Supplier Performance Analysis in Food Industry: A Data Envelopment Analysis and Statistical Approach

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Abstract

Supply chain management in food industry comprises stakeholders to achieve goals. Supplier performance need to be evaluated to control the supply chain product quality and performance. This study aims to evaluate supplier performance and provide recommendation to improve the performance. A data envelopment analysis (DEA) and Pearson correlation are adopted to analyze supplier performance and provided recommendation for further improvement. This study defined five supplier performance criteria, involving raw material price, customer care and responsiveness, raw material quality, perfect order fulfilment and on-time delivery performance to evaluate suppliers at the food industry in the last three months. From 216 data pairs of supplier criteria, it showed that 61.1% of the supplier had inefficient performance where the rest were efficient. Looking for the result, this study suggested to improve raw material price and perfect order fulfilment immediately to produce significant impact to supplier performance and food industry's competitive advantages.

Keywords
data envelopment analysis, evaluation, food industry, performance, supplier.

1. Introduction

Supply chain management and operations comprises all stakeholders to achieve supply chain goals. Chopra and Meindl (2013) stated that supply chain operation is not only pay attention into factory, but also it must consider transportation, distribution, marketing, strategy even upstream and downstream parts. In the normal process, scholars agree that factory is the main actors or focal stakeholder of the supply chain (Asrol et al. 2020; Ganeshkumar et al. 2017), moreover the upstream and downstream stakeholder are also need to provide services to enhance supply chain performance in the supply chain's goal achievements.

In the first business process in supporting supply chain operations, supplier holds an important role to delivers a high-quality raw material. After that, the raw materials are processed at the factory using specific processing flow and standard. The processed raw materials are transformed into a value-added product to fulfill consumer demands. It is also confirmed that the importance of raw materials in performing high and value-added products. In this situation, a supplier holds an important role to ensure the quality of raw materials to performs high quality products with specific standards to process at the industry. Besides that, a routine supplier performance analysis and evaluation may minimize potential risk along supply chain and find risk mitigation activities, as proposed by Prahinski and Fan (2020) to provide supplier development programs and incentives for performance improvement. Despite the importance of supplier role in the supply chain, this research discusses the supplier selection and evaluation topics.

Supplier selection and evaluation has been largely discussed in the literature, moreover this study offers a new approach to enhancing the impact to supply chain and firm performance. The number of methods in supplier selection and evaluations has grown extensively since the complexity of decision making and supplier analysis in industry (De Boer 2001). Generally, the supplier selection and evaluation method is divided into two parts, qualitative and quantitative (Banaeian et al. 2018). In the qualitative approach, scholars define indicators with theoretical testing using statistical approach, as found in Kim et al. (2020); Maestrini et al. (2018) and Salam (2019). In the quantitative approach, scholars applied various quantitative technique supported by secondary data, as found in Akyüz Tosun and Aka, (2018); Cavalcante et al., (2019); Tong et al., (2020); and Wahyudi, (2022). In the last two decades, methods in

supplier selection and evaluations are very diverse which supported by scholar innovations, computer technology, science, and engineering.

Current and Benton (1991) has reviewed literatures to define criteria and method for supplier selection and found five important criteria: price, delivery, quality, production, facility, and capacity. These are the most popular criteria that applied in supplier performance analysis (Banaeian et al. 2018). These criteria are also in line with Ho Xu and Dey (2010) and found that service, price and quality as the most applied criteria in supplier performance analysis. Using appropriate criteria to evaluate supplier performance may assist in improving product quality in food industry. Further, these criteria are required to evaluate supplier performance with appropriate method and analysis.

Supplier selection and evaluation related to huge of data that obtained during the business process and operations. Related to this context, scholars has proposed a various method and techniques to evaluate the supplier performance in supply chain. Banaeian et al. (2018) and Liu et al. (2019) evaluate supplier performance at agri-food industry using the integration of fuzzy technique, AHP and TOPSIS. Mohammed et al. (2018) also evaluate supplier performance using fuzzy approach and multi-criteria decision making technique with traditional and green supplier performance criteria. Goswami and Ghadge (2019) evaluate supplier performance in automotive industry using data envelopment analysis (DEA) and linear programing to find an optimal solution in improving the efficiency. Dobos and Vörösmarty, (2018) also applied DEA for supplier selection and evaluation with in-complete data constraint.

