\frac{t_D-\mu_{Di}}{\sigma_{Di}}\right)\right]\Bigg]. \end{aligned} \tag{11}$$

3.4 Loss of Flexibility

In many markets, a company's ability to respond to increases and decreases in demand is an important factor in its ability to compete. Flexibility is then one of the important measures. Flexibility is related to the ability of a vendor to respond to a company. It is normally measured by the ratio of the proportional change in response with respect to proportional change of the company. The proportional change in response is normally less than the proportional change of the company. Hence, the ratio is between zero and one. If vendor i gets the ratio equal to one, it means any changes incurred by the company can be responded to. Contrarily, if vendor i gets the ratio equal to zero, it means vendor i cannot respond to the changes incurred by the company. In the company's view, the value one is the best while the value zero is the worst. When the ratio equals to one, there is no loss incurred in the company's view and when the ratio equals to zero, the loss may be infinity. It seems that the type of Taguchi loss function most appropriate for this situation is the 'bigger the better' type. However, inserting the ratio into the model in Eq. (2) would show the following: when the ratio equals one, the loss equals the coefficient and when the ratio equals zero, the loss may be infinity. Therefore, the model in Eq. (2) needs to be adjusted. Eq.(12) shows the modification of the bigger the better model.

$$L_{Fi} = k_F(1/F_i^2 - 1) \tag{12}$$

where L_{Fi} is the loss due to vendor i not responding the changes when required, k_F is the loss coefficient of flexibility, and F_i is the flexibility ratio of vendor i. Assuming that F_i is normally distributed with mean μ_{Fi} and variance σ^2_{Fi}, the expected loss is then

$$E[L_{Fi}] = k_F\left[\frac{1}{\mu^2_{Fi}} - 1\right]\left[1 + \left(3\sigma^2_{Fi} / \mu^2_{Fi}\right)\right]. \tag{13}$$

3.5 Cost

The cost here is defined as the item cost. Each vendor normally provides a different cost. Some vendors may believe in their item quality and set their price high while other vendors may want to compete with the price, so the price is set low. Some vendors may emphasize their services and believe that they can respond to any changes incurred by the company, so the price is high. Let C_M be the item cost when items are produced by the company and C_i be the item cost of vendor i. Those costs are included in the mathematical model.

4. Model development

The objective of this paper is to give an answer whether outsourcing is appropriate and which vendors should be selected based on a Taguchi loss function. The previous section discussed four types of losses and the item cost. The expected losses for those four types are also provided. The objective, then, is to minimize all the losses incurred and the item costs. The objective function is

$$\begin{aligned} \text{Minimize. } & N_M E[L_{QM}] + \sum_i N_i E[L_{Qi}] + \sum_i N_i E[L_{Si}] + \sum_i N_i E[L_{Di}] + \sum_i N_i E[L_{Fi}] \\ & + \sum_i N_i C_i + N_M C_M \end{aligned} \tag{14}$$

Subjected to

$$N_M + \sum_i N_i \geq \text{DM} \tag{15}$$

$$N_i \leq Ca_i \text{ for } \forall i \tag{16}$$

$$N_M \leq Ca_M \tag{17}$$

$$N_M, N_i \in \text{Non-negative integer} \tag{18}$$

where N_M and N_i are the amount of items being produced by the company and the amount of items outsourced to vendor i. Since the expected value given in the above section is the expected value per item, the total losses and costs incurred due to producing the item internally and outsourcing to vendor *i* are the summation of the expected losses and costs per item multiplied by the item quantity.

The constraints relating to this issue is the demand constraint. Since all demand must be met, the constraint in Eq. (15) is utilized. Note that DM is the amount of demand. The next two constraints, Eqs. (16-17), are related to the vendor's and the company's capacity, respectively. Normally, each vendor has a different capacity to produce and provide items to the company. Ca_M and stand for the company capacity and vendor *i* capacity. The last constraint, Eq. (18) is used to ensure that the amount of items producing inside the company and through outsourcing to vendor *i* are non-negative integers.

5. A numerical example

In order to illustrate the use of the mathematical model, this numerical example is given. Please note that all data have been coded. Based on the model, data and cost collections are required. The coefficients of loss functions are generated by managers and relevant people. Data collection of means and variances of each vendor in many forms are also needed. Table 1 shows the coefficients of loss functions for each non-cash performance measure. Table 2 shows the vendor performances for each non-cash measure and its associated item costs. The mean and variance of defective rate when items are produced by the company are 0.05 and 0.01, whereas the company's capacity is 200. The number of days and items the company desires are 7 days and 1,000 items. Lastly, the cost per item if the items are produced internally is 110.

