

Development-or-Switching Decisions Under Uncertainty for Dealing with Problematic Suppliers Considering the Strategic Potential

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ABSTRACT

This study investigates managing the relationship with problematic suppliers. Three options are supposed, development, switching, or bearing the current situation. We consider a two-dimensional supplier evaluation structure to develop an analytical formulation for resolving the issue. The proposed solution is presented in two sections: the first section utilizes the lost market share considering the supplier performance and the second section examines the role of strategic potential as a critical indicator of suppliers besides the performance using the earned market share to make the development-or-switching decision. Results revealed that strategic potential plays a critical role in the considered decision. We develop a decision map based on the strategic potential of the incumbent and alternative suppliers. We realize that the effectiveness of the development decision is independent of the performance and relies mainly on the strategic potential of the incumbent supplier. Furthermore, besides the strategic potential of the incumbent supplier, the performance of the alternative supplier has a double effect on the optimality area of switching in the decision map. Finally, our work is numerically compared to a well-known model in the literature.

Keywords: *mathematical modeling, strategic potential, supplier development, supplier switching*

1. INTRODUCTION

As global supply chains are expanding and becoming more complex growingly, businesses must formulate effective strategies for managing relationships with suppliers (Ur Rehman *et al.*, 2024). As many researchers mentioned, in recent decades there has been a growing interest in the buyer-supplier relationship and companies have heavily been dependent on their suppliers. The dependency has grown up to 70% in some industries. Indeed, suppliers have a significant impact on the quality, price, and delivery of final products as critical performance criteria (Krause *et al.*, 2000). Therefore, companies are

concerned about how to manage their suppliers to enhance their products and gain competitive advantages.

Problematic suppliers are those that companies should be careful about them. They are useful sources of supply but pose serious performance problems (Schuh *et al.*, 2014). Managing problematic suppliers has always been challenging so researchers and practitioners have developed concepts such as “supplier relationship management” (SRM) as a comprehensive perspective on the buyer-supplier relationship. SRM is about planning and managing all the strategic interactions with suppliers and aims to define differentiated strategies and behaviors for various suppliers (Glock *et al.*, 2017). It includes activities such as the identification and selection of eligible suppliers, the supplier evaluation (continuous monitoring of the performance), and the development of qualified suppliers (Glock *et al.*, 2017).

Based on this concept, there are two main strategies to deal with problematic suppliers: (1) supplier development (i.e., to conduct activities to improve supplier’s capabilities on cost, quality, delivery, and/or service performance (Friedl & Wagner, 2012; Wagner, 2010) or (2) supplier switching (i.e., to search for a more capable supplier as an alternative source of supply) (Jain *et al.*, 2020; Li *et al.*, 2006). They are the only remedies for the performance problems of such suppliers where vertical integration is not possible (Wagner, 2006; Handfield *et al.*, 2000).

To deal with a problematic supplier, companies may decide to develop its performance and/or capabilities (i.e., investing time, effort, expertise, and capital (Nasr & Jaber, 2019; Agrawal, 2016) due to the problems such as low quality, low service levels, insufficient capacity, low innovative strength, or low environmental awareness, etc.) (Glock *et al.*, 2017; Wagner, 2006). Supplier development has widely been applied in various industries (Talluri *et al.*, 2010) and studies such as (Gu *et al.*, 2021) indicated its positive effect on supplier performance.

From its origin, in Japan, Toyota helped its suppliers to fix quality problems and to provide on-site assistance using Toyota Production System (Sako, 2004; Dyer & Nobeoka, 2000). John Deere's Enterprise Supply Management Group developed some supplier capacity enhancement initiatives through the "Achieving Excellence" program. As another example, Airbus initiated the "Power 8 Program" for sourcing from India and other emerging economies (Jain *et al.*, 2020). Moreover, significant supplier investments have been done by Honda, Nissan, Chrysler, Ford, General Motors, General Electric, Dell, Microsoft, and Boeing to improve productivity (Nasr & Jaber, 2019; Agrawal, 2016; Dyer & Nobeoka, 2000).

Another option for dealing with a problematic supplier may be considered when suitable alternative sources have offered the potential for quality improvements, cost savings, and delivery superiorities; the company will be tempted to cut with the problematic supplier, especially when the investment is risky or infeasible. However, in contrast to the incumbent supplier, the characteristics of alternative suppliers are usually hidden (Wagner & Friedl, 2007), and exploiting the above-mentioned potentials are not guaranteed. Therefore, the company encounters fundamental issues with the switching decision.

To cope with a problematic supplier and make a reasonable development-or-switching decision, companies are confronted with two critical challenges: decision risks and supplier evaluation. As mentioned, problematic suppliers are useful sources although there might be some problems with their performance (mostly on quality, delivery, or price) that should be resolved. This makes the decision not to be straightforward. For the supplier development option, besides the supplier's cost of capital, companies face some risks such as the lack of a proper return on investment, information leakage, the loss of business and market, and the breach of trust (Rashidi & Farzipoor Saen, 2018; Mohanty *et al.*, 2014; Mizgier *et al.*, 2017).

On the other hand, besides the one-step switching costs, the relevant information about the offerings of alternative suppliers is open to doubt which makes the company feels uncertain about the switching option (Friedl & Wagner, 2012; Lewis & Yildirim, 2005). Therefore, a feasible ROI for the development decision is not ensured and a higher performance with the alternative supplier is not guaranteed. It is challenging to distinguish a problematic supplier that is worth developing or should be replaced (Schuh *et al.*, 2014).

The other challenge, i.e., evaluation, is actually about dimensions or categorizations of criteria. Using different criteria for supplier evaluation in decision support models has been controversial. Mathematical models for supplier development used criteria with different roles in the same modeling structure. In the supplier segmentation area and also some conceptual supplier development studies, two dimensions; i.e., supplier performance and supplier potential (capability), have mostly been used for supplier evaluation (Schuh *et al.*, 2014; Olsen & Ellram, 1997; Osiro, 2014; Sarkar & Mohapatra, 2006).

As a comprehensive definition, Schuh *et al.* (2014) introduced the supplier's strategic potential as the supplier's relevancy concerning the execution of the company's strategies. They considered growth (i.e., to improve the company's value proposition for existing customers), innovation (i.e., supplier owns or proposes new

technologies), scope (i.e., the supplier relevancy across most business units of the company), and collaboration (i.e., the right mindset of a supplier in working with the company across different functional areas) as high-level criteria of a supplier's strategic potential. Similarly, Osiro *et al.* (2014) used partnership for the evaluation of this dimension. They related partnership to technical and financial capabilities, communication, and commitment. To sum up, we can say that the mentioned two-dimensional model considers both the current performance and the capability of suppliers that affect the companies' strategies.

Many researchers (such as Araz & Ozkarahan (2007) and Talluri & Narasimhan (2004)) declared that supplier potential plays a critical role in the development of supplier performance. It means that ROI for supplier development is highly dependent on the supplier's strategic potential. The supplier potential can affect the long-term performance of the company considering its collaboration and innovation capabilities. Schuh *et al.* (2014) mentioned that the supplier's strategic potential is key to the competitive advantage of a company. They emphasized innovation and new product development (NPD) as projects that are significantly influenced by the strategic potential which is critical for the future market share of the company. Masella & Rangone (2000) stated while the short-term competitive advantage is related to the performance of the current product, it mainly depends on the potential-related criteria of suppliers in the long term. Thus, the strategic potential can affect both the short-term and long-term performance of companies and they are not independent.

To this end, this study considers the problematic supplier of a given manufacturing company and proposes an analytic solution approach to decide whether and how to develop it or switch to an appropriate alternative supplier. It is worth noting that (1) the development and switching are two interrelated sourcing decisions but researchers studied them independently (Glock *et al.*, 2017; Friedl & Wagner, 2012) and (2) the existing methodologies have mostly been empirical or conceptual in nature Glock *et al.* (2017) and quantitative models are rare for both the strategic decisions. This study develops a two-dimensional (i.e., performance and strategic potential) supplier evaluation approach to make the development-or-switching decision. The proposed model addresses two main uncertainties: ROI for the development decision and alternative supplier inappropriateness for the switching decision. To evaluate the performance, the well-known quality, cost, and delivery (QCD) criteria are formulated. In brief, we aim to answer the following research questions:

- (1) How can we decide about a problematic supplier when the ROI for the development and the performance of the alternative supplier for switching are both uncertain?
- (2) What is the role of the strategic potential in the development-or-switching decision for a problematic supplier?
- (3) What is the relationship between performance and strategic potential in the development-or-switching decision?