Despite many techniques has been applied in supplier selection and evaluation in various industry, we found some potential improvement. Most literatures applied multi-criteria decision-making techniques to evaluate supplier performance. An operation research technique, i.e., DEA and linear programming are also possible to applied which has ability to find solutions in the defined constraint. Moreover, we found that most literatures are only evaluate supplier performance without further analyses, especially in data attribute and correlation of the supplier criteria for supply chain performance improvement. A huge of data in supplier performance offers opportunity to discuss and find strategy and solution to keep supplier performance in the right side. Therefore, a data attribute analysis with a simple statistical and data science approach are necessary to find the solution in supplier performance improvement.
This study aims to evaluate supplier performance based on specific criteria and explore the correlation of the criteria to improve supplier performance. An analytical approach using data envelopment analysis and statistical analysis are applied to explore the supplier performance criteria and its impact to performance.

2. Methods

2.1 Research framework

The research framework is depicted in Figure 1. In the first stage, the supplier evaluation criteria are explored. Scholars had defined various criteria to evaluate supplier performance, moreover this study proposed criteria for supplier performance in food industry. We collected data regarding to supplier criteria as defined in the previous stages. We collected data from food industry supplier which delivers raw materials to produce cheese cheddar. A pre-processing stage is provided to ensure data is ready to analyze. To analyze data and supplier performance, data envelopment analysis (DEA) is proposed. Supplier criteria will be divided into input and output parts. DEA enable to identify the supplier efficiency based on the proposed criteria. To proposed recommendations for improvement, a statistical analysis is obtained. In this case, criteria are explored to find correlation in improving supplier performance. Below are details stage of the data processing stage.

2.2 Data pre-processing

The data pre-processing is an important stage in data analysis. Data pre-processing ensures that data are clean and ready to use for data analysis. In the first stage, the data attributes are explore including minimum, maximum, and standard deviation of each criterion. Furthermore, since supplier performance criteria has different scale and unit, a normalization technique must be adopted.

Data normalization ensures that all data for each criterion are scaled into [0.1] (Bakri et al. 2017; Yani et al. 2022). Since each supplier evaluation criteria have different unit and target (minimum/maximum), data normalization procedure is necessary to further processing in DEA. According to Phillis et al. (2011), data normalization is described at Eq. 1 and 2.

Suppose that *Ci* as supplier evaluation criteria, *T(Ci)* as target score of each criterion which is also adopted as maximum (max *i*) or minimum (min *i*) value of the criterion. Each criterion should be defined its target, maximum or minimum. If the target maximum, the highest value contributes to supplier performance, and vice versa. Therefore, if the target of criterion is maximum and minimum are calculated using Eq. 1 and 2, respectively.

$$S(C_i) = \begin{cases} \dfrac{C_i - \min i}{T(C_i) - \min i}; if\ C_i \le T(C_i) \\ 1 \qquad\qquad ; if\ C_i \ge T(C_i) \end{cases} \tag{1}$$

$$S(C_i) = \begin{cases} 1 \qquad\qquad ; if\ C_i \le T(C_i) \\ \dfrac{\max i - C_i}{\max i - T(C_i)}; if\ C_i \ge T(C_i) \end{cases} \tag{2}$$

