

A Quality Model for a Multi-layered Sourcing Supply Chain

JrJung Lyu and Chia-Wen Chen

Department of Industrial and Information Management,
National Cheng Kung University
Tainan, Taiwan, R.O.C.

Abstract

Under globalization, many firms increasingly opt to blur their organizational boundaries to enhance the quality of both raw materials and final products. Manufacturers typically purchase components or parts from suppliers to manufacture products for customers. First-tier suppliers then purchase components from second-tier suppliers in a multi-layered sourcing supply chain. The quality of components or parts purchased from first- and second-tier suppliers affects the quality of finished products. In this study, a quality model is proposed to ensure the yield rate of each tier (second-tier suppliers, first-tier suppliers, and the manufacturer). This model can be applied to satisfy customers of manufacturers in a multi-layered sourcing supply chain.

Keywords

Multi-layered sourcing supply chain, quality model

1. Introduction

As countless suppliers are available in the global marketplace, identifying appropriate suppliers via multiple sourcing to ensure product quality in a global supply chain is extremely important. Manufacturers typically purchase components or parts from suppliers to produce finished products for customers. First-tier suppliers then purchase components from second-tier suppliers in multi-layered sourcing supply chain. The quality of components and parts is central to supplier evaluation (Wu *et al.*, 2008). Notably, the quality of components and parts purchased from first- and second-tier suppliers affects the quality of finished products. In a three-echelon supply chain, product defects are repaired prior to delivery to customers. Repair costs are based on the number of finished processes use to repair a defective product. Repair cost increases and has a significant effect on quality when a defect can be traced to the second-tier supplier. Therefore, only the considerations of processing yield rate of manufacturer and first-tier supplier are unsatisfied, and the second-tier supplier is also considered. As mentioned, the existence of multi-sourcing and multi-layered supply chains increase the difficulty of generating a quality model for a supply chain that ensures that product quality meets customer needs. In Fig. 1, F_m means the first-tier supplier providing the same part to a manufacturer; however, these parts have different quality. $S_{m,n}$ purchases the required components from their second-tier suppliers, respectively. Therefore, how to select the best first- and second-tier suppliers to achieve product quality with minimal cost becomes increasingly complex and difficult.

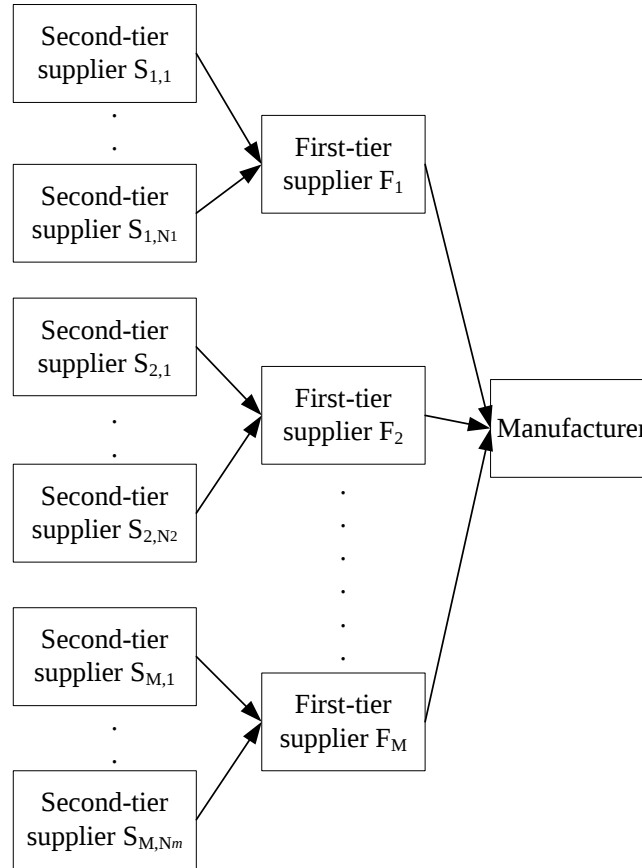


Figure 1. A typical multi-layered sourcing supply chain showing the relationships among the manufacturer, first-tier suppliers, and second-tier suppliers.