The rest of the paper is organized as follows. The relevant body of literature is reviewed in section 2. Section 3 includes the modeling and analysis of the development-or-

switching decision considering the performance and strategic potential dimensions. In section 4, our work is numerically compared to a well-known model in the literature. Discussion and managerial insights are presented in section 5. In section 6, concluding remarks and future research is provided.

2. LITERATURE REVIEW

The development of an incumbent supplier is the most common research stream in the relevant literature. Forker & Mendez (2001) developed an analytical model for identifying the best-performing and low-performing suppliers with the aim of development. They stated that low-performing suppliers that are not efficient frontiers but have the potential to move toward them, could be candidates for the supplier development efforts. They used DEA for the supplier evaluation considering the quality as output and the time and money as inputs. Liu *et al* (2000) considered the same approach for supplier selection and performance improvement to support JIT Manufacturing. Li & Xia (2022) developed a mathematical model for supplier selection, sustainability investment, and order allocation. They considered sustainability and operational performance as well as cost efficiency.

Bhattacharyya & Guiffrida (2015) developed an optimization model for supplier delivery improvement. They considered a buyer that invests in a supplier's delivery performance to reduce untimely deliveries. This study used the net present value of late delivery costs and made the investment decision based on a learning or improving rate. Meisel & Glock (2018) studied a situation in which a company is in the force of customers' demand and should ramp up the suppliers' production using the development. They proposed a deterministic profit-maximizing mathematical model that supports supplier selection and development and the order allocation to the supplier(s). Trapp & Sarkis (2016) developed an optimization model for sustainable supplier selection and development. Sustainability was considered in the form of ratings in the objective function to select suppliers that combatively have the highest sustainable rates and in the form of training activities (development) under budgetary constraints.

Nasr & Jaber (2019) studied a two-level joint production system focused on non-conforming items. The quantity of non-conforming items was a random variable its mean and standard deviation are reduced by the learning rate. They assumed the learning rate depends on two elements: the number of production runs and the buyer investment. Karaer *et al* (2020) considered a buyer with its tier-1 and tier-2 suppliers and assumed it controls two suppliers by sharing development costs among them. The goal was the development of quality capabilities of suppliers which the end customers are sensitive to. Avery *et al* (2014) examined the relationship between various aspects of social capital and buyer performance in the buyer-supplier dyad.

Golmohammadi *et al* (2018) studied the development of supply and demand uncertainties from the supplier viewpoint. They explored how a supplier can facilitate the supplier development effort of its buyer and identified three strategies including (1) manipulating the wholesale price, (2) paying a share of investment, and (3) controlling the investment in this regard. They showed that the optimal decisions of the players under all three strategies are unique.

Awasthy & Hazra (2019) studied a buyer and a supplier collaboration for improving safety in the suppliers' facility. They considered three strategies including (1) the buyer and the supplier jointly collaborate to provide safety at the supplier's manufacturing facility (Accord), (2) the buyer supports the supplier by providing external funding (Alliance), and (3) the buyer does not provide any support to the supplier for the upcoming safety (base policy). Using an analytical framework, they found that low-capability suppliers prefer the accord strategy when the buyer capability is high. Otherwise, they will choose the alliance strategy.

Golmohammadi & Hassini (2020) studied joint investment in improving the supplier's capacity under buyer-led and supplier-led situations. In the former, the first buyer makes the investment decision, and in the latter, the decision order is vice versa. They demonstrated that in the buyer-led game, the buyer follows an order inflation strategy to increase the investment of the supplier while in the supplier-led game, the buyer has no motivation to use the order inflation strategy. When the supplier is the only investor, the buyer-led game results in a higher profit for two players, and the supply chain. Chen *et al* (2019) investigated incentive contracts for capacity restoration. They considered two incentive contracts including sharing restoration cost and adjusting wholesale price with ex-ante and ex-post commitment strategies and analyzed disruption effects on the buyer's selling price to end customers.

Shokoohyar & Katok (2022) studied the incentive Mechanisms for Supplier Development based on scorecard evaluation. They consider a two-period supplier-manufacturer contractual agreement where the manufacturer evaluates and reviews supplier performance during each period. According to this research, scorecard evaluation incentives suppliers to improve their performance during the contract period and the manufacturer awards the supplier if the supplier's final score is at least at some pre-determined target level at the end of the contract.

Starita & Scaparra (2021) proposed a non-linear optimization model to determine an effective distribution of protective resources among facilities in the supply chain. The proposed model reduces the probability of failure to which facilities are exposed in case of external disruptions. This study assumed the failure probability of protected assets depends on the level of protection investments. Dye *et al* (2017) Consider a two-echelon supply chain with one manufacturer and one retailer cooperatively managing a single deteriorating item over an infinite time horizon. They assumed that the retailer can invest in preservation technology to reduce the deterioration rate and determined pricing and investment that maximizes the retailer and manufacturer profit.

In another stream, researchers investigated alternative suppliers as options for switching. Friedl & Wagner (2012) studied a cost-based single-sourcing development-or-switching problem. They considered the development will reduce the unit price of the supplier. Moreover, the costs of the incumbent supplier and the market demand are supposed as uncertain parameters. Considering a disruptive incumbent supplier and a reliable alternative supplier, Hu *et al* (2013) studied whether to invest in the restoration capabilities of the incumbent supplier or diversify a part of the order to a reliable supplier. In the investment option, the company should implement incentive mechanisms

(e.g., higher order quantities or higher wholesale price) to motivate the supplier to invest in the process's reliability.

To mitigate the product recall risk, Dong *et al* (2020) considered a two-echelon SC in which two contract manufacturers can decide the investment level to reduce defect possibility and share recall loss with an original equipment manufacturer. They studied the sourcing strategy when the recall loss sharing rate is fixed or not. Jain *et al* (2020) studied the problem of the capacity allocation between an incumbent supplier and a new supplier over a two-period horizon. In the first period, a buyer allocates some of its capacity requirements to the incumbent supplier and invests in the new supplier. In addition, both suppliers make process improvement efforts and therefore, enhance the effective capacity available in the second period. In the second period, the buyer allocates the rest of its capacity requirements among two competing suppliers.

Chen & Baddam (2015) formulated a mathematical model for the sourcing decision of two kinds of ethical and unethical suppliers in two periods. The unethical supplier could contribute to a lower-end product price due to the customer's punishment, but it is possible to reduce the cost of unethical suppliers by learning. Clemons & Slotnick (2016) considered a company that procured a product from an unreliable high-quality supplier whose deliveries are subject to random disruptions. They supposed the company has another option for sourcing the product from a reliable low-quality supplier whose quality can be developed by the investment. They developed a mathematical model to decide whether the company should undergo unexpected disruptions, or it should make a contract with the alternative supplier and undertake quality development investments.

Jafarian *et al* (2021) proposed a mathematical model to deal with problematic suppliers under risk. They considered three options: developing the incumbent supplier to improve its performance (development), switching to an appropriate alternative supplier (switching), and continuing with the incumbent supplier (status quo). This study developed a variable (lost market share) to evaluate decision risks considering the core performance measures of quality, cost, and delivery. Karadayi-Usta & Serdarasan (2023) focused on the evaluation and selection of service suppliers for a medical assistance company and then the allocation of their available capacity to the medical tourist demands. Pathak (2023) conducted an empirical qualitative content analysis to study the impact of digitalization on the Buyer Supplier relationship in the context of Industry 4.0. Ur Rehman *et al* (2023) analyzed the impact of buyer ethical environment on supplier performance with mediating role of trust.

Some research on supplier development considered some kinds of categorization. Talluri & Narasimhan (2004) categorized suppliers based on their performances and candidate them for strategic long-term partnerships, supplier development programs, and pruning. Talluri & Lee (2010) considered three kinds of long-term, medium-term, and short-term contracts for suppliers and assumed that investment is possible for medium-term and long-term suppliers to reduce their prices by a discount factor. Noorizadeh *et al* (2018) proposed a supplier categorization based on the efficiency targets for development investment in the construction industry. They used the customer

pyramid method as a final result of the categorization and established investment categories according to the supplier's position in the supplier pyramid.

Araz & Ozkarahan (2007) developed an evaluation and management system for strategic sourcing. This study evaluated suppliers by PROMETHEE and categorized them into predefined groups of strategic partner, development, competitive, and pruning.