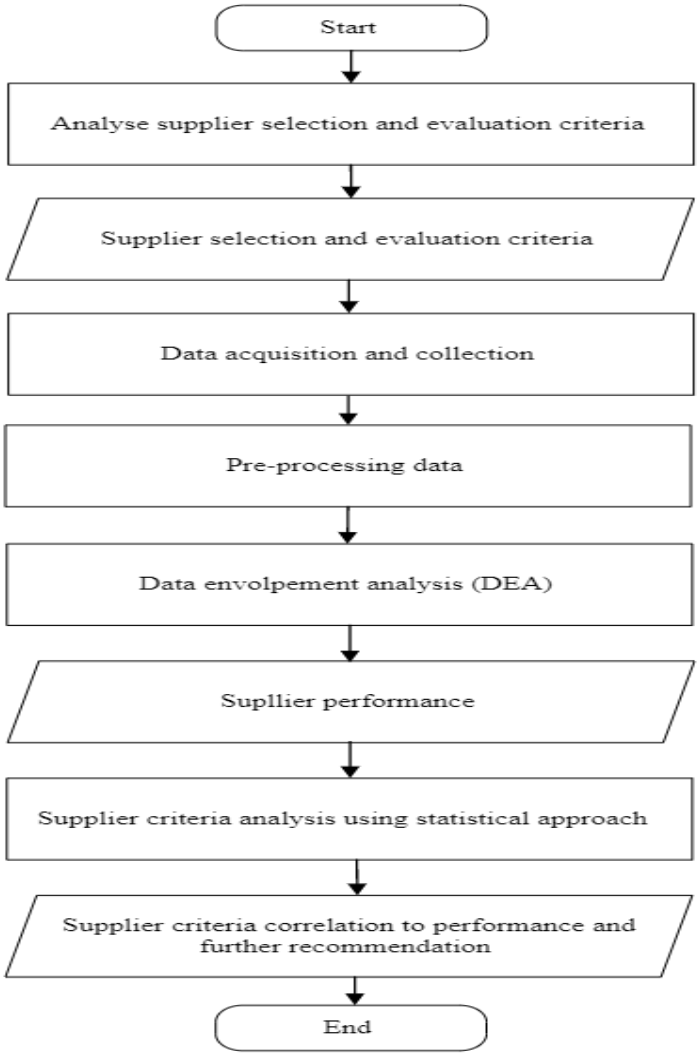


Figure 1. Research framework

2.3 Data envelopment analysis

Data envelopment analysis is a mathematical programming approach for efficiency assessment that was applied in group of decision making unit (DMU) (Wei 2001) which firstly proposed by Charnes et al. (1978). DEA has largely applied in performance measurement in different fields, further Dutta et al. (2021) suggest to apply DEA for vendor selection and evaluation using a variety of criteria.

In this research, we proposed DEA to explore supplier performance and find which criteria has significant contribution to the performance. DEA search the efficiency score of output divided by input. DEA seeks to find a maximum efficiency score with total score of 1. Following Liu et al. (2000), DEA to find maximum efficiency score of the DMU's is described at Eq. 3.

$$maximize\ efficiency = \frac{DMU\ input}{DMU\ output} \tag{3}$$

2.4 Statistical analysis for supplier performance criteria

A simple Person correlation is adopted to describe the correlation between supplier criteria to supplier performance. Suppose that there are two variables, *x,* and *y*, where s_x and s_y as variation of *x* and *y*, respectively. According to Lind et al. (2018), the Pearson correlation coefficient (*r*) is calculated using Eq. 4.

$$r = \frac{\sum(x - \bar{x})(y - \bar{y})}{(n-1)s_x s_y} \tag{4}$$

The Pearson correlation coefficient is ranging from -1.00 to +1.00 where 1 means strong correlation while 0 means no correlation. A positive and negative marks means that these two variables have positive or negative impact each other, respectively.

3. Results and Discussion

3.1 Supplier performance criteria

To evaluate supplier performance, some criteria must be defined. Scholars has provided various criteria for supplier performance. This study analyses food supply chain to evaluate supplier performance. At the food industry, raw materials that are provided by supplier holds an important role to ensuring the food quality and security. Therefore, related to this industry, we define five criteria for supplier evaluation, namely raw material price, customer care and responsiveness, raw material quality, perfect order fulfilment, and on time delivery performance. The detail supplier performance criteria for evaluation are described at Table 1.

Table 1. Supplier performance criteria

No.	Supplier metrics	Description	References
1	Raw material price (C1)	Cost to delivers raw materials from supplier to factory for further processing. Each supplier has different price with specific product characteristic.	Grisi Guerra and Naviglio, (2010); Nydick and Hill, (1992); Weber et al. (1991)
2	Customer care and responsiveness (C2)	Supplier response performance to provide materials for factory.	Banaeian et al. (2018); Ho et al. (2010)
3	Raw material quality (C3)	The raw material quality and characteristics met the factory requirements for production.	Weber et al. (1991); (Banaeian et al. (2018); Chaharsooghi and Ashrafi (2014); Grisi et al. (2010); Ho et al. (2010)
4	Perfect order fulfilment (C4)	Supplier commitment to deliver product quantity as required by factory.	SCC, (2012)
5	On time delivery performance (C5)	Supplier commitment to deliver materials on time.	Weber et al. (1991); (Banaeian et al. (2018);

To analyze suppliers' performance, 216 pair dataset have been obtained from food industry's supply chain in the last three month. There are five criteria for supplier performance evaluation have different unit and dimensions. As suggested, a normalization technique is required to set the data into same dimensions. This study normalized data into [0, 100] as required to analyze supplier performance using DEA. Data attributes and samples are provided at Table 2 and 3, respectively.

Supplier criteria have different units and target. A normalized technique scales data into [0, 100] for further analysis. In this case, criteria target is applied to define the normalized score using Eq. 1 and 2. A criteria with minimum target means that a lower value of criteria will improve the supplier performance, while maximum target suggests achieving higher value. All 216 pairs dataset are normalized for further DEA analysis for supplier performance evaluation.

