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A case of food supply chain management with AHP, DEMATEL, and TOPSIS

Miguel Ortiz-Barrios[1] | Carlos Miranda-De la Hoz[1] | Pedro López-Meza[2] | Antonella Petrillo[3] | Fabio De Felice[4]

[1]Department of Industrial Management, Agroindustry and Operations, Universidad de la Costa CUC, Barranquilla, Colombia

[2]Department of Engineering in Industrial Processes, Institución Universitaria ITSA, Soledad, Colombia

[3]Department of Engineering, University of Napoli "Parthenope", Naples, Italy

[4]Department of Civil and Mechanical Engineering, University of Cassino and Southern Lazio, Cassino, Italy

Correspondence
Miguel Ortiz-Barrios, Department of Industrial Management, Agroindustry and Operations, Universidad de la Costa CUC, 58th Street # 55-66, Barranquilla, Colombia.
Email: mortiz1@cuc.edu.co

Abstract

The bullwhip effect leads to considerable inefficiencies along the food supply chain such as missed production schedules, poor customer service, excessive inventory, and misguided capacity plans. To tackle this problem, it is necessary, apart from other interventions, to continuously monitor the performance of food suppliers so that the demand information flow, order batching, transportation planning, and inventory management can be substantially improved. Therefore, supplier assessment has then become critical decision-making support for identifying and addressing inefficiencies of food providers, which ends up reducing the variation of several key logistics parameters for upstream members of the food supply chain. In addition, such assessment is of multicriteria nature given the presence of several criteria from different domains and various food suppliers. With these considerations in mind, this paper proposes a hybrid approach integrating the analytic hierarchy process (AHP), decision-making trial and evaluation laboratory (DEMATEL), and the technique for order of preference by similarity to ideal solution (TOPSIS) for evaluating the performance of pork suppliers. Thereby, the economic and operational burden caused by the bullwhip effect throughout the pork supply chain can be alleviated. AHP was first used to determine the criteria and subcriteria weights. Then DEMATEL was applied to assess the interdependence and feedback between the decision elements. Finally, TOPSIS was implemented to discriminate between high-performance and low-performance pork suppliers. A case study from the Colombian pork supply chain is presented to validate the proposed approach. The results of this study evidenced that the most important criterion was the "service level" and the most influencing factor was the "financial profile." In addition, based on the supplier assessment results, improvement plans, and new negotiation, strategies were established for each supplier in order to diminish the bullwhip effect along the pork supply chain.

KEYWORDS

AHP, bullwhip effect, DEMATEL, food industry, multicriteria decision-making (MCDM), TOPSIS

1 | INTRODUCTION

Economy of industry growth depends on proper supply of goods and food items to the ultimate consumers at right place, right time, and right quantity with right price based on effective prediction or judgement of demand (Perez, de Castro, & Font i Furnols, 2009; Matloub et al., 2012). In detail, in Colombia, the country's pork industry is facing new challenges. As reported by *Pig Progress magazine—Volume 32.1 (2016)*, in 2015, Colombia had about 200,000 pig farm sites, with in total 4.6 million pigs. About more than half of the pigs (2.5 million) are held in the most pig dense provinces: Antioquia (1.6 million), Cundinamarca (0.5 million), and Valle del Cauca (0.4 million). One third of the pigs are held in backyard systems and about two third in "tecnified farms"—or farms producing pigs indoors. The group contains around 20,000 farms having less than 10 sows. In 2015, Colombia counted 46,500 tecnified farms, with a total of 204,500 sows. In the last decade, there has been a serious increase in Colombia's pig production. Its pig inventory almost doubled from 2.5 million in 2005 to 4.6 million in 2015. In the most pig dense province Antioquia, the pig population almost quadrupled: from 465,000 in 2005 to 1.6 million in 2015. There is a continuous pressure on cost of production if the sector aims to develop further. Production costs are mainly made up by feed costs. This is shown by a summary of production cost from the Bogotá area. For a pig leaving a farm, feed costs represent 74–78%, followed by labour costs (6–8%), breeding stock costs (4.5–5%), buildings (2.6%), and medication (2.6%). During the present and coming years, there will be serious challenges to overcome. It is evident that by looking at pork production as a chain instead of as individual steps made by different companies, the meat sector can more easily meet the challenge of accurately responding to changing customer demands. Competitive advantage arises from a supply chain creating value for the consumer, and this value is dependent on the activities of all partners in the chain (Das & Dutta, 2012).

The failure to predict proper demand by a company leads to fluctuation of demand between supply chain stages. This extends to bullwhip effect, which is a threat for economic growth.

The bullwhip effect generally refers to the phenomenon where order variability increases as the orders move up streaming the supply chain. It is serious problem for every member of the supply chain (Somashekhar, Raju, & Patil, 2013). This effect begins at customers and passes through the chain to producers, which are at the end of the logistic chain. Especially, food supply chains are affected by this issue (Ma, Huang, Jiang, & Cao, 2011). Agribusiness industries, including some within the pork industry, have shown that involvement in supply chain management can provide (a) improved product quality and consistency of supply, (b) improved profitability and efficiency with less price variation, (c) development of new markets or expansion of existing markets, and (d) reduced costs through collective business planning and purchasing activities streamlining the chain by removing redundant or unnecessary activities.

Thus, a major goal in supply chain management strategy is to minimize the bullwhip effect as it is a supply chain error that generates false supply and demand variations. Specifically, the supply is amplified, and the inventory increases faster than the demand.

The bullwhip effect is caused by demand forecast updating, order batching, price fluctuation, and rationing and gaming. Reducing the bullwhip effect involves some research to locate the problem causing a bullwhip. In this regard, an effective supply chain manager should search for strategies reducing and improving the overall efficiency of the supply chain. An important strategy then consists of improving the responsiveness, accuracy, and efficiency of the supply chain by implementing supplier assessment models (Seung-Kuk et al., 2007). As such assessment is of multicriteria nature given the presence of several criteria from different domains, supply chain managers can identify the specific aspects that each provider must improve in order to increase the global customer satisfaction at a minimum cost. Some of these aspects (i.e., E-business, IT infrastructure, and price) are directly related to the bullwhip effect occurrence within supply chains. Therefore, supplier assessment models can serve as tools for monitoring these features and designing focused intervention plans when failures are observed. Thereby, such model may contribute to the reduction of false supplies and demand variability, which is highly beneficial for increasing the net utility of upstream companies (Vachon & Klassen, 2006; Zhao, Mashruwala, Pandit, & Balakrishnan, 2018).

Thus, according to the previous consideration, the aim of the present paper is to propose a multicriteria supplier assessment model based on AHP-DEMATEL-TOPSIS techniques for supporting the bullwhip effect management within supply chains. Multicriteria approach helps the organization to alleviate inconsistencies in decision-making problems, as argued by several authors (Jayant, Gupta, & Khan, 2014; Jayant, Singh, & Patel, 2011).

This paper presents the problem of the bullwhip effect in the real supply chain in the food industry or more detail in pork sector. From a managerial point of view, our results might help firms develop better strategies to cope with the bullwhip effect, thereby increasing the efficiency.

The rest of the paper is structured as follows. Section 2 presents a perspective on bullwhip effect respect the state of art; Section 3 defines research methods. In Section 4, methodological approach applied in a real case study is presented; results are analysed. In the final section, conclusions and further research opportunities are presented.

2 | PERSPECTIVES ON BULLWHIP EFFECT

As analysed by Braz, De Mello, de Vasconcelos Gomes, and de Souza Nascimento (2018), the bullwhip effect has been widely discussed in supply chain management literature. In fact, since the first publication of Forrester (1961), a number of researchers have investigated the causes and mitigating factors of the bullwhip effect in forward supply chains (Dev, Shankar, & Choudhary, 2017; Hofmann, 2017). In other words, since the 1990s, a large amount of literature on the bullwhip effect and its various proofs, interpretations, and remedies has emerged and continues to grow (Wang & Disney, 2016). Early studies attempted to demonstrate the existence of the bullwhip effect and identify its causes (Forrester, 1958). Subsequently, numerous studies focused to "solve" the bullwhip effect in a serial supply chain using different approaches (Rostami-Tabar, Babai, Ali, & Boylan, 2019).

Due to the various orientations and disciplines of research papers under this topic, a statistical systematic review is not appropriate. For a general overview of the bullwhip effect and its causes, see Lee, Padmanabhan, and Whang (1997) and Bray and Mendelson (2012).

Rather, this section aims to analyse intends to provide some elements for reflection on the topic with attention to our specific field of application.

To this end and to understand the phenomenon, an investigation on Scopus, the largest abstract and citation database of peer-reviewed literature, has been carried out. The survey shows approximately 1.140 results for the query "bullwhip effect AND supply chains." Despite this consistent body of knowledge concerning the bullwhip effect in supply chains, surprisingly few studies have investigated the application of multicriteria analysis in bullwhip effect. In fact, a second survey for the query "bullwhip effect AND supply chains AND AHP" shows only three documents; for the query "bullwhip effect AND supply chains AND DEMATEL," only one document; and for the query "bullwhip effect AND supply chains AND TOPSIS," only two documents. No documents were found for the query "bullwhip effect AND supply chains AND AHP AND TOPSIS AND DEMATEL."

Although several studies on bullwhip effect were analysed in literature by several authors, the integration of multicriteria decision-making techniques (MCDM) on bullwhip effect has been evaluated in literature by a very limited number of studies. Thus, this study tries to cover this gap.

In fact, MCDM is a technique that combines alternative's performance across numerous, contradicting, qualitative, and/or quantitative criteria and results in a solution requiring a consensus. The objective of MCDM is not to suggest the best decision but to aid decision makers in selecting shortlisted alternatives or a single alternative that fulfils their requirements. There are several MCDM methods available such as the analytical hierarchal process (AHP), decision-making trial and evaluation laboratory (DEMATEL), and the technique for order of preference by similarity to ideal solution (TOPSIS). MCDM has been one of the fastest growing problem areas in many disciplines (Kilic, 2013). For their part, MCDM methods have also attracted significant attention among researchers and practitioners in the field of Supply Chain Management (SCM) (Arikan, 2013; Roshandel, Miri-Nargesi, & Hatami-Shirkouhi, 2013). MCDM techniques can then deal with the multicausality nature of the bullwhip effect problem, which can be represented by a set of criteria related to the main causes of this phenomena: demand forecasting updating, order batching, price fluctuations, gaming, and rationing. In addition, the use of AHP and DEMATEL methods enable supply chain managers to design both short-term and long-term strategies based on linear dependency, interdependence, and feedback so that bullwhip effect management can be facilitated (Khan, Chaabane, & Dweiri, 2018; Ortiz-Barrios et al., 2017; Ortiz-Barrios et al., 2018; Wu & Tsai, 2012). This is complemented by the use of TOPSIS, which can calculate the gap between the current performance of bullwhip-phenomena-related criteria and the desired target (Saeida Ardakani, Nejatian, Farhangnejad, & Nejati, 2015; Shukla, Agarwal, Rana, & Purohit, 2017). Thereby, progress in addressing the problem can be easily monitored and administered.