In this study, a multi-layered sourcing quality model (MSQM) is developed to address this problem in a supply chain. The proposed quality model can be applied to improve yield rate for each layer (second-tier supplier, first-tier supplier, and manufacturer) using inspection and repair to satisfy customers of manufacturers.

The remainder of paper is organized as follows. Section 2 reviews relevant literature. Section 3 describes the proposed quality model. Section 4 addresses the case study of a motorcycle manufacturer. Finally, Section 5 gives conclusions.

2. Literature Review

Quality cost estimation can be utilized to help manufacturers with different levels of risk aversion select suppliers to construct an appropriate quality model and satisfy customers in a multi-layered sourcing supply chain. In this era of global competition, suppliers are distributed worldwide; thus sourcing material is a significant task for global supply chains. Manufacturers typically pay close attention to supplier selection. Chan *et al.* (2008) proposed a fuzzy-based analytical hierarchy process to generate guidelines and directions for decision-makers when selecting appropriate global suppliers. An example from a manufacturing industry searching for a global supplier of a critical component was employed to demonstrate the effectiveness of the process. Abdel-Malek *et al.* (2005) developed a framework for assessing the performance of outsourcing strategies in a multi-layered supply chain. Cooper and Yoshikawa (1994) developed a three-phase supply chain framework that has an automobile assembly plant, first-tier supplier, and second-tier supplier. Inter-organizational systems were developed for sharing information to reduce the cost of products supplied by the chain. Ghodsypour and O'Brien (2001) generated a mixed-integer non-linear programming model to solve the multiple sourcing problem; this model accounts for the total cost of logistics.

Quality cost can be utilized to estimate the related costs between supplier and manufacturer. Freeman (1995) divided quality cost into prevention cost, appraisal cost, international failure cost, and

external failure cost. Chang *et al.* (1996) developed a method for determining quality costs in multi-stage manufacturing systems by considering these four costs. Tagaras and Lee (1996) developed a quality cost model that considers quality cost, input quality, and imperfections during supplier selection.

A quality model can be constructed that considers quality cost. From the viewpoint of suppliers, Starbird (1994) applied numerical methods to examine how a risk-averse supplier reacts to acceptance of the sampling plan used by a customer. Starbird demonstrated that risk-averse suppliers deliver high-quality goods. Notably, manufacturers also have different levels of risk aversion. From the manufacturer perspective, Moskowitz and Plante (1984) presented an optimization algorithm that combines Bayesian sampling and a risk function to obtain an optimal sampling plan while maximizing expected utility. In considering the viewpoints of both suppliers and manufacturers, Reyniers (1992) indicated that quality control and a sampling plan are important to reducing cost for both suppliers and manufacturers.

3. Multi-layered Sourcing Quality Model (MSQM)

This study proposes a multi-layered sourcing quality model (MSQM) to improve the yield rate for each layer in a supply chain (second-tier supplier, first-tier supplier, and the manufacturer) using inspection and repair for manufacturers.

To meet the quality requirements of customers, the MSQM evaluates the total cost, including quality cost (cost of repairing defects) and purchase cost, for each supplier to help manufacturers select suppliers. A manufacturing operation can be protected against poor input quality by inspecting incoming materials.

Consider a manufacturer receiving one type of input material from a particular supplier. These materials are processed and transformed into finished products. Incoming materials and the manufacturing process may be imperfect. The simple module (SM) makes the following assumptions.

- Defective output is only identified in the inspection process.
- q_2 , q_1 , and q_0 are independent.
- No inspection of incoming material is performed.

Notably, q_2 and q_1 are the probabilities that a unit of incoming material from the second- and first-tier suppliers is defective, respectively. Additionally, q_0 is the probability that the manufacturing process is producing defective output.