Table 2. Data Attributes

No.	Supplier criteria	Unit	Min	Max	Std.	Target
1	Raw material price (C1)	$	4.000	4.120	0.029	Min
2	Customer care and responsiveness (C2)	Rating	70.000	90.000	4.279	Max
3	Raw material quality (C3)	%	0.000	16.593	3.065	Max
4	Perfect order fulfilment (C4)	%	0.000	5.000	1.059	Max
5	On time delivery performance (C5)	Day	19.700	24.700	1.165	Max

Table 3. Data Samples and Pre-processing

No	Real dataset					Normalized dataset				
	C1	C2	C3	C4	C5	C1	C2	C3	C4	C5
1	4.04	82.50	4.17	100.00	0.00	80.00	82.50	95.83	100.00	100.00
2	4.10	80.00	8.16	100.00	0.00	75.00	80.00	91.84	100.00	100.00
3	4.10	85.00	9.22	98.79	1.00	75.00	85.00	90.78	98.79	90.00
4	4.02	90.00	5.39	96.67	3.00	81.67	90.00	94.61	96.67	70.00
5	4.00	85.00	10.64	97.92	1.00	83.33	85.00	89.36	97.92	90.00

3.2 Data envelopment analysis for supplier performance

DEA is applied to evaluate supplier performance with five criteria as aforementioned. To analyze supply chain performance using DEA, criteria should divide into two parts, input, and output, which further called as decision-making unit (DMU). Two criteria are set as input, and the rest are output of DMU. The DMU input are raw material price and responsiveness while raw material quality, perfect order fulfilment and on time delivery are set as output. The DEA framework for supplier performance evaluation is depicted at Figure 2.

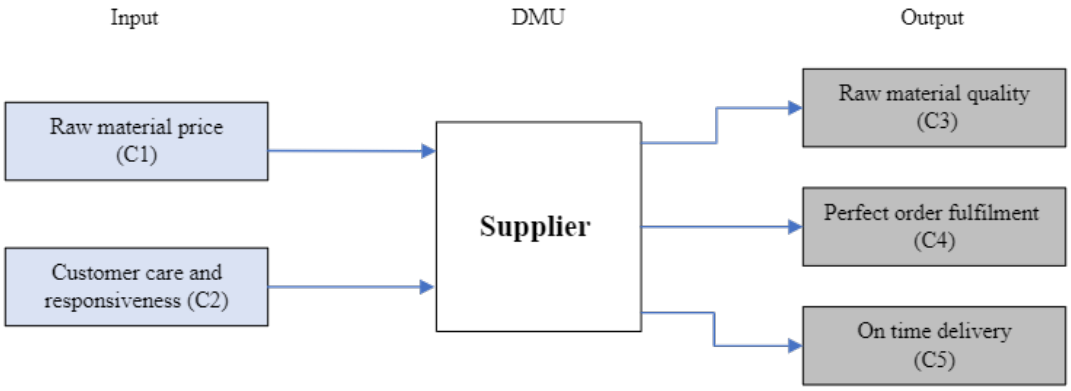


Figure 2. A Framework for Supplier Performance Analysis using DEA

Supplier performance in the last three months is evaluated using five criteria with DEA technique. Number of pairs data had normalized and evaluated to find the efficiency of the supplier performance. The supplier performance is ranged into 0 to 1, with the maximum value means efficient. Table 4 describes the supplier performance score which find that the supplier performance is ranged into 0.8 to 1. The supplier performance has a low standard deviation score and 0.95 score for data dispersion. This study classifies the supplier performance score into two class: efficient (0.95 - 1) and inefficient (0.8 – 0.94).

A DEA analysis for supplier performance with five attributes and 216 dataset confirms that supplier performance in the last three months has low performance. Most of the data show that most supplier has inefficient performance. It found that only 38.8% suppliers have efficient performance where the rest are inefficient. For further analysis, it needs a statistical analysis to find which criteria has the most contribution to supplier performance score. (Table 4)

Table 4. Supplier Performance Efficiency Score using DEA

No	Attribute	Value
1	Min	0.803
2	Max	1.000
3	Standard Deviation	0.041
4	Dispersion	0.935
5	Number supplier with efficient performance score	84 (38.8%)
6	Number supplier with of inefficient performance score	132 (61.1%)

3.3 Statistical analysis and correlation for supplier performance criteria and Proposed Improvements

Previous stage has described the supplier performance with five criteria. Further this stage explores the supplier criteria and its contribution to supplier performance. A simple statistical analysis with correlation is adopted to describe supplier criteria contribution to supplier performance. A Pearson correlation is adopted to explore supplier criteria to supplier performance. The supplier criteria correlation to supplier performance is showed at Table 5.