Finally, the investigation for the query "bullwhip effect AND supply chains AND food" shows 11 documents. Among these documents, in our opinion, one of the most relevant for our study is the research proposed by Chocholáč and Průša (2016). The research pointed out that the phenomenon of the bullwhip effect is very problematic in the food supply chain, especially in the situation of perishable goods. In fact, as stated by Govindan, Soleimani, and Kannan (2015), the existence of bullwhip effect in food industry can cause losses for every member of this chain, reduction of customer satisfaction, and reduction of revenues and put requirements on information systems, collaboration, and cooperation between every member

Definitively, our findings suggest that the literature might have developed from two perspectives. The first one regarding how to reduce the bullwhip effect in food supply chain. The second one regarding the use of multicriteria methods to investigate the bullwhip effect.

3 | RESEARCH METHOD

3.1 | Description of the proposed methodology

A five-phase methodology (Figure 1) was proposed to evaluate the performance of pork suppliers:

Phase 1: A group of experts is invited to enrol in the supplier assessment model. Such a group will support the design of the hierarchy model and the ensuing paired comparisons for importance and influence evaluation.

Phase 2: The model is set considering the suitable scientific literature, customer needs, and experts' opinion.

Phase 3: AHP is implemented to estimate the relative weights of criteria and subcriteria. In this phase, the group of experts is asked to make the paired comparisons. Such comparisons are then processed in accordance with the AHP technique as detailed in Section 3.2.

Phase 4: DEMATEL is applied to discriminate between the dispatchers and receivers as well as calculate the strength of influence between the decision elements. The DEMATEL procedure is described in Section 3.3.

Phase 5: TOPSIS method is used to evaluate the performance of pork suppliers based on their closeness coefficient (Section 3.4). Considering the supplier assessment results, improvement plans, and new negotiation, strategies are established for each supplier in order to diminish the bullwhip effect along the pork supply chain.

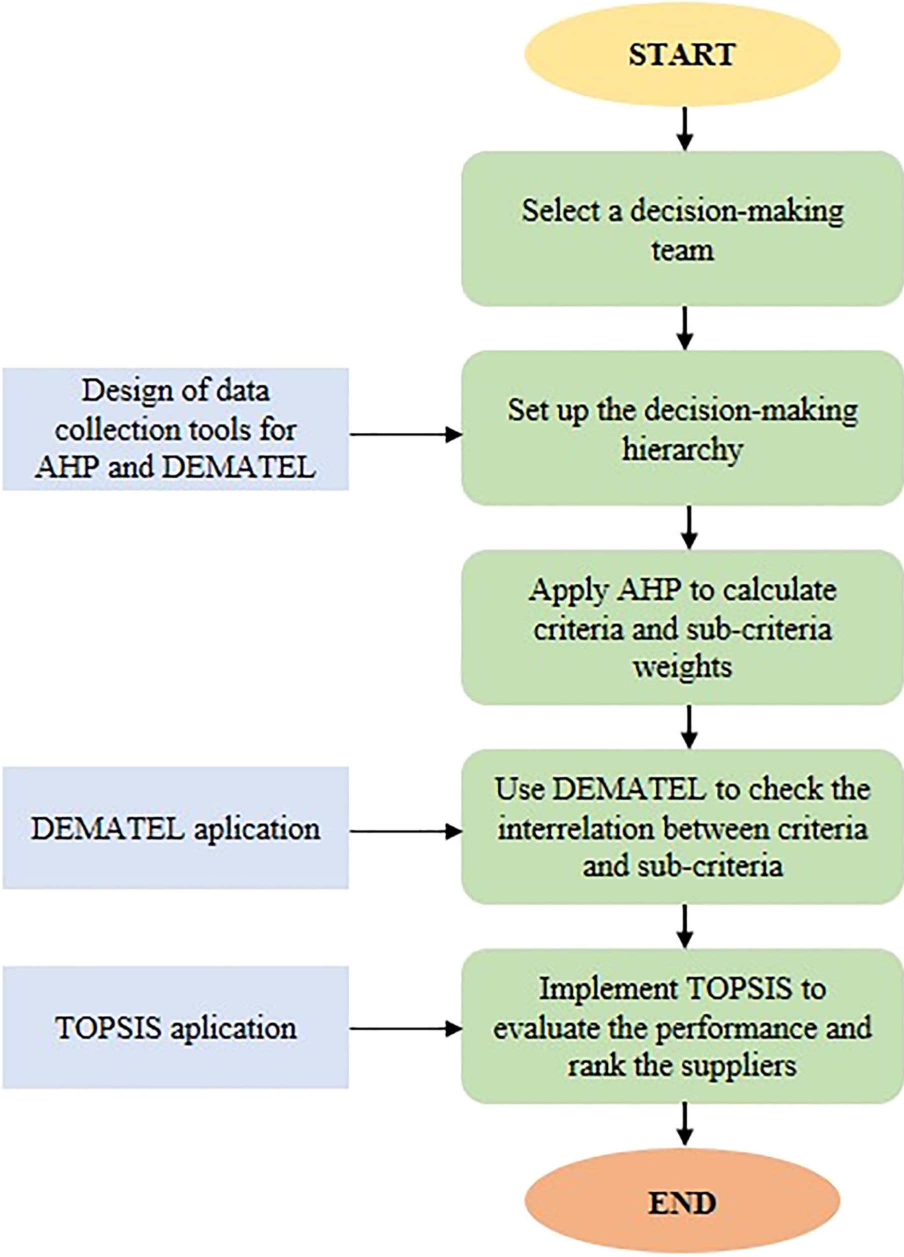


FIGURE 1 The proposed framework for the performance evaluation process of pork suppliers

3.2 | AHP

AHP is a well-known method proposed by Thomas Saaty that allows analysing and decomposing a complex decision-making problem into several separate structures. Furthermore, AHP enables decision makers to calculate the relative weights of criteria and subcriteria based on pairwise comparisons (Saaty, 2008; Sherekar & Tatikonda, 2016). The steps of AHP are as follows:

TABLE 1 Reduced analytic hierarchy process (AHP) scale

Reduced AHP scale	Definition
1	Equally important
3	More important
5	Much more important
1/3	Less important
1/5	Much less important

- Step 1 "Collect the pairwise comparisons": First, the paired comparisons between criteria/subcriteria are gathered through a survey format. Although there is widespread use of the fundamental scale (Joshi, Banwet, & Shankar, 2011; Shaik & Abdul-Kader, 2013), a shorter scale is adopted (refer to Table 1) to avoid confusion throughout the decision-making process and the ensuing inconsistencies. This is more useful in experts who are not qualified in complex mathematics or the AHP technique. In addition, it has been proved that most the responders tend to use only five judgments (much less, less, equally, more, and much more) for assessing the importance of decision elements (Barrios et al., 2016; Meesariganda & Ishizaka, 2017; Pecchia et al., 2013; Wang, Qin, Li, & Chen, 2009)

- Step 2 "Establish the paired comparison matrix": From the above information, a $n \times n$ paired comparison matrix is created. Here, n represents the number of criteria or subcriteria under assessment. In particular, the matrix A^k (refer to Equation (1)) was defined for criteria and matrix B^k (refer to Equation (2)) for subcriteria. Consequently, the element a_{ij}^k denotes the kth expert's preference of the criterion i compared with the criterion j whereas b_{ij}^k represents the kth expert's comparative importance of subcriterion i with respect to subcriterion j:

$$A^k = \begin{bmatrix} 1 & a_{12}^k & \dots & a_{1n}^k \\ a_{21}^k & 1 & \dots & a_{22}^k \\ \dots & \dots & \dots & \dots \\ a_{n1}^k & a_{n2}^k & \dots & 1 \end{bmatrix}, \tag{1}$$

$$B^k = \begin{bmatrix} 1 & b_{12}^k & \dots & b_{1n}^k \\ b_{21}^k & 1 & \dots & b_{2n}^k \\ \dots & \dots & \dots & \dots \\ b_{n1}^k & b_{n2}^k & \dots & 1 \end{bmatrix} \tag{2}$$

As seen in Equations (1) and (2), the diagonal values of matrices A and B are equal to 1 because a particular criterion/subcriterion is compared with itself, in other words, $i = j$. In addition, considering a group decision-making scenario, a_{ij} and b_{ij} values are calculated using the geometric mean of the comparisons as stated in Equations (3) and (4) correspondingly (K is the number of experts participating in the supplier assessment model). Such values are then arranged in matrixes A (refer to Equation (5)) and B (refer to Equation (6)) correspondingly.

$$a_{ij} = \sqrt[K]{a_{ij}^1 * a_{ij}^2 * \dots * a_{ij}^k}, \tag{3}$$

$$b_{ij} = \sqrt[K]{b_{ij}^1 * b_{ij}^2 * \dots * b_{ij}^k}, \tag{4}$$

$$A = \begin{bmatrix} 1 & a_{12} & \dots & a_{1n} \\ a_{21} & 1 & \dots & a_{2n} \\ \dots & \dots & \dots & \dots \\ a_{n1} & a_{n2} & \dots & 1 \end{bmatrix}, \tag{5}$$

$$B = \begin{bmatrix} 1 & b_{12} & \dots & b_{1n} \\ b_{21} & 1 & \dots & b_{2n} \\ \dots & \dots & \dots & \dots \\ b_{n1} & b_{n2} & \dots & 1 \end{bmatrix} \tag{6}$$

- Step 3 "Obtain the weights of criteria and subcriteria": The relative importance of each subcriterion i compared with another subcriterion within the same criterion c is called local weight LW_i^c (refer to Equation (7)), and the importance of each criterion c in relation to the objective is denoted as "criterion global weight" FW^c (refer to Equation (8)). Then, by multiplying LW_i^c and FW^c, "the subcriterion global weight" GW_i can be finally achieved (refer to Equation (9)).