Attention to the supplier development area has been significant in the past two decades (Talluri *et al*, 2010; Mizgier *et al*, 2017; Worthmann *et al*, 2016), but researchers mainly focused on empirical and conceptual works, and the formulation of decision support models was few (Talluri *et al*, 2010; Mizgier *et al*, 2017; Starita & Scaparra, 2021; Bai & Sarkis, 2010; Meisel, 2012; Glock, 2016). Our literature review illustrates that researchers mostly addressed the disruption as a development trigger whereas the attention to the problematic suppliers as development cases has been a rare research topic.

Moreover, for development purposes, researchers have limited their own to the performance dimension. Friedl & Wagner (2012), Jain *et al* (2020), Nasr & Jaber (2019), Karaer *et al* (2020), Chen *et al* (2019), Hu *et al* (2013), Chen & Baddam (2015), and Clemons & Slotnick (2016) considered only a single performance criterion for supplier evaluation and development. Friedl & Wagner (2012) developed a model for risk-neutral decision makers and assumed a deterministic investment-cost reduction coefficient while this is not the case in practice. Hu *et al* (2013) studied a risk-neutral problem and assumed a deterministic capacity for the alternative supplier. Meisel & Glock (2018), Trapp & Sarkis (2016), Karaer *et al* (2020), Golmohammadi & Hassini (2020), Chen *et al* (2019), Starita & Scaparra (2021), Chen & Baddam (2015) and Clemons & Slotnick (2016) assumed a deterministic improvement parameter. Jain *et al* (2020), Shokoohyar & Katok (2022), Starita & Scaparra (2021), and Dye *et al* (2017) assumed the buyer and suppliers are risk neutral. Golmohammadi *et al* (2018), Awasthy & Hazra (2019), and Golmohammadi & Hassini (2020) didn't address the alternative supplier as a switching option. Note that none of the mentioned studies considered the strategic potential of the supplier(s) in their models.

Therefore, we can derive a research gap to decide on the development-or-switching which simultaneously considers uncertainties in the incumbent and alternative suppliers and investigates the impact of the strategic potential of suppliers. To the best of our knowledge, this is the first paper that proposes an analytical modeling approach to study the effect of the strategic potential of suppliers on the development-or-switching decision. We address a company with a problematic supplier (having performance issues mainly about the well-known QCD criteria) that should make a sourcing decision considering a potential alternative supplier as an option to switch. Two kinds of uncertainty are formulated: (1) ROI for the development and (2) the alternative supplier inappropriateness for the switching. The lost market share criterion is introduced for evaluating the performance dimension and the earned market share criterion is defined for evaluating the strategic potential. **Table 1** provides a comparative view of the most relevant literature.

Table 1 Review summary.

Papers	Development	Switching	Buyer investment	Supplier investment	Alternative supplier	Performance	Strategic potential	Uncertain improvement	Uncertain Alt. Sup. performance
Talluri & Narasimhan (2004)	✓	✓			✓				
Talluri & Lee (2010)	✓		✓		✓	✓			
Friedl & Wagner (2012)	✓	✓	✓		✓	✓			
Hu <i>et al</i> (2013)	✓	✓		✓	✓	✓		✓	
Bhattacharyya & Guiffrida (2015)	✓		✓			✓			
Chen & Baddam (2015)	✓	✓	✓		✓	✓			
Clemons & Slotnick (2016)	✓		✓		✓	✓			
Rashidi & Farzipoor Saen (2018)	✓		✓		✓				
Jain <i>et al</i> (2020)	✓		✓	✓	✓	✓		✓	
Karaer <i>et al</i> (2020)	✓		✓			✓			
Nasr & Jaber (2019)	✓		✓			✓		✓	
Golmohammadi <i>et al</i> (2018)	✓		✓	✓		✓		✓	
Golmohammadi & Hassini (2020)	✓		✓	✓		✓			
Awasthy & Hazra (2019)	✓		✓	✓		✓			
Trapp & Sarkis (2016)	✓				✓	✓			
Meisel & Glock (2018)	✓	✓			✓	✓			
Chen <i>et al</i> (2019)	✓			✓		✓			
Jafarian <i>et al</i> (2021)	✓	✓	✓		✓	✓		✓	✓
Shokoohyar & Katok (2022)	✓		✓	✓		✓		✓	
Starita & Scaparra (2021)	✓		✓	✓		✓		✓	
Dye <i>et al</i> (2017)	✓		✓			✓		✓	
Li & Xia (2022)	✓		✓		✓	✓			
This work	✓	✓	✓		✓	✓	✓	✓	✓

3. MODELING AND ANALYSIS

The proposed mathematical model for the development-or-switching decision on the problematic suppliers is developed in two subsections. At first, we formulate the performance dimension under two uncertainties (i.e., ROI and alternative supplier performance). Then, we investigate the role of strategic potential in the decision. Considering the status quo, our decision-making is actually to compare three objective functions. So, in each subsection, first, a comparison is

made between the main decisions (i.e., development and switching) and the status quo condition. If the former is more effective, a final comparison should be done among the main decisions.

3.1 Performance

As discussed earlier, the development-or-switching decision is not straightforward and should be made under two uncertainties: (1) ROI for the development of the incumbent supplier; it is unclear how much the help of the company will result in the performance improvement of the

supplier, and (2) the performance of the alternative supplier; before the relationship is made, we cannot be sure about the alternative supplier performance.

We use the lost market share as a measure for deciding on the problematic supplier considering the performance dimension. This measure evaluates how the performance of the incumbent supplier affects the market (customer satisfaction) in which it supplies component(s). The market shares the company captures depends highly on the performance of related suppliers. To develop this measure, we need a demand function to account for the supplier performance criteria. There exists a variety of demand functions in the literature. Usually, researchers used a linear demand function (Liu *et al*, 2000) when several criteria are considered.

Considering the quality, delivery, and price as the critical performance criteria of suppliers and nominating q , d , and p as their scores in $[0,1]$ intervals, respectively, we will have demand function D as follows:

$$D = f(q, d, p) \tag{1}$$

$$D = M(aq + bd + cp) \tag{2}$$

where M is the total accessible market share of a given product that the corresponding supplier supplies its item(s) and a , b , and c are, respectively, corresponding weights of quality, delivery, and price of the supplier. The weights show the effect of supplier criteria on the related product demand. This function estimates the earned market share. As mentioned earlier, the suggested measure for the performance dimension is lost market share; therefore, the difference in current market share from the desired amount is our aim. The desired performance is determined by the company (the buyer) based on its strategic goals. Assuming q^* , d^* and p^* , respectively, as desired quality, delivery, and price scores, D is converted to ΔD as follows:

$$\Delta D = M(a(q^* - q) + b(d^* - d) + c(p^* - p)) \tag{3}$$

where ΔD denotes the lost market share. For the problematic supplier, ΔD is considerable due to its poor performance. In equation (3), we call the coefficient of lost market share (inside parenthesis) SBE in the rest of our study. Using the lost market share as the critical supplier measure, now, we can formulate development and switching in the following.

3.1.1 Development Under the Performance Dimension

We define Q , Dlv , and P as quality, delivery, and price scores after the investment, using investment variables Iq , Id , Ip , respectively. Also, we define the investment-improvement coefficient as β . After substitution of the new equations in ΔD and reordering (see Appendix 1) we will have:

$$SBE_D = k - i\beta \tag{4}$$

where i is the sum of weighted investments on performance criteria and k includes the desired and current performance

scores and indicates the current coefficient of the lost market share (i.e., current SBE). Without loss of generality, we assume QCD criteria have the same weights, and, the investment is done on one criterion. Considering φ as the unit profit of the product, $(SBE_D M)\varphi$ demonstrates the cost of lost market share. By adding the amount of investment, the cost-based objective function for the development decision will be as follows:

$$f_D = i + (k - i\beta)\varphi M \tag{5}$$

We apply utility functions for dealing with uncertainties and taking risk levels into account. Suppose a utility function $(e^{-\alpha f})/\alpha$ in which α is the risk tolerance level of the decision maker and f is the total variable cost which follows a normal distribution. Then, the certain equivalent of f is expressed by the following equation (f_D^C) (Giri 2011, Xie *et al*, 2011). (see Appendix 2 for more illustration)

$$f_D^C(i) = [0.5\alpha\varphi^2 M^2 Var(\beta)]i^2 + [1 - \varphi ME(\beta)]i + \varphi Mk \tag{6}$$

As equation (16) shows, the certain equivalent of the development decision objective is quadratic concerning the amount of investment (i.e., i). The cost will be increased by the variance increase and will be decreased by the expected value increase. And, as the confidence level increases the cost will increase. We should now find out when the development is solely the effective decision. We should determine where the investment lessens the cost. For more illustration, we depict f_D^C respect to i in **Figure 1**.