Utilizing the mathematical model presented in the previous section, the result shows that 200 items should be manufactured by the company and 800 items should be outsourced. 300 items of the outsourcing items should be given to vendor 4 and the remaining parts, 500 items, should be given to vendor 5. The results show total losses and costs at 133,925.79. The reason of 200 items manufactured inside is, only quality and item costs are considered in the model. Speed, dependability, and flexibility inside the company are assumed to be managed. In fact, managing speed, dependability and flexibility may incur costs.

Considering only item costs, the lowest item costs go to vendors 1, 2, 3, 4, 5, and manufacturing insided the company, respectively. Hence, the items should be outsourced to vendor 1-100 items; vendor 2-200 items, vendor 3-300 items, and vendor 4-400 items based on their capacities. The total losses and costs in this case are 251,599.31. It can be seen that basing outsourcing decisions solely on item costs may lead to higher non-cash losses.

Table 1. Coefficients of loss functions

Ca_i

Quality		Speed	
k_{Qm}	15	k_{SL}	0.2
k_{Qo}	15	k_{SR}	0.7
Dependability		**Flexibility**	
k_{DL}	0.0005	k_F	2
k_{DR}	0.0001		

Table 2. Means and standard deviations of performance measures and costs

Vendor		1	2	3	4	5
Quality	μ_{pi}	0.05	0.03	0.1	0.07	0.07
	σ_{pi}	0.01	0.02	0.05	0.09	0.012
Speed	μ_{Si}	5	6	7	8	9
	σ_{Si}	2.5	2	1.5	1	2
Dependability	μ_{Di}	400	450	500	510	520
	σ_{Di}	10	8	10	8	10
Flexibility	μ_{Fi}	0.3	0.5	0.7	0.8	0.9
	σ_{Fi}	0.05	0.02	0.01	0.09	0.05
Cost		50	60	70	80	90
Capacity		100	200	300	400	500

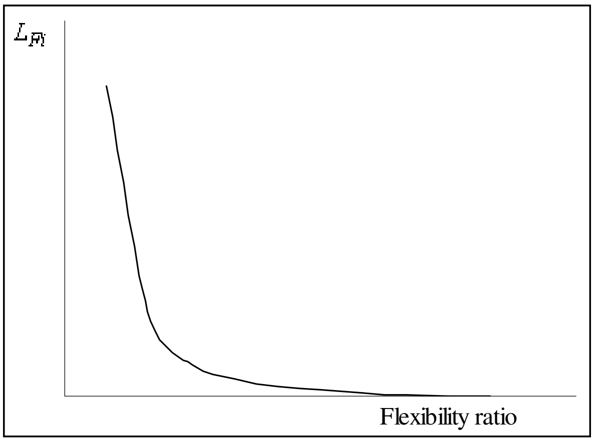

Figure 5. Losses due to the inability to adapt when required

6. Conclusions and Discussions

Outsourcing and vendor selection is tedious work. Many attributes need to be considered. This paper considers the attributes of quality, speed, dependability, flexibility, and cost. Quality, speed, dependability, and flexibility are non-cash impacts while item cost is a cash impact. The non-cash impact is difficult to measure. This paper applies a Taguchi loss function to measure those non-cash impacts and give the expected value of loss for each type of non-cash impact. A mathematical model is given and the use of the model is illustrated though a numerical example. Based on the example, it can be seen that basing outsourcing and vendor selection solely on cash impacts may lead to substantial non-cash costs.

Even though implementing the non-cash impacts in the model seems to be reasonable, determining the loss coefficients is tedious. Practitioners need to be careful in assigning the loss coefficients. For example, to determine the loss coefficient due to quality, practitioners should include the cost of inspection, the loss of passing defective parts into the manufacturing process, and the loss to the customers when the defects cannot be detected in the process. Similarly, when determining the loss coefficients due to speed, dependability, and flexibility, many types of losses incurred both inside and outside the manufacturing process need to be considered.

This paper assumes an equal weight to each type of performance measures. In the case that the company desires to emphasize in some measure over the others, different weights may be applied to the model. Moreover, it is suggested that there should be a discussion on the constraints applied to the amount of items outsourcing to a vendor in the future research.

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