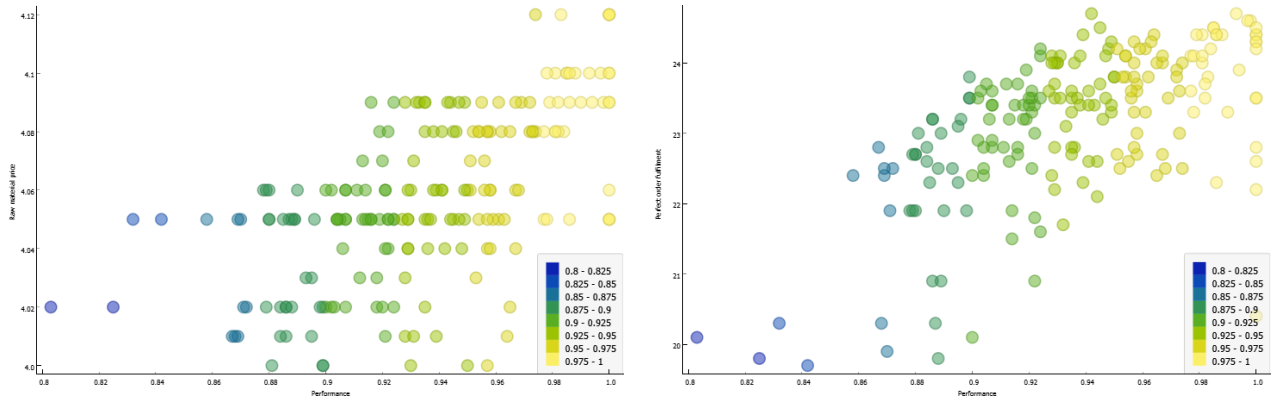
Table 5. Supplier criteria correlation to supplier performance score

No	Supplier criteria	Pearson correlation to supplier performance
1	Raw material price	+ 0.608
2	Customer care and responsiveness	- 0.374
3	Raw material quality	- 0.337
4	Perfect order fulfilment	+ 0.608
5	On time delivery performance	- 0.413

The result show that there are two criteria with positive correlation and the rest are negative correlation to supplier performance. A Pearson correlation score is ranging from -1 to 1 with lowest score means negative impact while the highest score contributes a positive impact. If the score is higher than 0.5, it means that the criteria contribute a significant impact to supplier performance.

The result confirms that raw material price and perfect order fulfilment are two of supplier criteria that contributes a positive significant impact to supplier performance. While the other three supplier criteria contribute insignificant impact. This result confirms that to increase the supplier performance, food industry may focus on improving raw material price and perfect order fulfilment of the supplier. The illustration of raw material price and perfect order fulfilment correlation to performance is depicted to Figure 3.

To improve supplier performance, it needs all supply chain stakeholder's cooperation. As found by Connor et al. (2020) that inter-organizational cooperation may improve supplier performance. Besides that, Asrol et al. (2018) also stated that stakeholders coordination and cooperation may improve supply chain performance and competitive advantages. Primary and secondary stakeholders in supply chain including supplier and focal company need to set supply chain goals and provide downstream stakeholders a high-quality materials and product.



(a) (b)

Figure 3. (a) Raw material price and (b) perfect order fulfillment correlation to supplier performance

4. Conclusion

Supplier evaluation in food industry holds an important role to maintain supply chain performance. Previous research had explored supplier performance using qualitative and quantitative approach with various techniques and tools. This study found that the previous analysis is limited supplier performance measurement with no further explorations the impact of criteria to supply chain performance. To define supplier performance, it needs supplier criteria definition which was adopted from literature review. This study has explored five supplier criteria involving raw material price, customer care and responsiveness, raw material quality, perfect order fulfilment and on time delivery performance to evaluate supplier performance. A food supply chain that must ensure high quality product with food security standard is adopted for supplier performance analysis. Suppliers of food supply chain are evaluated during the last three months with 216 data pairs. Data envelopment analysis (DEA) is applied to evaluate supply chain performance. The result show that most of the supplier performance are inefficient and only 38.8% are efficient. Further, a statistical approach is provided to further improvement in supplier performance which is focused on supplier indicators. Based on statistical analysis this research recommends for food industry to control with raw material price and perfect order fulfilment score to improve supplier performance.

For further research, study in supplier performance analysis needs experienced expert validation and cost benefit analysis to supply chain and firms' performance.

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