$$LW_i^c = \frac{\left(\prod_{j=1}^{n} b_{ij}\right)^{1/n}}{\sum_{i=1}^{n}\left(\prod_{j=1}^{n} b_{ij}\right)^{1/n}}, i,j = 1,2,\dots,n. \tag{7}$$

$$FW^c = \frac{\left(\prod_{j=1}^{n} a_{ij}\right)^{1/n}}{\sum_{i=1}^{n}\left(\prod_{j=1}^{n} a_{ij}\right)^{1/n}}, i,j = 1,2,\dots,n. \tag{8}$$

$$GW_i = LW_i^c * FW^c \; i,j = 1,2,\dots,n. \tag{9}$$

- Step 4 "Evaluate the decision consistency": Calculate the consistency index (CI) in accordance with Equation (10). Then establish the consistency ratio using Equation (11). In this formula, RI represents the random index whose values were already estimated (Saaty, 2008). If $CR < 0.1$, the matrix is considered as sufficiently consistent.

$$CI = \frac{\lambda_{\max} - n}{n-1}, \tag{10}$$

$$CR = \frac{CI}{RI}. \tag{11}$$

3.3 | DEMATEL

DEMATEL is an MCDM method used to describe the interrelationships between criteria/subcriteria. In addition, it helps to visualize the degree of influence between subsystems through an impact digraph map (Gabus & Fontela, 1972; Ortiz Barrios, Combita Nino, La De Hoz, De Felice, & Petrillo, 2016). The DEMATEL procedure is described as follows:

- Step 1 "Create the group-direct influence matrix Z": The paired comparisons between criteria/subcriteria (z_{ij}^k) are initially performed by each decision maker k ($k = 1,2,\dots,K$) through a data-collection format. The element z_{ij}^k then denotes the kth expert's influence of criterion i over the criterion j. To evaluate interdependence and feedback, DEMATEL uses a 5-point scale: *no influence* (0), *low influence* (1), *moderate influence* (2), *high influence* (3), and *very high influence* (4). Such comparisons are later arranged in matrix Z^k as shown in Equation (12). In this matrix, the values of the principal diagonal are set as 0 because $i = j$.

$$Z^k = \begin{bmatrix} 0 & z_{12}^k & \dots & z_{1n}^k \\ z_{21}^k & 0 & \dots & z_{2n}^k \\ \dots & \dots & \dots & \dots \\ z_{n1}^k & z_{n2}^k & \dots & 0 \end{bmatrix}. \tag{12}$$

The judgments are then aggregated by applying Equation (13). The resulting z_{ij} values are later arranged in the group-direct influence matrix Z.

$$z_{ij} = \frac{1}{K}\sum_{k=1}^{K} z_{ij}^k, \quad i,j = 1,2,\dots,n. \tag{13}$$

- Step 2 "Normalize the group-direct influence matrix Z": The normalized matrix X is calculated using Equation (14).

$$X = \frac{Z}{s}, \tag{14}$$

$$s = \max\left\{\max_{1\le i\le n}\sum_{j=1}^{n} z_{ij}, \max_{1\le i\le n}\sum_{i=1}^{n} z_{ij}\right\}. \tag{15}$$

- Step 3 "Calculate the total influence matrix T": The total influence matrix $T = [t_{ij}]_{nxn}$ is achieved using the Equation (16). Here, I represents the identity matrix.

$$T = X + X^2 + X^3 + \dots = \sum_{i=1}^{\infty} X^i = X(I - X)^{-1}. \tag{16}$$

- Step 4 "Identify the receivers and dispatchers": D_i (refer to Equation (17)) is the total of ith row of matrix T. D_i then represents the sum of direct or indirect influence dispatched from criterion/subcriterion i to the rest of decision elements. On the other hand, R_j (refer to Equation (18)), defined as the sum of jth column of matrix T, denotes the total influence that a particular decision element j receives from the others. Using *relation* values $D - R$, criteria and subcriteria can be classified into *dispatchers* and *receivers*. In particular, a decision element is categorized as a *dispatcher* if $D - R > 0$. In contrast, when $D - R < 0$, the criterion or subcriterion is considered as a *receiver*. In addition to the *relation* parameter, DEMATEL also evaluates the degree of the central role that a particular decision element exerts on the goal. This is done using the *prominence* measures $D + R$, which compiles the dispatching and receiving the influence of a specific criterion. By identifying the *receivers* and *dispatchers*, supply chain managers can better establish the main focus of improvement strategies, which, in the meantime, optimizes the investment costs.

$$D = \sum_{i=1}^{n} t_{ij}, \tag{17}$$

$$R = \sum_{j=1}^{n} t_{ij}. \tag{18}$$

- Step 5 "Establish the threshold value and obtain the influence relation map (IRM)": Calculate the threshold value θ using Equation (19). Such value helps to discard the minor effects in the decision-making model. In particular, if $t_{ij} < \theta$, the influence is considered as nonsignificant. Otherwise, the effect is substantial and must be graphed in the IRM.

$$\theta = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} t_{ij}}{n^2}, \tag{19}$$

3.4 | The AHP-DEMATEL approach

A hybrid AHP-DEMATEL technique is suggested to calculate the relative weights of criteria and subcriteria considering influence (Ortiz-Barrios et al., 2017; Zavadskas, Antucheviciene, Turskis, & Adeli, 2016). This is done by implementing Equations (20)–(22) where LW_i^{c*}, FW^{c*}, and GW_i^* denote respectively the local weight, criterion global weight, and subcriterion global weight with basis on interdependence. The use of this approach lies in the fact that AHP is not suitable for assessing interrelations and feedback in a decision-making model (Ishizaka & Labib, 2009). In addition, by combining AHP and DEMATEL methods, the logistics managers can perform short-term and long-term interventions that mitigate the bullwhip effect along the supply chain. Such an approach can also assist in the development of improvement programmes for each supplier so that logistics costs can be minimized and inventory service level can be increased.

$$LW_i^{c*} = \begin{bmatrix} 0 & x_{12} & \dots & x_{1n} \\ x_{21} & 0 & \dots & x_{2n} \\ \dots & \dots & \dots & \dots \\ x_{n1} & x_{n2} & \dots & 0 \end{bmatrix} * \begin{bmatrix} LW_1^c \\ LW_2^c \\ \dots \\ LW_n^{c*} \end{bmatrix}, \tag{20}$$

$$FW^{c*} = \begin{bmatrix} 0 & x_{12} & \dots & x_{1n} \\ x_{21} & 0 & \dots & x_{2n} \\ \dots & \dots & \dots & \dots \\ x_{n1} & x_{n2} & \dots & 0 \end{bmatrix} * \begin{bmatrix} FW^1 \\ FW^2 \\ \dots \\ FW^n \end{bmatrix}, \tag{21}$$

$$GW_i^* = LW_i^{c*} * FW^{c*}. \tag{22}$$

3.5 | TOPSIS

TOPSIS is an MCDM ranking technique that chooses, from a finite set of options, the alternative with the shortest distance from the ideal solution and the farthest distance from the negative ideal solution (Chai, Liu, & Ngai, 2013; Park, Park, Kwun, & Tan, 2011). The positive ideal solution is composed of all the best criterion/subcriterion values (A^+); in contrast, the negative scenario represents the worst attribute values (A^-). TOPSIS then calculate a closeness coefficient for each alternative so that the best alternative can be identified quickly (Olson, 2004). This method originally works based on criteria/subcriteria weights subjectively provided by decision makers; however, in this study, they are derived from the AHP-DEMATEL approach. The TOPSIS procedure is expressed as follows:

- Step 1: Establish an initial decision matrix X with "Sp" pork suppliers and "n" subcriteria (refer to Equation (23)). Here, x_{ij} denotes the value of the subcriterion SF_j (j = 1,2,3,…,n) in each supplier Sp_i(i = 1,2,…,p). To do this, a performance indicator needs to be defined for each subcriterion and then gathered for each supplier.

$$X = \begin{array}{c} \\ Sp_1 \\ Sp_2 \\ Sp_3 \\ \vdots \\ Sp_p \end{array} \begin{array}{c} \begin{array}{cccc} SF_1 & SF_2 & \cdots & SF_n \end{array} \\ \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ x_{31} & x_{32} & \cdots & x_{3n} \\ \vdots & \vdots & \ddots & \vdots \\ x_{y1} & x_{y2} & \cdots & x_{yn} \end{bmatrix} \end{array}. \tag{23}$$

- Step 2: Standardize matrix X by converting x_{ij} into normalized measures s_{ij} (refer to Equation (24)). Let n_{ij} be the norm used by TOPSIS (refer to Equation (25)).

$$S = X \cdot n_{ij}, \tag{24}$$

$$n_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{y} x_{ij}^2}}. \tag{25}$$

- Step 3: Calculate the weighted normalized decision matrix V (refer to Equation (26)). The set of importance weights is provided by the AHP-DEMATEL approach.

$$V = \left[w_j s_{ij}\right] = \left[v_{ij}\right], \tag{26}$$

- Step 4: Identify the positive (A^+) and reverse (A^-) extreme performance of each criterion/subcriterion using Equations (27)–(28) correspondingly:

$$A^+ = \left\{\left(\max_i s_{ij} \mid j \in J\right), \left(\min_i s_{ij} \mid j \in J'\right) for\ i = 1,2,\ldots,p\right\} = \left\{s_1^+, s, \ldots, s, \ldots, s\right\}, \tag{27}$$

$$A^- = \left\{\left(\min_i s_{ij} \mid j \in J\right), \left(\max_i s_{ij} \mid j \in J'\right) for\ i = 1,2,\ldots,p\right\} = \left\{s_1^-, s, \ldots, s_j^-, \ldots, s_n^-\right\}, \tag{28}$$

where

$J = \{j = 1,2,\ldots,n \mid j$ associated with the benefit subcriteria/criteria$\}$,

$J' = \{j = 1,2,\ldots,n \mid j$ associated with the cost subcriteria/criteria$\}$.

- Step 5: Set the distance measures of each supplier to A^+ and A^- using the Euclidean distance as outlined in Equations (29)–(30).

Distance to (A^+)

$$s_i^+ = \sqrt{\sum_{j=1}^{n}\left(s_{ij} - s_j^+\right)^2} \quad i = 1,2,\ldots,p. \tag{29}$$

Distance to (A^-)

$$s_i^- = \sqrt{\sum_{j=1}^{n}\left(s_{ij} - s_j^-\right)^2} \quad i = 1,2,\ldots,p. \tag{30}$$

- Step 6: For each pork supplier, determine the closeness coefficient (R_i) applying Equation (31). If R_i = 1, the supplier performance is equal to A^+. Therefore, high R_i values indicate satisfactory supplier's behaviour.

$$R_i = \frac{s_i^+}{\left(s_i^+ + s_i^-\right)}, \quad 0 < R_i < 1, \quad i = 1,2,\ldots,p. \tag{31}$$

- Step 7: Rank the pork suppliers by considering R_i values obtained in Step 6.