The result of defective output can be rework, scrap, and external failure costs. The unit cost of defective output when defects are due to an imperfection is r_0 . The unit cost of defective output is r_{01} and r_{02} when defects are produced from imperfect input from the first- and second-tier suppliers, respectively, and the manufacturing process is imperfect. The unit cost of defective output is r_{012} when the defect was produced using inputs from the first- and second-tier suppliers, and the manufacturing process is imperfect. Both r_1 and r_2 are the unit costs of a defective output when the defect is due to defective input from the first- and second-tier suppliers, respectively. Notably, r_{12} is the unit cost of defective output when the defect is due to defective input from the first- and second-tier suppliers. Thus, the probabilities for the incurrence of costs r_0 , r_1 , r_{01} , r_2 , r_{02} , r_{12} and r_{012} are $(1-q_2)(1-q_1)q_0$, $(1-q_2)q_1(1-q_0)$, $(1-q_2)q_1q_0$, $q_2(1-q_1)(1-q_0)$, $q_2(1-q_1)q_0$, $q_2q_1(1-q_0)$, and $q_0q_1q_2$, respectively. Hence, for a given q_2 and q_1 , the expected failure cost per unit processed is derived by Eq. (1).

$$\begin{aligned} \phi(q_2, q_1) = & (1-q_2)(1-q_1)q_0r_0 + (1-q_2)q_1(1-q_0)r_1 + (1-q_2)q_1q_0r_{01} \\ & + q_2(1-q_1)(1-q_0)r_2 + q_2(1-q_1)q_0r_{02} + q_2q_1(1-q_0)r_{12} + q_0q_1q_2r_{012} \end{aligned} \quad (1)$$

When the input material from the second- and first-tier suppliers is perfect, the expected failure cost per unit is $\phi(q_2 = 0, q_1 = 0) = (1-q_1)(1-q_0)r_0$. The average quality cost of finished product with material from the second- and first-tier suppliers per unit, $Q(q_2, q_1)$ is derived by Eq. (2).

$$\begin{aligned} Q(q_2, q_1) = & \phi(q_2, q_1) - \phi(q_2 = 0, q_1 = 0) = (1-q_2)q_1(1-q_0)r_1 + (1-q_2)q_1q_0r_{01} \\ & + q_2(1-q_1)(1-q_0)r_2 + q_2(1-q_1)q_0r_{02} + q_2q_1(1-q_0)r_{12} + q_0q_1q_2r_{012} \end{aligned} \quad (2)$$

To evaluate a particular supplier, both purchase and quality costs must be considered. Generally, unit purchase cost depends on average product quality, *i.e.*, on probabilities q_2 and q_1 that a random unit purchased from a supplier is defective. Total acquisition and quality costs relevant to supplier evaluation are derived by Eq. (3). Let c be the unit cost of guaranteed conforming product ($q_2=0, q_1=0$), the unit purchase cost is then $C(q_2, q_1) = c(1 - q_2)^2(1 - q_1)^2$.

$$K(q_2, q_1) = C(q_2, q_1) + Q(q_2, q_1) = c(1 - q_2)^2(1 - q_1)^2 + (1 - q_2)q_1(1 - q_0)r_1 + (1 - q_2)q_1q_0r_{01} + q_2(1 - q_1)(1 - q_0)r_2 + q_2(1 - q_1)q_0r_{02} + q_2q_1(1 - q_0)r_{12} + q_0q_1q_2r_{012} \quad (3)$$

The relationship between q_2 , q_1 , and $C(q_2, q_1)$ can be expressed in formulas. The optimal q_2 and q_1 (suppliers) satisfy the first derivatives $\frac{dK}{dq_2} = 0$ and $\frac{dK}{dq_1} = 0$, as well as the second derivatives $\frac{\partial^2 K(q_2, q_1)}{\partial q_2^2} \geq 0$, $\frac{\partial^2 K(q_2, q_1)}{\partial q_1^2} \geq 0$, and $\frac{\partial^2 K(q_2, q_1)}{\partial q_2 \partial q_1} = \frac{\partial^2 K(q_2, q_1)}{\partial q_1 \partial q_2} \geq 0$. The first derivatives of total cost with respect to q_2 and q_1 are derived by Eqs. (4) and (5), respectively.