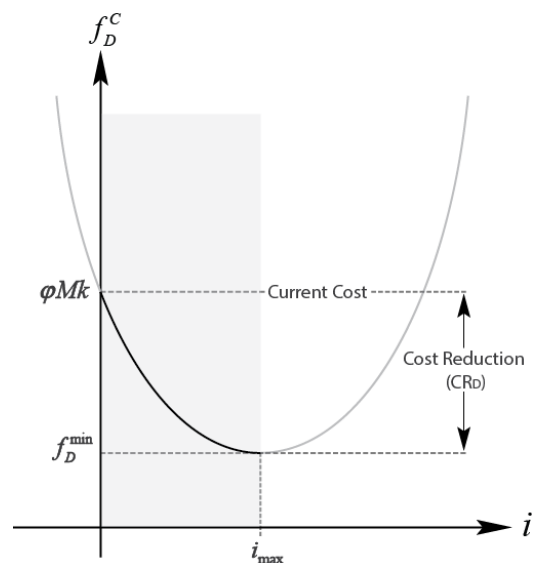


Figure 1 The development objective versus the investment

Figure 1 shows the development objective versus the investment. The figure shows the investment lessens the cost down to a specific value (i_{max}) which indicates when the development decision is effective. In this figure, the

intercept shows the current cost. f_D^{min} , i_{max} and CR_D are as follows:

$$f_D^{min} = f_D^C(i_{max}) = \varphi M k - \frac{(\varphi M E(\beta) - 1)^2}{2a\varphi^2 M^2 Var(\beta)} \quad (7)$$

$$i_{max} = \frac{\varphi M E(\beta) - 1}{a\varphi^2 M^2 Var(\beta)} \quad (8)$$

$$CR_D = \varphi M k - f_D^{min} = \frac{(\varphi M E(\beta) - 1)^2}{2a\varphi^2 M^2 Var(\beta)} \quad (9)$$

Proposition 1: *If the expected value of the investment-improvement coefficient is greater than the inverse of the market financial value (equation 20), then the development decision is effective. (See Appendix 3 for proof).*

$$E(\beta) > \frac{1}{\varphi M} \quad (10)$$

According to equation (10), the effectiveness of the development decision does not depend on the amount of investment. In other words, no variation in the feasible investment area changes the development decision from ineffective to effective or vice versa. Based on equation (8), as the variance of β increases the investment decreases. In addition, by increasing the variance of β the cost increases while the intercept is constant; therefore, the expected cost reduction (CR_D) will be decreased by the increase in $Var(\beta)$ and will be increased by leveling up the $E(\beta)$, supposing the effective development decision (i.e., when equation (10) is satisfied). It means that by increasing the variance, the investment is going to be less economically feasible. Inversely, as the expected value of β increases the investment increases which means that by increasing the expected value, the investment will be more economically feasible. Moreover, the investment and cost reduction will be decreased by increasing α . It shows that being risk averse makes the investment unattractive.

3.1.2 Switching Under Performance Dimension

For the switching decision, we consider the lost market share for the alternative supplier (SBE_R) and add the switching cost that the company should pay. For this, we consider three uniformly distributed variable corresponding to three performance criteria of quality, delivery, and price (Aq , Ad , and Ap). After substitution and reordering (see Appendix 4 for more illustration) we will have:

$$SBE_R = k' - A \quad (11)$$

where A indicates weighted sum of three performance criteria and k' represents weighted sum of desired performance criteria. Assuming Aq , Ad , and Ap to be uniformly distributed and supposing equal weights, A will be the sum of three uniform random variables whose density

function will be like a normal distribution. The objective function of the switching decision (f_R) will be as follows:

$$f_R = C_{sw} + \varphi M(k' - A) \quad (12)$$

The certain value of this function will approximately be as follows (see Appendix 5):

$$f_R^C = C_{sw} + \varphi M k' - \varphi M E(A) + \frac{a\varphi^2 M^2 Var(A)}{2} \quad (13)$$

Like the development, we should find out the effectiveness of the switching decision solely. Hence, we should determine when the cost of switching decisions will be less than the current cost.

$$f_R^C < \varphi M k \quad (14)$$

We should formulate the relationship between k and k' . Considering equations (A6) and (A20) and defining k'' as (15):

$$k'' = aq' + bd' + cp' \quad (15)$$

we will have equation (16):

$$k = k' - k'' \quad (16)$$

Note that k'' indicates the performance score of the current supplier. By substituting k and f_R^C in equation (14), we will have equation (17) as follows:

$$C_{sw} + \frac{a\varphi^2 M^2 Var(A)}{2} < \varphi M(E(A) - k'') \quad (17)$$

Equation (17) shows the condition in which the switching decision will solely be effective. The left-hand side of the equation includes the switching cost and the risk statement and the right-hand side includes the difference between the expected value of the performance of alternative and incumbent suppliers. In other words, considering the market financial value (φM), the right-hand side is the difference between the expected earned market share profit of alternative and incumbent suppliers. So, for the effectiveness of the switching decision, the net (added) profit due to the switching should be greater than the sum of costs and risk of switching.

3.1.3 Comparing the development and switching under the performance dimension

If both decisions are effective, then we should compare their objective functions to decide whether to develop or switch. Therefore, we define Δf as follows:

$$\Delta f = f_D - f_R \quad (18)$$

$$\Delta f = i - C_R - \varphi M k'' + \varphi M[E(A) - iE(\beta)] + \left(\frac{a\varphi^2 M^2}{2}\right)[i^2 Var(\beta) - Var(A)] \quad (19)$$

where Δf is the difference between the development and switching decision costs. Supposing that both decisions are effective solely, the decision is switching for a positive Δf and the development will be the choice when Δf is negative. The equation does not include k' indicating that the development-or-switching decision does not depend on the desired performance. $\varphi M k''$ -i.e., the current earned market share profit- has a negative sign; therefore, better performance of the incumbent supplier makes the development decision more preferable than the switching one. In equation (19), the terms inside brackets are critical and play a key role in decision-making. If two brackets have inverse signs, then there exists a situation in which the variation of risk level (α) changes the development-or-switching decision.

As an example, considering $C_R = 15$, $\varphi = 0.1$, $M = 10000$, $E(A) = 0.925$, $Var(A) = 0.014^2$, $E(\beta) = 0.007$, $Var(\beta) = 0.001^2$, $k = 0.2$ and $k' = 1$, for $\alpha > 0.85$ the development and otherwise the switching are suitable choices. **Figure 2** indicates this analysis.

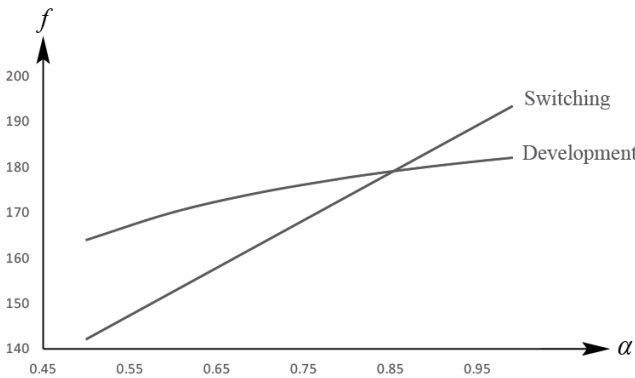


Figure 2 Development and switching costs concerning α

3.2 Strategic Potential

In this subsection, we analyze the effect of the strategic potential on the development-or-switching decision. As discussed in the first section, researchers emphasized the role of the strategic potential in the accomplishment of development efforts by suppliers and also in the company's competitiveness in the future market that depends on collaboration in innovation, i.e., NPD and productivity. Therefore, we derive a twofold role of the supplier strategic potential: (1) the effect on ROI for the supplier development and (2) the long-term effect on the company competitiveness in the market.

Note that as performance development depends on strategic potential, in the mathematical modeling, performance, and strategic potential cannot be independent.