4 | THE SCENARIO UNDER STUDY: A FOOD SUPPLY CHAIN

The motivation of this study lies in the need for reducing the bullwhip effect along a pork supply chain located in Colombia (refer to Figure 2). The members of the supply structure (i.e., pork suppliers, distributors, and restaurants) have been involved in the pork industry for more than 10 years and have recently enrolled in a continuous improvement programme whose primary aim is to optimize the collaboration flows among suppliers, distributors, and restaurants. In particular, it has been established that pork providers contribute significantly to this problem. Their poor performance has caused economic losses estimated at US$11.753 per year. In addition, substantial delays in the delivery of pork products have been reported across the supply chain structure. This is even more critical considering the perishable nature and short life cycle of these products. Being aware of the importance of these aspects, a supplier assessment model has then proposed for identifying and addressing inefficiencies of pork providers so that variation of several key logistics parameters can be meaningfully lessened for upstream members.

5 | DEPLOYMENT OF THE SUPPLIER ASSESSMENT FRAMEWORK FOR SUPPORTING THE BULLWHIP EFFECT MANAGEMENT IN THE FOOD INDUSTRY

5.1 | Establishing a decision-making team

As noted above, suppliers play a relevant role to reduce the bullwhip effect along the pork supply chain. Supplier assessment models are then highly required by logistics managers to detect low-performance suppliers and develop continuous improvement programmes. Such considerations were discussed with the stakeholders involved in this problem with the goal of obtaining feedback and formal approval before the intervention. Such intervention was led by two academicians who are coauthors of this paper. The decision-making team was comprised of representatives from four departments: Production and Supplies, General Management, Administration, and General Directorate. A summary of the representatives' profile is presented below:

- Two managers (Head of General Management Department and Head of Production and Supplies Department) with more than 5 years of experience in the pork industry.
- Two academicians from industrial engineering departments with wide expertise and experience (approximately 10 years) in MCDM methods, supply chain management, and supplier assessment models. In addition, they have been involved in several logistics projects that have been implemented within diverse sectors of the industry (including the food sector).
- One assistant (administrative assistant) with extensive knowledge in logistics and experience (>3 years) in the pork supply chain.
- One shareholder with great expertise and knowledge in financial management and commercial transactions between pork suppliers and restaurants.

Specifically, the academicians drafted the supplier assessment model for supporting the bullwhip effect management in the food sector. They also trained experts on how to make the pairwise comparisons required in AHP and DEMATEL techniques. Moreover, they designed the set of performance indicators used in TOPSIS implementation. The shareholder and managers were included in the decision-making team because they can provide a panoramic view of the pork supply chain and its particularities as well as identify the critical needs that must be satisfied by pork suppliers to minimize the bullwhip effect throughout the supply chain. Ultimately, the administrative assistant was asked to participate in this process given her experience and permanent contact with pork suppliers during several periods.

5.2 | Setting up the decision-making hierarchy

The supplier assessment model was first discussed with the decision-making team during two sessions in order to determine whether it was pertinent and easy to understand. Related studies from the reported literature were also used to support this process. The resulting scheme included seven criteria, 18 subcriteria, and four pork suppliers (refer to Figure 3). A description of each criterion can be found in Table 2.

The description of each subcriterion is shown below:

- ISO 9001 certificate (S1): This subcriterion establishes whether the pork supplier is certified in ISO 9001 standards.

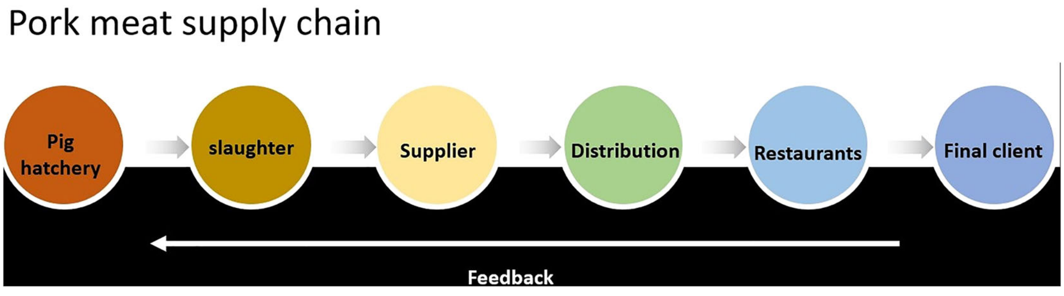


FIGURE 2 Pork meat supply chain structure

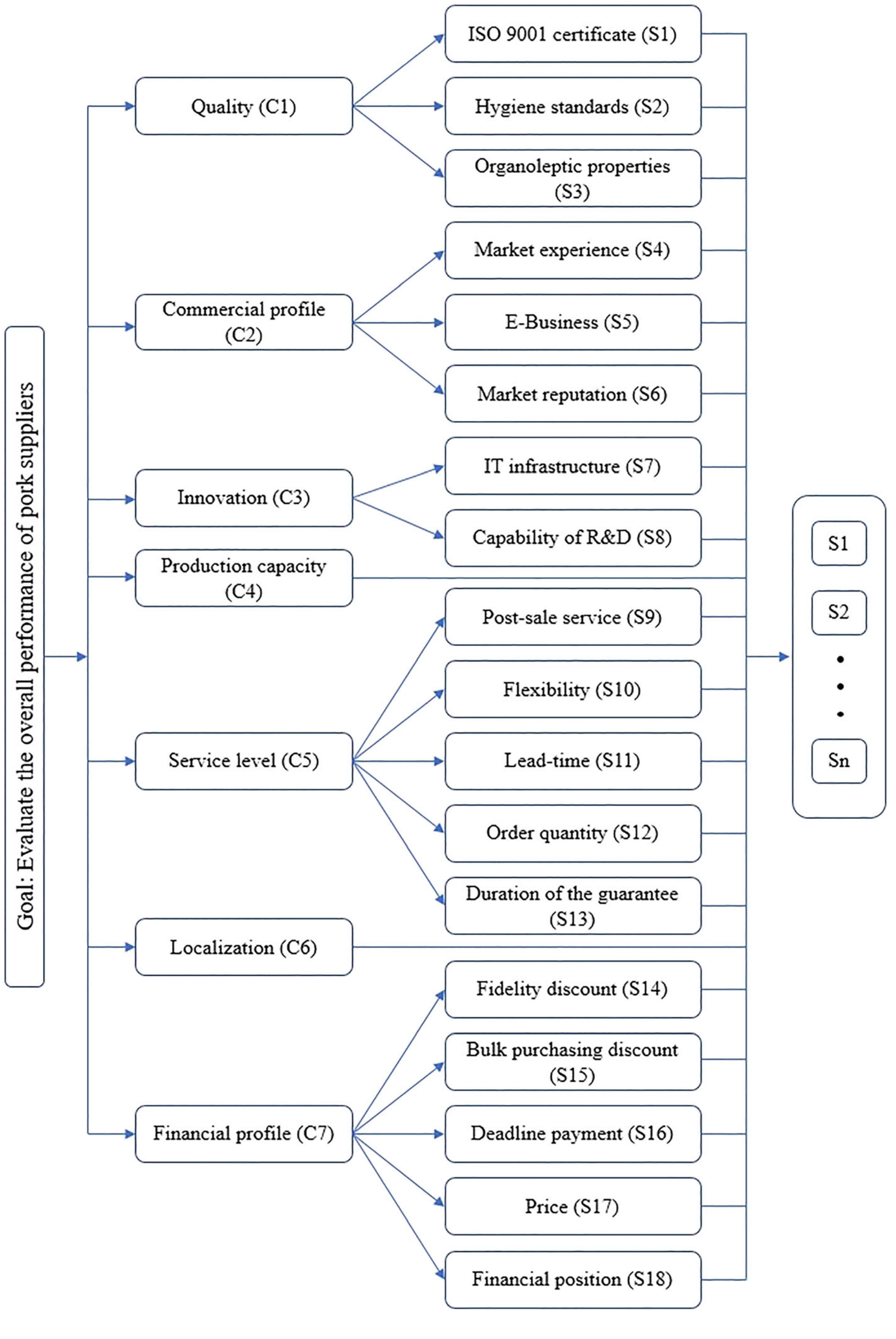


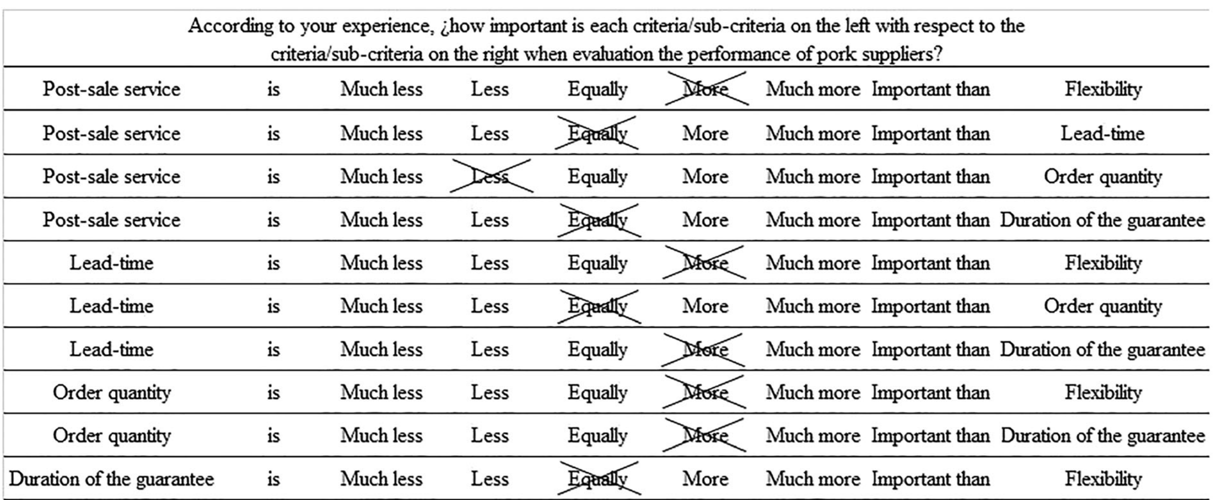
FIGURE 3 MCDM model to evaluate the overall performance of pork suppliers

- Hygiene standards (S2): It is defined as the set of rigid sanitary standards that must be fulfilled for ensuring and controlling the quality of pork meat.
- Organoleptic properties (S3): This aspect evaluates the physical and chemical characteristics that must be guaranteed to protect consumer health.
- Market experience (S4): This element assesses the maturity and trajectory of a pork supplier as an indicator of reliability and market positioning.
- E-business (S5): It verifies the availability of a business platform that facilitates the information sharing between pork suppliers and restaurants as well as better resource planning, scheduling, and inventory management. Therefore, S5 can be concluded as a supplier performance element supporting the bullwhip effect management.
- Market reputation (S6): The inclusion of this decision element is motivated by the need for partnering with reliable pork suppliers that lessen the uncertainty across the supply chain structure.
- IT infrastructure (S7): This subcriterion examines whether the pork supplier has a decision support system that underpins the logistics operations and collaboration flows with the restaurants. S7 is then another subcriterion underpinning the reduction of the bullwhip phenomenon.