$$\frac{\partial K(q_2, q_1)}{\partial q_2} = -2c(1 - q_2)(1 - q_1)^2 - q_1(1 - q_0)r_1 - q_1q_0r_{01} + (1 - q_1)(1 - q_0)r_2 + (1 - q_1)q_0r_{02} + q_1(1 - q_0)r_{12} + q_1q_0r_{012} \quad (4)$$

$$\frac{\partial K(q_2, q_1)}{\partial q_1} = -2c(1 - q_2)^2(1 - q_1) + (1 - q_2)(1 - q_0)r_1 + (1 - q_2)q_0r_{01} - q_2(1 - q_0)r_2 - q_2q_0r_{02} + q_2(1 - q_0)r_{12} + q_0q_2r_{012} \quad (5)$$

The second derivatives of total cost with respect to q_2^2 , q_1^2 , and q_1q_2 (q_2q_1) are derived by Eqs. (6)–(8), respectively.

$$\frac{\partial^2 K}{\partial q_2^2} = 2c(1 - q_1)^2 > 0 \quad (6)$$

$$\frac{\partial^2 K}{\partial q_1^2} = 2c(1 - q_2)^2 > 0 \quad (7)$$

$$\frac{\partial^2 K}{\partial q_2 \partial q_1} = \frac{\partial^2 K}{\partial q_1 \partial q_2} = 4c(1 - q_2)(1 - q_1) - (1 - q_0)r_1 - q_0r_{01} - (1 - q_0)r_2 - q_0r_{02} + (1 - q_0)r_{12} + q_0r_{012} \quad (8)$$

To search for the minimum total cost, $\frac{\partial^2 K}{\partial q_2^2} * \frac{\partial^2 K}{\partial q_1^2} - \left(\frac{\partial^2 K}{\partial q_2 \partial q_1} \right)^2$ must be larger than zero.

When the output of Eq. (9) exceeds zero, it means that $\frac{\partial K}{\partial q_2} = 0$ and $\frac{\partial K}{\partial q_1} = 0$. It indicates that the optimal solution (q_2^*, q_1^*) are exist resulting the minimum $K(q_2, q_1)$.

$$4c^2(1 - q_2)^2(1 - q_1)^2 - \{4c(1 - q_2)(1 - q_1) + [(r_{12} - r_1 - r_2) + q_0(r_1 + r_2 + r_{012} - r_{01} - r_{12} - r_{02})]\}^2 \quad (9)$$

$$\text{Let } W = (1 - q_0)r_1 + q_0r_{01} + (1 - q_0)r_2 + q_0r_{02} - (1 - q_0)r_{12} - q_0r_{012}, \quad \frac{\partial K}{\partial q_2} = 0 \quad \text{and}$$

$\frac{\partial K}{\partial q_1} = 0$ be represented by Eqs. (10) and (11), respectively. The solutions of q_1 and q_2 are acquired using Mathematica.

$$-2c(1 - q_2)(1 - q_1)^2 - q_1W + (1 - q_0)r_2 + q_0r_{02} = 0 \quad (10)$$

$$-2c(1 - q_2)^2(1 - q_1) - q_2W + (1 - q_0)r_1 + q_0r_{01} = 0 \quad (11)$$

4. Case Study

The case in this study is the supply chain of a motorcycle manufacturer, which includes the manufacturer (assembly plant), first-tier supplier (electrical machinery plant), and second-tier supplier (component plant). The case company's assembly plant purchases parts from the electrical machinery plant and sells motorcycles to customers. The first-tier supplier, the electrical machinery plant, purchases raw materials from the component plant and sells components to the assembly plant. The second-tier supplier, the component plant, provides raw materials to the electrical machinery plant for part production.