We use the earned market share of the company to study the strategic potential. The accessible market share is not constant here. In fact, as the strategic potential increases, the market share increases but the lost market share coefficient decreases; hence, we use the earned market share coefficient to get the right results. Recalling equations (1)-(2), changing SBE to the market share coefficient, we will have:

$$SBE = aq + bd + cp \tag{20}$$

$$D = M.SBE \tag{21}$$

D indicates the product market share. Considering φ as the unit profit of the corresponding product, the total profit (R) will be as follows:

$$R = \varphi.M.SBE \tag{22}$$

Based on equations (20)-(22), we model development and switching decisions in the following.

3.2.1 Development Under Strategic Potential Dimension

Recalling the first role of the strategic potential, its value should affect β . We consider a linear relationship as $\beta = m\tau_I$, where τ_I is the strategic potential of the incumbent supplier, m is its weight (i.e., the effect on the investment-improvement coefficient). By substituting this equation and reordering, final SBE will be rewritten as follows (see Appendix 6 for illustration):

$$k_I = aq' + bd' + cp' \tag{23}$$

$$SBE_I = k_I + i(m\tau_I) \tag{24}$$

k_I indicates the performance score of the incumbent supplier (current SBE_I).

The second role of strategic potential is its long-term effect on the company's competitiveness in the market. For example, the success of the NPD highly depends on the suppliers' collaboration and its strategic potential. A poor strategic potential of a supplier will lead to a poor collaboration and an unsuccessful NPD and as result, company will lose the competition, customer loyalty and its market share. Recalling equation (21), M indicates the accessible market share for a specific product.

Therefore, we can relate the strategic potential to the accessible market share for the considered product. Then, the actual value of market for the given product is supposed to be a multiple of the maximum accessible market share and the potential of the supplier as $M(m'\tau_I)$ where m' is the coefficient of the effect of strategic potential on the market share. By replacing SBE and market share in equation (21) and reordering, we will have:

$$D_D = M(m'\tau)(k + i(m\tau)) \tag{25}$$

$$R_D = \varphi M(imm'\tau^2 + km'\tau) \tag{26}$$

Finally, the profit function of the development decision is as follows:

$$f_D = R_D - i \tag{27}$$

$$f_D = \varphi M(m'\tau_I)(k_I + i(m\tau_I)) - i \tag{28}$$

$$f_D = \varphi Mimm'\tau_I^2 + \varphi Mk_I m'\tau_I - i \tag{29}$$

Proposition 2: Equation (30) is equivalent to equation (29) and if $\tau_I > \frac{1}{\sqrt{\varphi M m' m}}$, then the development decision is effective. (See appendix for proof)

The equivalent of equation (29) is as follows:

$$f_D = \varphi M m' \tau_I - \frac{1 - k_I}{m} \times \frac{1}{\tau_I} \quad (30)$$

Then, considering f_C as the current profit function, equation (32) indicates the subtraction of the development and current profit.

$$f_C = \varphi M m' k_I \tau_I \quad (31)$$

$$\Delta f_D = f_D - f_C = \varphi M m' \tau_I (1 - k_I) - \frac{1 - k_I}{m} \times \frac{1}{\tau_I} \quad (32)$$

As depicted in **Figure 3**, there is a specific value of strategic potential that determines the effective area of the development decision. The critical point is that the optimality condition of development is independent of the current performance of the incumbent supplier (k_I). In other words, is the development decision solely effective or not, depends on the strategic potential of the incumbent supplier, not its current performance.

3.2.2 Switching under strategic potential dimension

For the switching decision, we should rewrite **SBE**, **D**, **R** as follows:

$$SBE_A = a.Aq + b.Ad + c.Ap \quad (33)$$

$$D_R = M(m' \tau_A) SBE_A \quad (34)$$

$$R_R = \varphi M(m' \tau_A) SBE_A \quad (35)$$

The objective value of the switching decision includes **R** and switching costs. Here, SBE_R indicates the performance of the alternative supplier, like development, we call it k_A .

$$f_R = \varphi M m' k_A \tau_A - C_R \quad (36)$$

We analyze the sole optimality condition for the switching decision as follows:

$$\Delta f_R = f_R - f_C = \varphi M m' (k_A \tau_A - k_I \tau_I) - C_R \quad (37)$$

$$\Delta f_R \geq 0 \Rightarrow \tau_A \geq \frac{k_I}{k_A} \tau_I + \frac{C_R}{\varphi M m' k_A} \quad (38)$$

Equation (38) indicates a linear relationship among the strategic potential of the alternative and incumbent suppliers in which the slope is the proportion of the performance of the incumbent supplier to the alternative supplier. A graphical view of the optimality condition is shown in **Figure 4**.

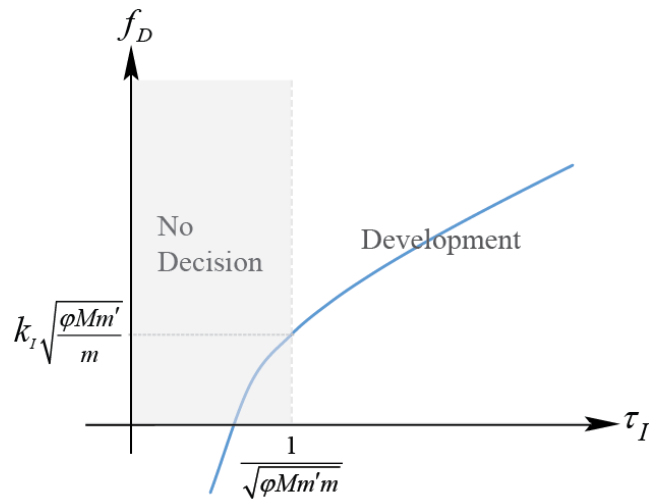


Figure 3 Development profit function and its (solely) optimal area

As the performance of the alternative supplier (k_A) increases, the elevation and slope decrease, and then the area of the switching decision is expanded. On the other side, increasing the strategic potential of the incumbent supplier shrinks the optimality distance of the strategic potential of the alternative supplier.

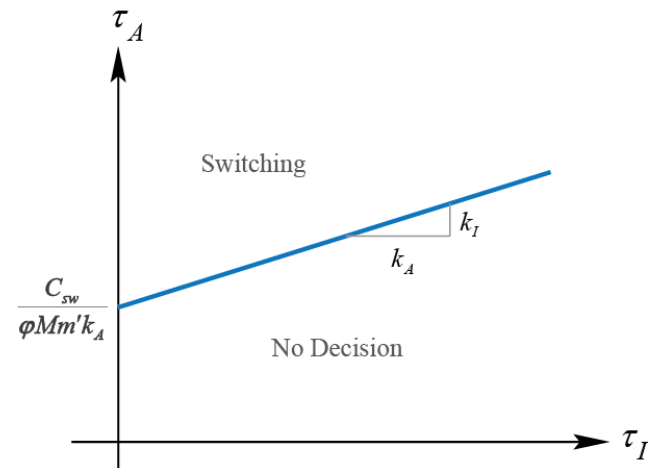


Figure 4 Switching profit function and its (solely) optimal area

3.2.3 Comparing the Development and Switching Under Strategic Potential Dimension

We analyzed the optimality condition of both development and switching decisions versus the current situation. Now, we should determine the development-or-switching decision for the cases in which both decisions are effective. But earlier, we detect the effect of the strategic potential on the objective function of both decisions and provide proposition 3 as follows.

Proposition 3: The effect of strategic potential on the development objective function is greater than its effect on the switching objective function. In other words, development is more sensitive to strategic potential than switching. (See appendix for proof)

To determine the boundary of the development-or-switching decision, we should solve for $f_D = f_R$.

$$f_R = f_D \Rightarrow \tau_A = \frac{1}{k_A} \tau_I - \frac{1 - k_I}{\varphi M m' m k_A} \times \frac{1}{\tau_I} + \frac{C_R}{\varphi M m' k_A} \quad (39)$$

The boundary of the development-or-switching (i.e., equation 39) is very similar to the development profit function (f_D). The only difference is the change in multipliers and the added constant. Function f_D is divided by $\varphi M m' k_R$ and constant $\frac{C_R}{\varphi M m' k_R}$ is added. So, the boundary function is in the shape of f_D that is vertically compressed and lifted (Figure 5).