- Capability of R&D (S8): It verifies whether the pork supplier has an R&D department that supports the incorporation of product and process innovations.
- Postsale service (S9): It measures the average time interval between the service request and postsale response provided by the pork supplier.

TABLE 2 Description of criteria

Criterion	Subcriteria	Criterion description
Quality (C1)	ISO 9001 certificate (S1) Hygiene standards (S2) Organoleptic properties (S3)	This criterion evaluates the organoleptic characteristics of the pork provided by suppliers as well as the technical and sanitary conditions that should be ensured in their production systems for preventing the introduction and spread of infectious agents. The presence of low-quality pork products may be caused by the presence of the bullwhip effect along the supply chain (Lindgreen & Hingley, 2003)
Commercial profile (C2)	Market experience (S4) E-Business (S5) Market reputation (S6)	This aspect assesses the commercial performance of suppliers as well as the conditions for requesting pork products. In this regard, if the partner is low experienced, not well reputed, and incapable of developing E-business, information disruption may appear within the pork supply chain.
Innovation (C3)	IT infrastructure (S7) Capability of R&D (S8)	This domain considers the supplier's ability to create and deploy new technological platforms and information systems that facilitate the collaboration between the suppliers and each component of the poultry supply chain (Emre, Genç, Kurt, & Akay, 2009)
Production capacity (C4)	Without subcriteria	It considers the maximum production volume (measured in kg of pork) that a particular supplier can offer to satisfy the restaurants' needs as well as their flexibility to adapt promptly to demand changes (Korpela, Kyläheiko, Lehmusvaara, & Tuominen, 2002)
Service level (C5)	Postsale service (S9) Flexibility (S10) Lead-time (S11) Order quantity (S12) Duration of the guarantee (S13)	This criterion examines the supplier's ability to deliver the right pork products, in the right quantity, to the right restaurant for the right price at the right time. In addition, it takes into account how its postsale service is deployed along the supply chain. Both considerations have a strong effect on the bullwhip effect management and should be therefore continuously controlled (Yücel & Güneri, 2011)
Localization (C6)	Without subcriteria	It measures the average distance between a specific pork supplier and a set of restaurants. Long distances combined with heavy traffic may cause high transportation costs, delayed product delivery, and the resulting increased bullwhip effect (Huang & Keskar, 2007)
Financial profile (C7)	Fidelity discount (S14) Bulk purchasing discount (S15) Payment deadline (S16) Price (S17) Financial position (S18)	This dimension analyses the financial stability and liquidity of pork suppliers as well as the payment conditions regulating the commercial transactions with the restaurants. This is critical to avoid shortages of pork and the resulting customer dissatisfaction and lost sales in restaurants.



According to your experience, ¿how important is each criteria/sub-criteria on the left with respect to the criteria/sub-criteria on the right when evaluation the performance of pork suppliers?

Post-sale service	is	Much less	Less	Equally	~~More~~	Much more	Important than	Flexibility
Post-sale service	is	Much less	Less	~~Equally~~	More	Much more	Important than	Lead-time
Post-sale service	is	Much less	~~Less~~	Equally	More	Much more	Important than	Order quantity
Post-sale service	is	Much less	Less	~~Equally~~	More	Much more	Important than	Duration of the guarantee
Lead-time	is	Much less	Less	Equally	~~More~~	Much more	Important than	Flexibility
Lead-time	is	Much less	Less	~~Equally~~	More	Much more	Important than	Order quantity
Lead-time	is	Much less	Less	Equally	~~More~~	Much more	Important than	Duration of the guarantee
Order quantity	is	Much less	Less	Equally	~~More~~	Much more	Important than	Flexibility
Order quantity	is	Much less	Less	Equally	~~More~~	Much more	Important than	Duration of the guarantee
Duration of the guarantee	is	Much less	Less	~~Equally~~	More	Much more	Important than	Flexibility

FIGURE 4 Survey layout for AHP (service level cluster)

TABLE 3 Analytic hierarchy process comparison matrix for "service level" cluster

	S9	S10	S11	S12	S13
S9	1	1.73	1	0.76	0.76
S10	0.58	1	1.32	0.51	0.45
S11	1	0.76	1	1	0.88
S12	1.32	1.97	1	1	1.32
S13	1.32	2.24	1.14	0.76	1

- Production capacity (C4): This subfactor considers the maximum amount of pork (measured in kg) that can be supplied in a month. Due to its influence on order batching, this criterion is also considered for the bullwhip effect management along the food supply chain.
- Flexibility (S10): It determines the number of pork products that can be offered by the supplier.
- Lead time (S11): It measures the average time period between the order request (emanating from a specific restaurant) and delivery. This is another aspect to be considered due to its influence on inventory management along the pork supply chain.
- Order quantity (S12): It is the minimum pork quantity per order that can be provided by the supplier considering the production and logistics costs to be covered for its delivery. Since its close relation to order batching, S12 can be also deemed as a contributing driver to the distribution channel phenomena.
- Duration of the guarantee (S13): The addition of this subcriterion is motivated by the fact that the restaurants are interested in partners providing long warranty periods and giving the choice of extension if required.
- Localization (C6): It estimates the average distance (measured in km) between the pork supplier and the restaurants. This criterion also affects the inventory management and may create distortions in the ordering behaviour.
- Fidelity discount (S14): It is defined as the pricing structure offered by a specific pork supplier in return for a restaurant's agreed or an increasing share of requirements (Hewitt, 2003).
- Bulk purchasing discount (S15): It is the financial incentive granted by the supplier to encourage restaurants to buy pork products in larger amounts. Considering that bulk purchasing discounts add variability to order quantities and consequently generate uncertainty to demand forecasts, logistics managers should continuously examine the special offers sent by the pork suppliers.
- Payment deadline (S16): It is the period indicated by the pork supplier to make the payment related to the orders delivered to the restaurants.
- Price (S17): This subfactor considers the average unit price established by the supplier per each kilogram of pork. Given that price fluctuations are one of the bullwhip effect causes, continuous monitoring is required for diminishing the false supplies and demand variations.
- Financial position (S18): This is a top subcriterion assessing the past financial performance of pork suppliers with the goal of

TABLE 4 LW and GW values for criteria and subcriteria (analytic hierarchy process method)

Cluster	GW	LW
Quality (C1)	0.265	
ISO 9001 certificate (S1)	0.073	0.275
Hygiene standards (S2)	0.096	0.362
Organoleptic properties (S3)	0.096	0.362
Commercial profile (C2)	0.155	
Market experience (S4)	0.059	0.382
E-Business (S5)	0.021	0.136
Market reputation (S6)	0.075	0.482
Innovation (C3)	0.091	
IT infrastructure (S7)	0.063	0.695
Capability of R&D (S8)	0.028	0.305
Production capacity (C4)	0.097	
Service level (C5)	0.188	
Post-sale service (S9)	0.036	0.192
Flexibility (S10)	0.027	0.142
Lead-time (S11)	0.035	0.184
Order quantity (S12)	0.047	0.248
Duration of the guarantee (S13)	0.044	0.233
Localization (C6)	0.062	
Financial profile (C7)	0.142	
Fidelity discount (S14)	0.021	0.151
Bulk purchasing discount (S15)	0.021	0.148
Payment deadline (S16)	0.045	0.316
Price (S17)	0.025	0.174
Financial position (S18)	0.030	0.211

TABLE 5 Consistency values for analytic hierarchy process matrices

Cluster	CR
Criteria	5.40%
Quality	0.00%
Commercial profile	0.16%
Innovation	0.00%
Service level	2.79%
Financial profile	3.02%

establishing their likelihood to continue or stop business operations. It is then an indicator that allows predicting the risk of stock-outs across the supply chain.

5.3 | Applying AHP to calculate the initial criteria and subcriteria weights

A survey format (refer to Figure 4) was designed to gather the pairwise comparisons provided by the decision-making team. In this regard, each expert was asked to respond the following question: According to your experience, how important is each criterion/subcriterion on the left with respect to the criterion/subcriteria on the right when assessing the performance of pork suppliers? The simplicity of this instrument avoids potential confusion and inconsistencies that may affect the reliability of the decision (Pecchia et al., 2013).

AHP application was underpinned using Superdecisions® software. An illustration of a paired comparison matrix is depicted in Table 3. Such matrix aggregated the comparisons made using Equations (1)–(6). After this, the criteria and subcriteria (both global and local) weights were established by applying Equations (7)–(9) (refer to Table 4). Finally, to evaluate the reliability of such

ISO 9001 certificate	has	No influence	Low influence	Medium influence	High influence	Very high influence	on	Hygiene standards
ISO 9001 certificate	has	No influence	Low influence	Medium influence	High influence	Very high influence	on	Organoleptic properties
Hygiene standards	has	No influence	Low influence	Medium influence	High influence	Very high influence	on	Organoleptic properties
Hygiene standards	has	No influence	Low influence	Medium influence	High influence	Very high influence	on	ISO 9001 certificate
Organoleptic properties	has	No influence	Low influence	Medium influence	High influence	Very high influence	on	ISO 9001 certificate
Organoleptic properties	has	No influence	Low influence	Medium influence	High influence	Very high influence	on	Hygiene standards

FIGURE 5 The data-gathering instrument used in DEMATEL

TABLE 6 Group-direct influence matrix for "service level" cluster

	S9	S10	S11	S12	S13
S9	0	2.50	2.00	2.00	1.75
S10	2.25	0	2.25	1.25	1.00
S11	2.75	2.75	0	2.00	1.75
S12	2.50	2.50	2.25	0	2.25
S13	2.25	2.00	1.50	1.50	0

TABLE 7 Normalized matrix *X* for "service level" cluster

	S9	S10	S11	S12	S13
S9	0.000	0.256	0.205	0.205	0.179
S10	0.231	0.000	0.231	0.128	0.103
S11	0.282	0.282	0.000	0.205	0.179
S12	0.256	0.256	0.231	0.000	0.231
S13	0.231	0.205	0.154	0.154	0.000

TABLE 8 Total influence matrix *T* for "service level" cluster

	S9	S10	S11	S12	S13
S9	1.03	1.24	1.05	0.93	0.89
S10	1.07	0.89	0.94	0.77	0.73
S11	1.35	1.36	0.97	1.00	0.97
S12	1.36	1.37	1.18	0.85	1.02
S13	1.10	1.09	0.92	0.81	0.66

weights, the consistency ratios were computed by implementing Equations (10)–(11) (refer to Table 5). In this case, given that all CR values are less than 0.1, the matrixes were concluded to be consistent and the resulting priorities can be therefore considered reliable. The low CR obtained in this process evidences that the adoption of a shorter evaluation scale and the use of a simple data-collection form reduce the inconsistencies and facilitate expert engagement in the decision-making process.