The defect rate of the assembly plant (q_0) is 0.04. The defect rates (q_1) of the electrical machinery plants, plants A and B (q_1^A and q_1^B), are 0.06 and 0.05, and defect rates (q_2) of the corresponding component plants (q_2^A and q_2^B), are 0.08, and 0.10. The unit cost of a defective output from the assembly plant (r_0), electrical machinery plants A and B (r_1), and component plants, second-tier supplier for first-tier supplier A and B (r_2) are 100, 800, and 1300. The unit costs of a defective output from the assembly plant and electrical machinery plant (r_{01}), assembly plant and component plant (r_{02}), and electrical machinery plant and component plant (r_{12}) are 1500, 2000, and 2500, respectively. The unit cost of defective output from the assembly plant, electrical machinery plant, and component plant (denoted by r_{012}) is 5000. The unit purchase cost of guaranteed conforming parts from the electrical machinery plant (c) is 800.

Figure 2 presents an example of feasible solutions. Figure 2 shows all solutions of the total cost function when the manufacturer selects supplier A. The X-axis represents the defect rate of the second-tier supplier, Y-axis represents the processing defective rate of the first-tier supplier, and Z-axis represents the total cost. The SM can be used to determine the optimal yield rates for the first- and second-tier suppliers by considering quality cost and purchase cost to minimize total cost.

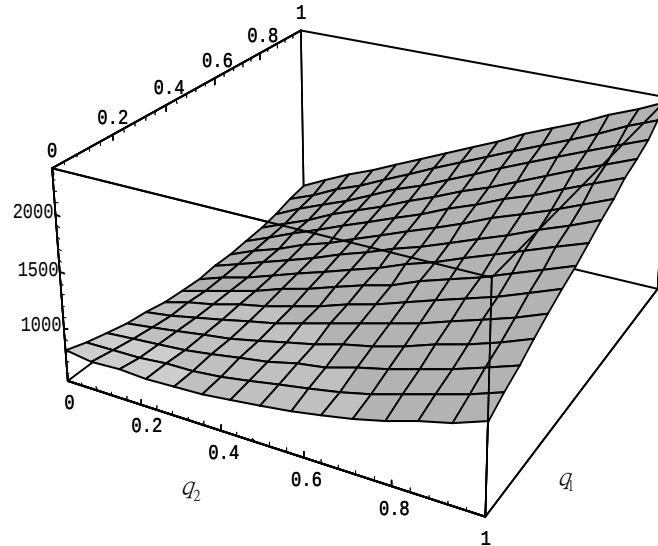


Figure 2. Numerical illustration.

After the defective rate and cost are read in, the total cost of the assembly plant purchasing parts from the electrical machinery plant via Eq. (3). For machinery plant A, total cost is 756.35. For machinery plant B, total cost is 761.24.

$$K(q_2^A, q_1^A) = C(q_2^A, q_1^A) + Q(q_2^A, q_1^A) = 598.30 + 158.05 = 756.35$$

$$K(q_2^B, q_1^B) = C(q_2^B, q_1^B) + Q(q_2^B, q_1^B) = 584.82 + 176.42 = 761.24$$

5. Conclusions

This study proposes a multi-layered sourcing quality model (MSQM) to help the manufacturer select the appropriate first- and second-tier suppliers while considering quality cost. In MSQM, assume that all parameters are fixed, except for defect rate of the second-tier supplier. The corresponding defect rate of the lowest total cost yields the optimal quality level of the supplier, resulting in the lowest cost for the manufacturer when considering both cost and manufacturer defect rate.

Under globalization, an appropriate quality model that considers quality cost is important for assuring product quality in a multi-layered sourcing supply chain. In addition to improving manufacturer capabilities, quality improvement in supplier product is required.

This study proposes MSQM to improve the yield rate for each layer (second-tier supplier, first-tier supplier, and manufacturer) in multi-layered sourcing supply chain. A motorcycle supply chain, which has a manufacturer (assembly plant), first-tier supplier (electrical machinery plant), and second-tier supplier (component plant), is used as a case study to assess the performance of the proposed quality model. The proposed MSQM can help manufacturer adjust their quality plans to reduce quality cost and improve customer satisfaction.

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