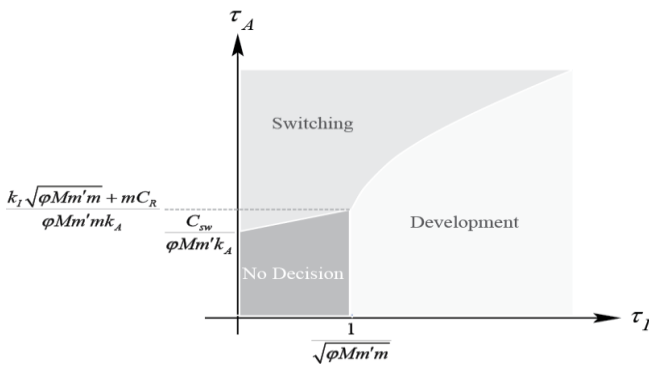


Figure 5 Map of proposed sourcing decision.

Figure 6 indicates the decision map of a given example, considering parameter values: $m = 0.01$, $m' = 0.5$ and $C_R = 50$ (the rest values are the same as in the previous example).

In this example, the development decision is effective for $\tau_I > 0.45$, the pair of $[\tau_I = 0.45, \tau_A = 0.49]$ indicates the indifference point of the decision and intercept elevation ($\tau_A = 0.10$) demonstrates the minimum strategic potential of the alternative supplier that the switching decision is effective.

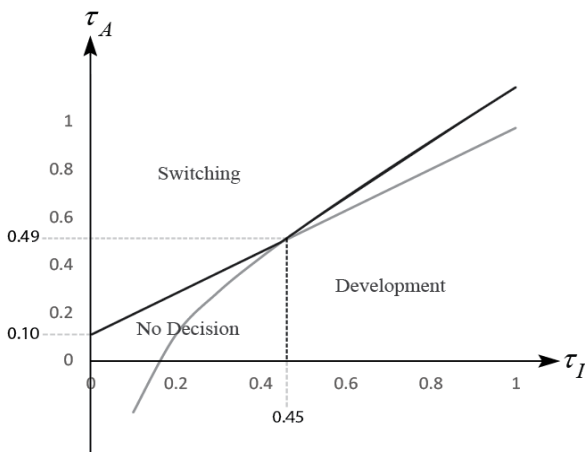


Figure 6 Decision map of the example

In a special case in which the strategic potentials of incumbent and alternative suppliers are near to each other ($\tau_A \sim \tau_R$), equation (39) is rewritten as follows:

$$\tau_A = \tau_I = \tau \Rightarrow \varphi M m' \tau (1 - k_A) = \frac{1 - k_I}{m} \times \frac{1}{\tau} - C_R \quad (40)$$

Since the effective distance of the strategic potential for development and switching is greater than zero, both sides of equation (40) are multiplied by τ , and the result (second-degree equation) is reformed and solved as follows.

$$\varphi M m' (1 - k_A) \tau^2 + C_R \tau - \frac{1 - k_I}{m} = 0 \quad (41)$$

$$\tau = \frac{-C_R + \sqrt{C_R^2 + 4\varphi M m' (1 - k_A) \frac{1 - k_I}{m}}}{2\varphi M m' (1 - k_A)} \quad (42)$$

Equation (42) is the solution of equation (41). τ is the strategic potential where both decisions have the same profits. Considering that the slope of the development profit function is less than that of the switching, the development is the right decision for values greater than τ and the switching for values less than τ . The second root of equation (41) is neglected because it is negative while τ is supposed to be in the $[0, 1]$ range.

Recalling that the optimal condition for the development decision is $\tau \in [1/\sqrt{\varphi M m' m}, 1]$ and referring to the

previous discussion that $f_R' < f_D'$, the switching function is located upper the development function (i.e. $f_R(\tau_I^u) > f_D(\tau_I^u)$ in the last point of range ($\tau_I^u = \tau_I = 1$)), and it is located under the optimal range of development (i.e. $f_R(\tau_I^l) < f_D(\tau_I^l)$ for the first point of range ($\tau_I^l = \tau_I = 1/\sqrt{\varphi M m' m}$)). Therefore, for more illustration,

we focus on these two critical points by replacing them in the solution as follows. For the last point, we have:

$$C_R < -\varphi M m' (1 - k_A) + \frac{1 - k_I}{m} \quad (43)$$

So, if the condition in equation (43) is met, then the decision will be switching for $\tau_A = 1$ and any value of τ_I . For the first point, we have:

$$C_R > (k_A - k_I) \sqrt{\frac{\varphi M m'}{m}} \quad (44)$$

So, if the condition in equation (44) is met, then the decision will be switching for τ_I in the solely optimal range and any value of τ_A less than $1/\sqrt{\varphi M m' m}$.

4. COMPARATIVE ANALYSIS

To illustrate numerically the privilege of our proposed study, a comparison is drawn with the most relevant study in the literature; i.e., Friedl & Wagner (2012) named the opposite study. To do this, we need to adapt the models. Equation (45) indicates the final model of Friedl & Wagner (2012).

$$\Delta\pi = \frac{1}{2b}((E[a(\theta)] - p_s)^2 - Var[c(\theta)]) + 2Cov[a(\theta), c(\theta)] - E[h(\theta)]\left(\frac{4b\gamma}{4b\gamma - 1}\right) - s \quad (45)$$

In the case of positive $\Delta\pi$ values, the opposite study suggests a switching decision while for the negative values of $\Delta\pi$, the development will be the right choice. Parameters of the opposite study are given in **Table 2**.

We consider our criteria as scores in [0,1] interval, so the corresponding value of a in our work is 1. Also, c and P_s are considered to be in this interval. P_s is related to Ap , considering that Ap is a score and its increase means a decrease in P_s , thus we consider the minimum price (P_s) of 0.5 for a reasonable relation among the two parameters and add the difference of the score from 1 to it to make the relationship (i.e., for the price score of 0.9 the equivalent price will be 0.6). We consider a similar approach for c but minus half of profit (ϕ) as a portion of the supplier. The parameter s is the exact equivalent of C_{sw} in our model. For the rest of the parameters, we should consider the equations as follows.

Table 2 Parameters of opposite study

Parameter	Description
a	Price level for zero demand (parameter of the linear inverse demand function)
c	Incumbent supplier's realized unit cost (without development investment)
b	Slope of the linear inverse demand function
γ	Cost level associated with the buyer's development investment
P_s	Entrant supplier's unit price
s	One-time switching costs
θ	Different states of the world

$$h(\theta) = a(\theta) - c(\theta) \quad (46)$$

$$p(q, \theta) = a(\theta) - 0.5bq \quad (47)$$

$$w(d) = 0.5\gamma d^2 \quad (48)$$

Equation (46) is clarified by determining a and c . In equation (47), q and p refer to the demand and the price, respectively. We rewrite it as follows to adapt with our study's correspondent equation.

$$q = \frac{1}{0.5b}(a - p) \quad (49)$$

Equation (48) is related to β in our study indicating the performance criteria improvement due to the unit investment. This description is right for d if we replace w with 1 as follows.

$$d = \sqrt{\frac{2}{\gamma}} \Rightarrow \beta = \sqrt{\frac{2}{\gamma}} \quad (50)$$

Table 3 demonstrates the adaptation of parameters for both studies. Three comparisons are designed: (1) good and bad incumbent supplier, (2) Low and high switching risk, and (3) Low and high strategic potential of the incumbent supplier.

Table 3 Adaptation of parameters for both studies

Opposite study parameters	Equivalent in our study
a	1
c	$0.5 + (1 - p) - 0.5\phi$
b	$\frac{2}{u}$
γ	$\frac{u}{\beta^2}$
p_s	$0.5 + (1 - Ap)$
s	C_{sw}

Table 4 Parameter values of comparison 1

Parameter	Value	Parameter	Value
Aq	0.9	β	0.001
Ad	0.9	a_i, b_i, c_i	0.33
Ap	0.9	$(dq_{si}, dd_{si} \text{ and } dp_{si})$	1
q	0.9 0.75	C_{sw_s}	100
d	0.9 0.75	ϕ	0.1
p	0.75 0.75	q_{si}, d_{si}, p_{si}	0.8
u	10000	a	0.5

4.1 Comparison 1: Good and Bad Incumbent Supplier

We define a good supplier who has a problem in only one criterion while satisfying the other criteria. Reversely, we consider a bad incumbent supplier whose other criteria are not satisfying in addition to the problematic one. Because price is a common criterion among the models, we consider it problematic and solve two models for the defined conditions. **Table 4** indicates the data of the considered example. Note that risk is not considered here. Parameter values for the opposite model are given in **Table 5**. **Table 6** indicates the results for the two conditions.