5.4 | Using DEMATEL to check the interrelations between criteria/subcriteria

Similar to AHP, a practical data-collection instrument (refer to Figure 5) was designed in an effort to efficiently introduce DEMATEL to the decision makers who are unskilled in this approach. In particular, it was asked: Considering your expertise in the pork supply chain, how much influence each aspect on the left exerts over the aspect on the right? The experts responded in accordance with the DEMATEL scale provided in Section 3.3. The comparison process was iterated until completing all the required judgments.

The resulting comparisons were aggregated and then arranged in the group-direct influence matrix Z using Equations (12)–(13). An example of this matrix (service level cluster) is depicted in Table 6. Later, Z was normalized (refer to Table 7) by applying Equations (14)–(15). Finally, the total influence matrix T (refer to Table 8) is achieved by implementing Equation (16). In this case, Excel spreadsheets were used to support the DEMATEL implementation.

Table 9 presents the prominence ($D + R$) and relation ($D - R$) values of each criterion and subcriterion. In addition, it details the dispatchers and receivers that have been identified in the supplier assessment model. Based on the $D + R$ values, it can be concluded that there is a very strong correlation in some clusters (i.e., the subcriteria into "quality," "innovation," service level clusters). In contrast, although some interrelations were detected among criteria, their strength is not as significant as those recognized in the aforementioned groups of subcriteria. The highest average $D + R$ measure (11,666) was found in quality cluster. This indicates that there is a good chance that "hygiene standards" and "organoleptic properties" would cause ISO 9001 certificate. The same $D + R$ value was also detected in innovation cluster where there is a high probability that "IT infrastructure" would cause "capability of R&D."

IRMs were drawn to deeply analyse the feedback and interrelations within the supplier assessment model (refer to Figures 6–8). In this sense, IRMs are relevant to design focused interventions and

TABLE 9 Relation ($D - R$) and prominence ($D + R$) values of criteria and subcriteria

Criteria/subcriteria	Prominence ($D + R$)	Relation ($D - R$)	Dispatcher	Receiver
Quality (C1)	3.7890	1.2265	X	
ISO 9001 certificate (S1)	11.7500	−1.2500		X
Hygiene standards (S2)	11.2778	0.2778	X	
Organoleptic properties (S3)	11.9722	0.9722	X	
Commercial profile (C2)	3.3702	0.5684	X	
Market experience (S4)	2.0482	0.6056	X	
E-Business (S5)	2.1796	−1.2931		X
Market reputation (S6)	2.1881	0.6875	X	
Innovation (C3)	3.1298	−0.9043		X
IT infrastructure (S7)	11.6667	1.0000	X	
Capability of R&D (S8)	11.6667	−1.0000		X
Production capacity (C4)	3.8233	−0.4925		X
Service level (C5)	3.7713	0.9917	X	
Post-sale service (S9)	11.0476	−0.7649		X
Flexibility (S10)	10.3344	−1.5459		X
Lead-time (S11)	10.7160	0.5802	X	
Order quantity (S12)	10.1452	1.4189	X	
Duration of the guarantee (S13)	8.8681	0.3118	X	
Localization (C6)	3.3114	−1.9068		X
Financial profile (C7)	3.8564	0.5170	X	
Fidelity discount (S14)	5.8788	−1.1078		X
Bulk purchasing discount (S15)	5.4593	−1.0614		X
Payment deadline (S16)	5.9722	1.4010	X	
Price (S17)	6.0952	−0.0636		X
Financial position (S18)	6.0152	0.8318	X	

improvement plans that help to reduce the bullwhip problem throughout the pork supply chain. First, the IRM for quality is presented in Figure 6a. The threshold value was set as $\theta = \frac{17,50}{3^2} = 1.94$. It can be noted that hygiene standards (S2) and organoleptic properties (S3) are the dispatchers, whereas ISO 9001 certificate (S1) is the receiver. In accordance with the graph, it can be also viewed that organoleptic properties (S3) also influences hygiene standards (S2). Therefore, this element should be highly taken into account as the centre of improvement plans designed for each supplier regarding quality dimension. Finally, no feedback relations were observed in this cluster.

The IRM for commercial profile is shown in Figure 6b. In this case, the threshold was accepted as $\theta = \frac{3,21}{3^2} = 0.36$. In addition, it can be seen that market experience (S4) and market reputation (S6) are the dispatchers, whereas E-business (S5) is the receiver. Furthermore, a feedback relation was detected between S4 and S6. Thus, supply chain managers should thoroughly examine these aspects in each pork supplier so that the bullwhip problem can be reduced. Low experienced and not well-reputed providers aggregate inconsistencies and uncertainty to communication flows with the restaurants.

An impact diagram was also mapped for innovation domain (refer to Figure 7a). For this cluster, the assigned threshold value was $\theta = \frac{11,67}{2^2} = 0.36$. With this in mind, it was established that IT infrastructure (S7) is the dispatcher and Capability of R&D (S8) is the receiver. No feedback relation was observed between these subcriteria. Hence, pork suppliers should invest in the development of technological infrastructure that guarantees a smooth flow of information across the supply chain. In this regard, it is necessary to interconnect the isolated databases that exist in both pork suppliers and restaurants through an electronic data interchange. Thereby, optimal whip-saw effect management can be ensured and faster responses can be consequently expected.

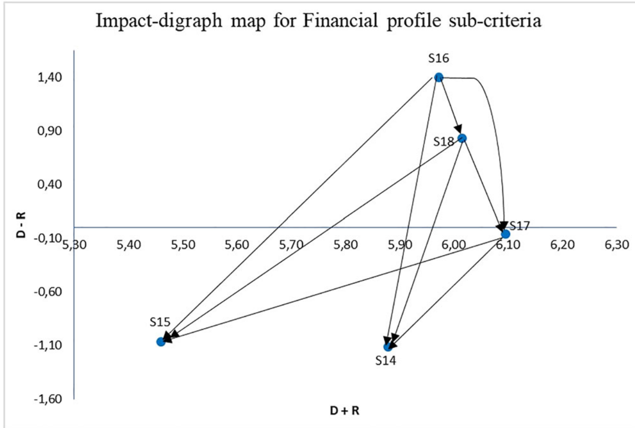


FIGURE 8 Impact-digraph map for financial profile cluster

Similarly, the interrelations and feedback among service level subcriteria were graphed in Figure 7b. For this case, the threshold value was set as $\theta = \frac{25,56}{5^2} = 1.02$. Based on this finding, it can be concluded that lead time (S11), order quantity (S12), and duration of the

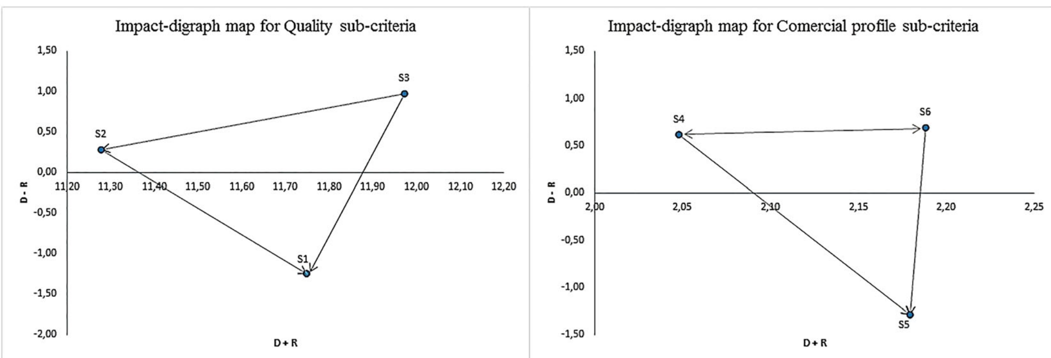


FIGURE 6 Impact-digraph map for (a) quality and (b) commercial profile clusters

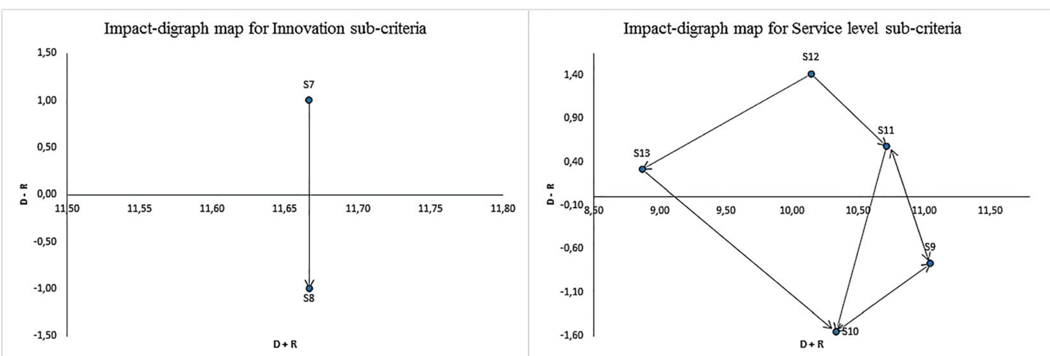


FIGURE 7 Impact-digraph map for (a) Innovation and (b) Service level clusters

TABLE 10 The LW_i^{c*}, FW^{c*}, and GW_i^* values of criteria and subcriteria (analytic hierarchy process–Decision Making Trial and Evaluation Laboratory method)

Cluster	Global weight	Local weight
Quality (C1)	0.186	
ISO 9001 certificate (S1)	0.059	0.315
Hygiene standards (S2)	0.059	0.317
Organoleptic properties (S3)	0.069	0.368
Commercial profile (C2)	0.156	
Market experience (S4)	0.065	0.418
E-Business (S5)	0.028	0.180
Market reputation (S6)	0.063	0.403
Innovation (C3)	0.087	
IT infrastructure (S7)	0.033	0.376
Capability of R&D (S8)	0.054	0.624
Production capacity (C4)	0.141	
Service level (C5)	0.194	
Post-sale service (S9)	0.040	0.204
Flexibility (S10)	0.034	0.174
Lead-time (S11)	0.044	0.228
Order quantity (S12)	0.043	0.222
Duration of the guarantee (S13)	0.033	0.171
Localization (C6)	0.056	
Financial profile (C7)	0.180	
Fidelity discount (S14)	0.030	0.165
Bulk purchasing discount (S15)	0.027	0.153
Payment deadline (S16)	0.041	0.231
Price (S17)	0.039	0.216
Financial position (S18)	0.042	0.236

guarantee (S13) are causal elements, whereas postsale service (S9) and flexibility (S10) are receivers. Moreover, two feedback relations can be observed in this graph: S9–S10 and S9–S11. Consequently, supply chain managers should establish interventions including the causal elements to counteract the distortion transmitted up to the chain. This is consistent with the fact that order batching and high variability of lead times have been found in several studies to contribute mostly to this problem (Keshari, Mishra, Shukla, McGuire, & Khorana, 2018; Nagaraja & McElroy, 2018; Shaban & Shalaby, 2018).