Table 5 Equivalent values for opposite study

Parameter	Value	Parameter	Value
a	1	γ	2^6
c	0.7	P_s	0.6
b	0.0002	s	100

Table 6 Results for comparison 1

Condition	Model	Obj. Value	Decision
Bad problematic supplier	Our model	38.5	Switching
	Opposite	172.9	Switching
Good problematic supplier	Our model	-60.5	Development
	Opposite	173.9	Switching

The same as the opposite model, our model suggests the switching decision for the positive objective values and the development decision for the negative ones. According to **Table 6**, the opposite model generates the same results for

the good and bad incumbent suppliers; but our model develops the good supplier and switches to the bad supplier. This is reasonable because of the comprehensive evaluation of suppliers in our model due to the inclusion of more performance criteria.

4.2 Comparison 2: Low and High Risk of an Alternative Supplier

We should consider low and high variances for the performance of the alternative supplier. We assume that the performance criteria are independent; so, the covariance of the cost and the maximum price of the incumbent supplier must be considered zero. Consider the above example with the variance values in **Table 7**.

Table 7 Additional data for comparison 2.

Parameter	Value
$E(A)$	0.89
$Var(A)$	$(0.89/2)^2$ $(0.89/10)^2$
β	0.0001
$Var(\beta)$	$(0.0001/5)^2$
$Var(c)$	$(0.7/5)^2$

To make a meaningful comparison, we use a constant coefficient of variation (*CV*) to determine variance values. As **Table 7** shows, for the investment-improvement coefficient and the cost of the incumbent supplier, *CV* is considered 5 and for the variance of the performance of the alternative supplier, *CV* values are set to 2 and 10 for the low and high variances, respectively. Results are given in **Table 8**.

Table 8 Results for comparison 2.

Condition	Model	Obj.	Decision
High-risk alternative supplier	Our model	41443	Switching
	Opposite model	26	Switching
Low-risk alternative supplier	Our model	-6190	Development
	Opposite model	26	Switching

Our model reacts to the high-risk alternative supplier and changes the development decision to the switching one. But the opposite model is indifferent to the risk of the alternative supplier.

4.3 Comparison 3: Low and High Strategic Potential of the Incumbent Supplier

The strategic potential of the incumbent supplier is examined here. Two conditions of low and high strategic potential values are considered. Equation (51) indicates the relation between the strategic potential in our study and the investment-improvement coefficient in the opposite study.

$$\tau_I = \frac{1}{m} \sqrt{\frac{2}{\gamma}} \quad (51)$$

We introduce the following data (**Table 9**) for the strategic potential.

Table 9 Additional data for comparison 3

Parameter	Value
τ_A	0.9
τ_I	0.8
	0.9

The results of this comparison are given in **Table 10**.

Table 10 Results for comparison 3.

Condition	Model	Obj. Value	Decision
The low strategic potential of the incumbent supplier	Our model	7	Switching
	Opposite model	66	Switching
The high strategic potential of the incumbent supplier	Our model	-54	Development
	Opposite model	63	Switching

Our study reacts to the high strategic potential of the incumbent supplier and changes the decision from switching to development. This is reasonable because it has two side effects on the problem including a short-term performance improvement (investment return) and a long-term performance improvement (market share).

5. DISCUSSION AND MANAGERIAL INSIGHTS

Choosing the best supplier evaluation criteria has always been controversial among researchers. As discussed in the literature section, researchers studied supplier issues in different aspects. Some focused on quality and reliability issues (Nasr & Jaber, 2019; Karaer *et al*, 2020; Clemons & Slotnick, 2016; Dong *et al*, 2020; Awasthy & Hazra, 2019), some targeted capacity from different viewpoints (Hu *et al*, 2013; Chen *et al*, 2019; Jain *et al*, 2020; Golmohammadi & Hassini, 2020), some other considered delivery issues (Bhattacharyya & Guiffreda, 2015), and there was many that addressed cost or price as a general rule (Friedl & Wagner, 2012).

This study focuses on a broader concept rather than a specific criterion. And that is an important segment of suppliers named problematics. For problematic suppliers when development-switching decisions take into account, overall evaluation is essential and addressing one or more performance criteria is not sufficient. Therefore, we add strategic potential and propose a new modeling to analysis situation perfectly. We developed an analytical modeling approach for the development-or-switching decision in the context of a two-dimensional perspective and investigated the role of both dimensions in the considered sourcing decisions.

In the previous section, we made a comparison between proposed model and a performance-based model (Friedl & Wagner, 2012) and defined different scenarios to address comprehensive comparison. Results showed how strategic potential outperforms single dimension models. For more illustration, in the rest, we discuss two part of study, single dimension and two dimensions, and their comparison in detail.

Considering the performance dimension, we found that the development decision is not effective when the expected value of the investment-improvement coefficient is less than the inverse of the maximum market financial value. It means that the effectiveness of the development decision is independent of the current performance of the incumbent supplier and the amount of investment. Nevertheless, by adding the strategic potential dimension, we realized the effectiveness of the development decision is dependent on the strategic potential of the incumbent supplier. Thus, we recommend practitioners avoid the development of suppliers who have a low strategic potential.

For the effectiveness of the switching decision according to the performance dimension, the net (added) profit due to the switching decision should be greater than the sum of switching costs and risks. Adding up the strategic potential dimension, besides the strategic potential and the performance of the alternative supplier, the strategic potential of the incumbent supplier plays a critical role. Recalling equation (38) and **Figure 3**, the performance of the alternative supplier has a double effect on the optimality area of the switching decision. Therefore, switching is reasonable for high-performance alternative suppliers. On the other side, increasing the strategic potential of the incumbent supplier shrinks the optimality distance of the strategic potential of the alternative supplier.

Regarding the comparison of both decisions, we found that the desired performance is useless. Moreover, the risk aversion level of the decision maker can change the decision between development and switching. We also concluded that the better performance of the incumbent supplier makes the development decision more preferable than the switching one. The same result may be held for the strategic potential. Comparing the objective functions of development and switching showed that strategic potential affects development more than switching. Besides the strategic potential of the alternative supplier, its performance plays a critical role in the optimality of the switching decision. If the strategic potential of the incumbent supplier is not high and the alternative supplier is a good performer, then the switching decision is a reasonable choice. On another side, if the strategic potential of the incumbent supplier is relatively high and the performance of the alternative supplier is not fine, development will be the right decision.

6. CONCLUSION

This study investigated analytically a critical sourcing decision as a common challenge of companies in all industries. Companies are always confronted with the poor performance of their suppliers as a big issue; they need to determine how to deal with problematic suppliers having performance issues mainly about the well-known QCD criteria and what decisions to make regarding a potential alternative supplier as an option to switch. Our study proposed and analyzed two decision options as effective remedies for such a problem: developing the incumbent supplier or switching to a suitable alternative supplier, and aimed to help companies to distinguish among options in different situations. The important contribution of our research is to develop a quantitative framework for the analysis of two crucial dimensions, i.e., performance and strategic potential, and to consider the uncertainty in both

the return on investment of development together with the performance of the alternative supplier. Notably, the lost market share criterion is introduced for evaluating the performance dimension and the earned market share criterion is defined for evaluating the strategic potential.

The main findings of our study are as follows:

- The effect of the strategic potential on the development decision is greater than the switching decision according to profit function derivatives concerning the strategic potential.
- The effectiveness of the development decision does not depend on the performance of the incumbent supplier but rather depends on its strategic potential.
- As the strategic potential of the incumbent supplier increases, the optimal range of the strategic potential of the alternative supplier is shrunk.
- The variation in the risk level can change the decision between development and switching or make both decisions ineffective.

To show the advantages of our study, a comparison was made with a well-known model in the literature, and the novelties of our proposed study were examined in three aspects of supplier evaluation, switching risk, and strategic potential. As a future study, researchers can take into account the uncertainty of the strategic potential, especially for the alternative supplier. Another interesting extension is to consider step-wise policies to clear the interaction with problematic suppliers. Moreover, the supplier contribution to the development and switching is worth being focused on.