Finally, an IRM was undertaken for mapping the interrelations within the financial profile criterion (refer to Figure 8). The adopted threshold for this cluster was $\theta = \frac{14,71}{5^2} = 0.59$. It can be noted that payment deadline (S16) and financial position (S18) are the influencing subcriteria, whereas fidelity discount (S14), bulk purchasing discount (S15), and price (S17) were categorized as receivers. Furthermore, no feedback relations were detected in this domain. In an expansive view of these results, pork suppliers are required to sustain superior financial performance in order to avoid disturbances across the pork supply chain. If this is not granted, an inventory-driven bullwhip effect and cash flow fluctuations may occur with the ensuing shock upstream.

5.5 | Integrating AHP and DEMATEL to calculate the final criteria and subcriteria weights

The LW_i^{c*}, FW^{c*}, and GW_i^* values emanating from the AHP-DEMATEL approach are shown in Table 10. The criterion global weights are graphed in Figure 9. In accordance with the results, quality was the aspect with major relevance (FW^{1*} = 26.5%) when assessing the performance of pork suppliers. However, the difference between quality (first place) and service level (second place) is not substantial (7.7%). This is complementary to the presence of strong interrelations detected in these clusters (see Section 5.4). In this regard, logistics managers should incorporate these elements into the improvement

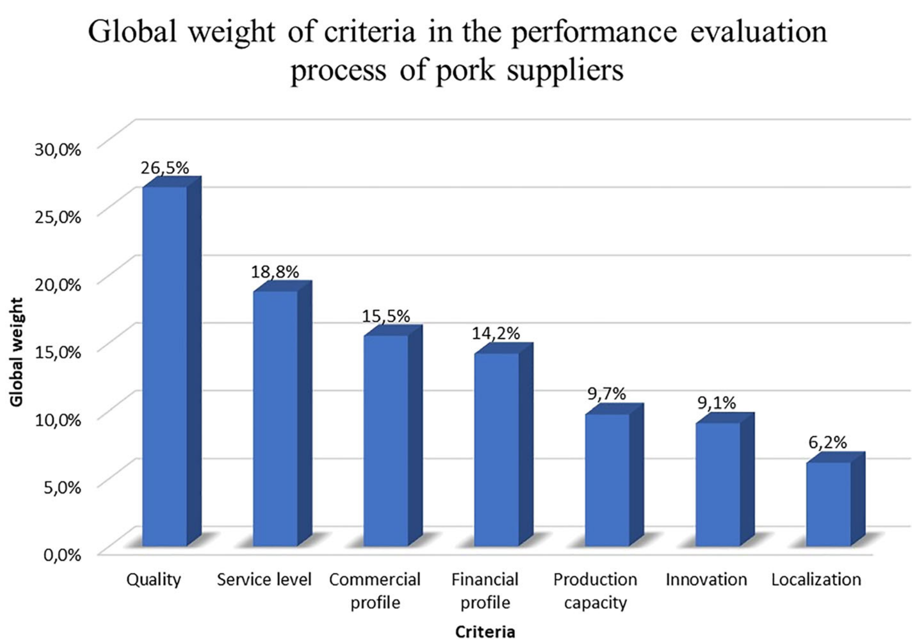


FIGURE 9 Global criterion weights when evaluating the overall performance of pork suppliers

programmes counteracting the whip-saw problem along the pork supply chain. For instance, it is suggested to implement just-time replenishment programmes that mitigate the effect of order batching in the bullwhip phenomenon. It is also recommended to integrate the lean six sigma approach into the quality control systems of each supplier so that the returns resulting from the poor quality of pork can be minimized.

In the quality cluster (refer to Figure 10a), the most important subcriterion was organoleptic properties (36.8%). However, the global importance of quality domain is widely dispersed within its three elements (refer to Figure 10a). It is then recommended to design initiatives considering these aspects simultaneously. Perishable products, like those emanating from the pork industry, are exposed to deterioration over time if the production environment is not properly controlled in each node. Therefore, the pork supply chain should be both responsive in the earlier stages and efficient in the later stages to address this problem (Blackburn & Scudder, 2009). In this sense, the adoption of ISO 9001 standards may serve as a mean to ensure that procedures and protocols for perishable product management are suitably implemented upstream.

In the commercial profile domain (refer to Figure 10b), the most relevant aspect was market experience (41.8%). Additionally, a slight difference can be observed between this element and market reputation (1.5%). This indicates the importance of partnering with well-reputed and experienced pork suppliers. Such companies may facilitate a better alignment with the demand changes through coordinated inventory planning, transportation management, and information sharing. This is possible due to the operational maturity that some of these companies have reached based on the implementation of continuous

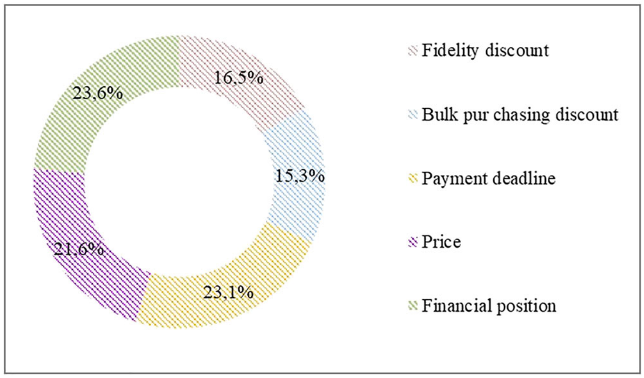


FIGURE 12 The local weights of subcriteria in financial profile cluster

improvement programmes. The result is a significant reduction of lead time variability and cost overruns across the supply structure.

In the Innovation cluster (refer to Figure 11a), Capability of R&D was concluded to be the most important aspect (62.4%). The pork suppliers with strong R&D processes lesser the time to respond to the uncertainty of market changes. Furthermore, R&D programmes help to smooth the volatility of lead times which results in the decrease of lost orders, excess capacity and obsolete inventory. Other important considerations are linked to the service level domain (refer to Figure 11b) where lead time was identified as the most critical subcriterion (22.8%). Nonetheless, the importance of this criterion is widely dispersed among its five decision elements. This is consistent with the low difference (D = 5.7%) found between lead time (first place) and duration of the guarantee (fifth place). Therefore, multicriteria strategies should be designed by decision makers to increase

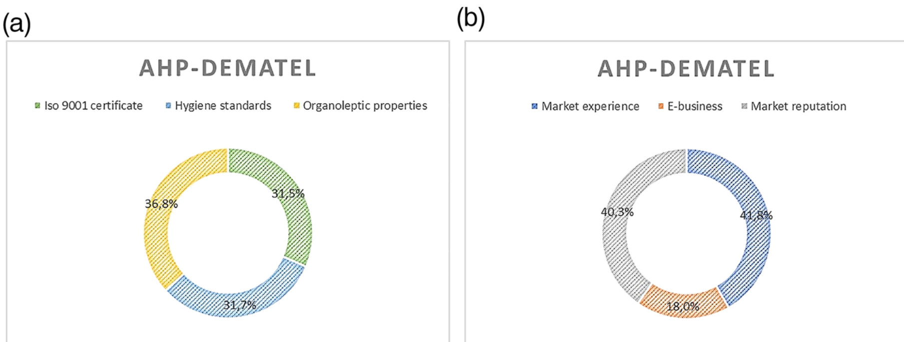


FIGURE 10 Local weights of subcriteria in (a) quality and (b) commercial profile

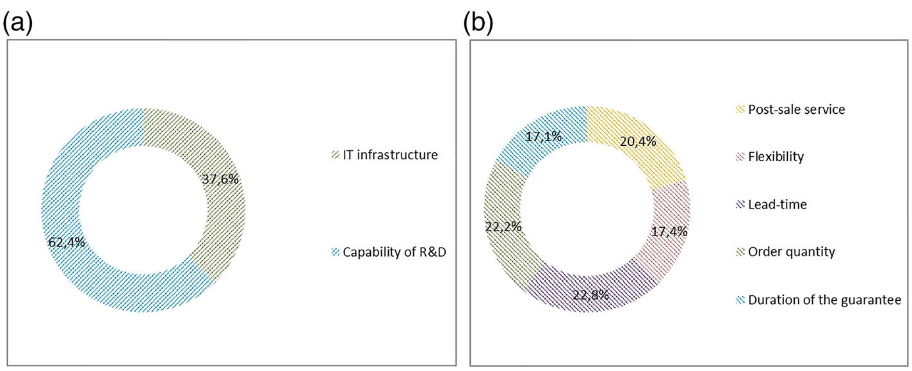


FIGURE 11 Local weights of subcriteria in (a) innovation and (b) service level clusters

TABLE 11 Technique for Order of Preference by Similarity to Ideal Solution key performance indicator (KPI) in the performance evaluation of pork suppliers