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APPENDIX

1. Consider Q , Dlv , and P as quality, delivery, and price scores after the investment, using investment variables Iq , Id , Ip , respectively. And β as investment-improvement coefficient. We will have,

$$SBE_D = a(q^* - Q) + b(d^* - Dlv) + c(p^* - P) \quad (A1)$$

$$Dlv = d' + \beta \cdot Id \quad (A2)$$

$$P = p' + \beta \cdot Ip \quad (A3)$$

$$Q = q' + \beta \cdot Iq \quad (A4)$$

where q' , d' , p' denote current quality, delivery, and price scores of the incumbent supplier and index D in SBE_D refers to the development decision. By putting equations (A2) - (A4) in equation (A1) and reordering, we will have:

$$SBE_D = [a(q^* - q') + b(d^* - d') + c(p^* - p')] - \beta(a \cdot Iq + b \cdot Id + c \cdot Ip) \quad (A5)$$

Calling the first constant term (inside bracket) k and the variable term multiplied by β (inside parenthesis) i , we will have:

$$k = [a(q^* - q') + b(d^* - d') + c(p^* - p')] \quad (A6)$$

$$i = a \cdot Iq + b \cdot Id + c \cdot Ip \quad (A7)$$

$$SBE_D = k - i\beta \quad (A8)$$

2. Considering utility function $(e^{-\alpha f})/\alpha$ in which α is the risk tolerance level of the decision maker and f is the total variable cost which follows a normal distribution. Then, the certain equivalent of f_D will be as the following equation.

$$f_D^C = E(f_D) + 0.5\alpha Var(f_D) \quad (A9)$$

$$E(f_D) = \varphi Mk + i(1 - \varphi ME(\beta)) \quad (A10)$$

$$Var(f_D) = \varphi^2 M^2 i^2 Var(\beta) \quad (A11)$$

Equation (A9) shows the certain equivalent of the development objective function. Parameter α is the confidence level and shows the risk aversion of the decision maker. Equations (A9) and (A10) indicate the expected value and variance of the development objective, respectively. By substituting equations (A10) and (A11) in equation (A9) and reordering, we will have:

$$f_D^C(i) = [0.5a\varphi^2M^2Var(\beta)]i^2 + [1 - \varphi ME(\beta)]i + \varphi Mk \tag{A12}$$

3. Proof of Proposition 1

The development objective function is as follows:

$$f_D^C(i) = [0.5a\varphi^2M^2Var(\beta)]i^2 + [1 - \varphi ME(\beta)]i + \varphi Mk \tag{A13}$$

Equation (A13) is quadratic concerning the investment as a decision variable, then we have coefficients as follows (considering general quadratic equation as $a'x^2 + b'x + c' = 0$):

$$\text{Quadratic coefficient (a')}: 0.5a\varphi^2M^2Var(\beta) \tag{A14}$$

$$\text{Linear coefficient (b')}: 1 - \varphi ME(\beta) \tag{A15}$$

$$\text{Constant term (c')}: \varphi Mk \tag{A16}$$

We have $a' \geq 0$ and $c' \geq 0$. Then the development objective is a convex function that intercepts the positive side of the vertical axis (f_D^C). To ensure that investment lessens the costs, the left-hand side of the quadratic function must intercept the vertical axis. It occurs when the minimum point has a positive horizontal (i^{max}) value. Then we have:

$$i^{max} = \frac{-b'}{2a'} = \frac{-(1 - \varphi ME(\beta))}{2(0.5a\varphi^2M^2Var(\beta))} = \frac{\varphi ME(\beta) - 1}{a\varphi^2M^2Var(\beta)} > 0 \tag{A17}$$

Considering that the denominator of equation (A17) is positive, then the positivity of the nominator will be sufficient. So,

$$\varphi ME(\beta) - 1 > 0 \Rightarrow E(\beta) > \frac{1}{\varphi M} \tag{A18}$$

4.

$$SBE_R = a.q^* + b.d^* + c.p^* - [a.Aq + b.Ad + c.Ap] \tag{A19}$$

$$k' = a.q^* + b.d^* + c.p^* \tag{A20}$$

$$A = [a.Aq + b.Ad + c.Ap] \tag{A21}$$

$$SBE_R = k' - A \tag{A22}$$

5. The certain value of the equation 12 will approximately be as follows:

$$f_R^C \approx E(f_R) + 0.5aVar(f_R) \tag{A23}$$

$$E(f_R) = C_{sw} + \varphi Mk' + -\varphi ME(A) \tag{A24}$$

$$Var(f_R) = \varphi^2M^2Var(A) \tag{A25}$$

Considering equations (A24)-(A25) as the expected value and variance of the switching objective function, respectively, we will have equation (A26) as the certain value of f_R .

$$f_R^C = C_{sw} + \varphi Mk' - \varphi ME(A) + \frac{a\varphi^2M^2Var(A)}{2} \tag{A26}$$

6. As we use market share instead of lost market share for the strategic potential section, **SBE** will be rewritten as follows for the development decision:

$$SBE_t = a.Q + b.Dlv + c.P \tag{A27}$$

$$Dlv = d' + i\beta \tag{A28}$$

$$P = p' + i\beta \tag{A29}$$

$$Q = q' + i\beta \tag{A30}$$

Remember that β is the investment-improvement coefficient and i is the amount of investment. Recalling the first role of the strategic potential, its value should affect β . We consider a linear relationship as $\beta = m\tau_I$, where τ_I is the strategic potential of the incumbent supplier, m is its weight (i.e., the effect on the investment-improvement coefficient). By substituting this equation, we will have:

$$Dlv = d' + i(m\tau_I) \tag{A31}$$

$$P = p' + i(m\tau_I) \tag{A32}$$

$$Q = q' + i(m\tau_I) \tag{A33}$$

Note that we suppose the development will be done for only one criterion and the weights of criteria are equal, then, by putting equations (A31)-(A33) in (A27) and reordering, we will have:

$$SBE_I = [aq' + bd' + cp'] - i(m\tau_I) \tag{A34}$$

Calling the first constant term (inside bracket) k_I indicating the performance score of the incumbent supplier (current SBE_I), we will have:

$$k_I = aq' + bd' + cp' \tag{A35}$$

$$SBE_I = k_I + i(m\tau_I) \tag{A36}$$

Proof of Proposition 2:

We have the development profit function as follows:

$$f_D = \varphi Mimm'\tau_I^2 + \varphi Mk_I m'\tau_I - i \tag{A37}$$

Rewriting the above equation based on i will result as follows:

$$f_D = (\varphi Mmm'\tau_I^2 - 1)i + \varphi Mk_I m'\tau_I \tag{A38}$$

The development profit function is linear concerning i . Thus, in the case of the effective development decision, the optimal value of decision variable i will be its maximum value. Considering that investment increases the performance score and the maximum score is 1, then its equivalent investment will be the choice (optimal value). So, we have:

$$k_I + i(m\tau) = 1 \Rightarrow i^{optimal} = \frac{1 - k_I}{m\tau} \tag{A39}$$

Replacing the optimal investment in equation (A37) yields equation (A40) (equation (30) in the context).

$$f_D = \varphi Mm'\tau_I - \frac{1 - k_I}{m} \times \frac{1}{\tau_I} \tag{A40}$$

Having the current cost as equation (A41), then Δf_D will be as follows:

$$f_C = \varphi Mm'k_I\tau_I \tag{A41}$$

$$\Delta f_D = f_D - f_C = \varphi Mm'\tau_I(1 - k_I) - \frac{1 - k_I}{m} \times \frac{1}{\tau_I} \tag{A42}$$

Finally, to have an effective development decision, the condition $\Delta f_D > 0$ must be satisfied. So

$$\Delta f_D > 0 \Rightarrow \tau_I > \frac{1}{\sqrt{\varphi Mm'm}} \tag{A43}$$

Proof of Proposition 3:

To determine the effect of adding the strategic potential to development and switching decisions, we compare the derivative of both profit functions with respect to the strategic potential as follows:

$$f'_D(\tau) = \varphi M m' + \frac{1 - k_I}{m} \times \frac{1}{\tau_I^2} \quad (A44)$$

$$f'_R(\tau) = \varphi M m' k_A \quad (A45)$$

Considering that $k_A \leq 1$, equation (A45) is less than or equal to the first term of equation (A44) (i.e., $\varphi M m'$). Regarding that the second term of equation (A44) is positive ($k_I \leq 1$), we can conclude that the slope of switching is less than the slope of development for any value of τ_I (i.e. $f'_R < f'_D$). This indicates that the development is more sensitive to strategic potential than the switching.

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