Subcriteria	KPI	Formula
ISO 9001 certificate (S1)	ISO 9001 certification	1 if certified, otherwise 0
Hygiene standards (S2)	BPM certification	1 if certified, otherwise 0
Organoleptic properties (S3)	Annuals complaints related to poor quality of pork	Number of complaints per year
Market experience (S4)	Market life	Number of years in the market
E-Business (S5)	Availability of business digital platform	1 if available, otherwise 0
Market reputation (S6)	Inclusion on sanction or settlement lists	1 if included, otherwise 0
IT infrastructure (S7)	Availability of IT infrastructure	1 if available, otherwise 0
Capability of R&D (S8)	Availability of R&D department	1 if available, otherwise 0
Production capacity *(C4)*	Monthly pork production capacity	Monthly capacity measured in Kg of pork
Post-sale service (S9)	Average time of post-sale service	$\bar{x}=\frac{\sum_{i=1}^{n}(Rd_i-Rt_i)}{n}$, where Rd_i = request date of service order *i* Rt_i = Response time of service order i *n* = number of service orders
Flexibility (S10)	Number of pork products that offers	Number of pork products offered by the potential supplier
Lead-time (S11)	Average lead-time	$\bar{x}=\frac{\sum_{i=1}^{n}(Rd_i-Dd_i)}{n}$, where *Rd* = request date of order *i* *Dd* = delivery date of order *i* *n* = number of orders
Order quantity (S12)	Minimum order quantity	Minimum amount of pork (in kg) per order required by the supplier
Duration of the guarantee (S13)	Duration of the guarantee	Number of hours of the guarantee
Localization (C6)	Distance	Distance (in km) between the supplier and the company
Fidelity discount (S14)	Fidelity discount	Fidelity discount (%) per order
Bulk purchasing discount (S15)	Bulk purchasing discount	Regular quantity discount (in % on the total purchase price) offered by the potential supplier
Payment deadline (S16)	Payment deadline	Time required (in days) between the delivery date and the payment date
Price (S17)	Price	Price per kg of pork
Financial position (S18)	Monthly net profit	$Np = Gp - Op - t$, where *Np* = net profit *Gp* = gross profit *Op* = operating profit *t* = taxes

the service level of pork suppliers with the goal of reducing the bullwhip effect along the supply chain. This is, of course, complementary to the initiatives generated in the aforementioned criteria.

In financial profile domain (refer to Figure 12), although the financial position was distinguished as the most relevant subcriterion (23.6%), two more elements should be also taken into account for mitigating the bullwhip problem: payment deadline (23.1%) and price (21.6%). In this regard, it is necessary to verify the financial stability of pork suppliers in order to avoid falling into noncompliance with the delivery of predefined orders. It is also required to establish the most beneficial pricing and payment conditions that will regulate the transactions between these suppliers and the restaurants. Pricing fluctuations may increase the bullwhip problem along the pork supply chain. For instance, when the price per kilogram of pork is low (i.e., promotions), the product demand tends to increase and the supply chain must stock up to address this variation. However, the restaurants should order optimally considering the perishable nature of pork products and the need for reducing damaged inventory. On the other hand, an optimum payment deadline should be established for the pork supply structure to avoid cash flow shortfalls and decrease the risk of insolvency associated, in some cases, with the bullwhip effect (Lee, Wu, & Tseng, 2018. Therefore, it is advisable to thoroughly examine the frequency of promotions offered to final customers as well as continuously monitoring the financial capability of each member in the supply chain.

5.6 | Using TOPSIS to evaluate the performance of pork suppliers

This subsection illustrates the application of the TOPSIS method to evaluate the performance of pork suppliers. Furthermore, the aspects with a major contribution to the total distance of each pork supplier can be fully recognized and analysed for supporting the development of improvement initiatives that address the bullwhip problem across the supply chain under study. To do this, a key performance indicator (KPI) was initially established for each subaspect in Table 11 (this was also done for production capacity and localization criteria because they have not been defined by subfactors within the supplier assessment model). The KPI values were then arranged in the initial decision matrix *X* (refer to Table 12), which relates the four pork suppliers (Sp_1, Sp_2,Sp_3,Sp_4) to the decision elements directly associated with the goal. The values of subcriteria were calculated considering the description depicted in Table 12. The positive (A^+) and reverse (A^-) extreme performance of each criterion/subcriterion were also estimated using Equations (27)–(28). The matrix *X* also includes the global weights provided by the AHP-DEMATEL approach.

The normalized decision matrix *S* is presented in Table 13 by implementing Equations (24)–(25). The weighted normalized decision matrix *V* (refer to Table 14) was derived using Equation (26). On the other hand, the distance of each pork supplier (Sp_1,Sp_2,Sp_3,Sp_4) from the positive ideal solution S_i^+ (refer to Table 15) and the negative ideal scenario S_i^- (refer to Table 16) were computed using Equations (29)

TABLE 12 Technique for Order of Preference by Similarity to Ideal Solution decision matrix *D* for assessing the performance of pork suppliers

	Sp 1	Sp 2	Sp 3	Sp 4	A^+	A^-	W	Norm
S1	1	1	1	1	1	1	0.059	2.00
S2	1	1	1	1	1	1	0.059	2.00
S3	0	0	0	0	0	0	0.069	0.00
S4	17	15	12	9	17	9	0.065	27.18
S5	1	0	1	1	1	0	0.028	1.73
S6	0	0	0	0	0	0	0.063	0.00
S7	1	1	1	1	1	1	0.033	2.00
S8	0	0	0	1	1	0	0.054	1.00
C4	4,500	3,400	5,100	7,800	7,800	3,400	0.141	10,893.12
S9	16.971	6	24	6	6	24	0.040	30.59
S10	5	4	4	5	5	4	0.034	9.06
S11	15	3	12	9.487	3	15	0.044	21.63
S12	500	330	400	350	330	500	0.043	800.87
S13	0	0	12	0	12	0	0.033	12.00
C6	2,300	91,700	14,200	5,300	2,300	91,700	0.056	92,972.63
S14	0.03	0.05	0.02	0.04	0.05	0.02	0.030	0.07
S15	0.08	0.1	0.09	0.07	0.1	0.07	0.027	0.17
S16	2	3	5	7	7	2	0.041	9.33
S17	9500	8500	8800	9500	8500	9500	0.039	18,171.13
S18	15,000,000	7,500,000	12,000,000	14,560,000	15,000,000	7,500,000	0.042	25,243,684.36

TABLE 13 Normalized decision matrix *S* for assessing the performance of pork suppliers

	Sp 1	Sp 2	Sp 3	Sp 4	A^+	A^-	W
S1	2.00	2.00	2.00	2.00	2.00	2.00	0.059
S2	2.00	2.00	2.00	2.00	2.00	2.00	0.059
S3	0.00	0.00	0.00	0.00	0.00	0.00	0.069
S4	462.14	407.77	326.21	244.66	462.14	244.66	0.065
S5	1.73	0.00	1.73	1.73	1.73	0.00	0.028
S6	0.00	0.00	0.00	0.00	0.00	0.00	0.063
S7	2.00	2.00	2.00	2.00	2.00	2.00	0.033
S8	0.00	0.00	0.00	1.00	1.00	0.00	0.054
C4	49,019,026.92	37,036,598.12	55,554,897.17	84,966,313.32	84,966,313.32	37,036,598.12	0.141
S9	519.22	183.57	734.26	183.57	183.57	734.26	0.040
S10	45.28	36.22	36.22	45.28	45.28	36.22	0.034
S11	324.50	64.90	259.60	205.24	64.90	324.50	0.044
S12	400,437.26	264,288.59	320,349.81	280,306.08	264,288.59	400,437.26	0.043
S13	0.00	0.00	144.00	0.00	144.00	0.00	0.033
C6	213,837,049.88	8,525,590,205.96	1,320,211,351.41	492,754,941.02	213,837,049.88	8,525,590,205.96	0.056
S14	0.00	0.00	0.00	0.00	0.00	0.00	0.030
S15	0.01	0.02	0.02	0.01	0.02	0.01	0.027
S16	18.65	27.98	46.64	65.29	65.29	18.65	0.041
S17	172,625,744.02	154,454,613.07	159,905,952.36	172,625,744.02	154,454,613.07	172,625,744.02	0.039
S18	378,655,265,380,002	189,327,632,690,001	302,924,212,304,002	367,548,044,262,189	378,655,265,380,002	189,327,632,690,001	0.042

TABLE 14 Weighted normalized decision matrix *V* for assessing the performance of pork suppliers

	Sp 1	Sp 2	Sp 3	Sp 4	A^+	A^-
S1	0.12	0.12	0.12	0.12	0.12	0.12
S2	0.12	0.12	0.12	0.12	0.12	0.12
S3	0.00	0.00	0.00	0.00	0.00	0.00
S4	30.04	26.50	21.20	15.90	30.04	15.90
S5	0.05	0.00	0.05	0.05	0.05	0.00
S6	0.00	0.00	0.00	0.00	0.00	0.00
S7	0.07	0.07	0.07	0.07	0.07	0.07
S8	0.00	0.00	0.00	0.05	0.05	0.00
C4	6,911,682.80	5,222,160.33	7,833,240.50	11,980,250.18	11,980,250.18	5,222,160.33
S9	20.77	7.34	29.37	7.34	7.34	29.37
S10	1.54	1.23	1.23	1.54	1.54	1.23
S11	14.28	2.86	11.42	9.03	2.86	14.28
S12	17,218.80	11,364.41	13,775.04	12,053.16	11,364.41	17,218.80
S13	0.00	0.00	4.75	0.00	4.75	0.00
C6	11,974,874.79	477,433,051.53	73,931,835.68	27,594,276.70	11,974,874.79	477,433,051.53
S14	0.00	0.00	0.00	0.00	0.00	0.00
S15	0.00	0.00	0.00	0.00	0.00	0.00
S16	0.76	1.15	1.91	2.68	2.68	0.76
S17	6,732,404.02	6,023,729.91	6,236,332.14	6,732,404.02	6,023,729.91	6,732,404.02
S18	15,903,521,145,960.10	7,951,760,572,980.05	12,722,816,916,768.10	15,437,017,859,011.90	15,903,521,145,960.10	7,951,760,572,980.05

TABLE 15 Distance from the positive solution

	Sp 1	Sp 2	Sp 3	Sp 4
S1	0.00	0.00	0.00	0.00
S2	0.00	0.00	0.00	0.00
S3	0.00	0.00	0.00	0.00
S4	0.00	12.49	78.06	199.83
S5	0.00	0.00	0.00	0.00
S6	0.00	0.00	0.00	0.00
S7	0.00	0.00	0.00	0.00
S8	0.00	0.00	0.00	0.00
C4	25,690,375,319,400.00	45,671,778,345,600.00	17,197,689,263,400.00	0.00
S9	180.26	0.00	485.23	0.00
S10	0.00	0.09	0.09	0.00
S11	130.47	0.00	73.39	38.13
S12	34,273,914.54	0.00	5,811,148.14	474379.44
S13	22.58	22.58	0.00	22.58
C6	0.00	216,651,314,294,554,000.00	3,838,665,002,233,600.00	243,965,715,840,000.00
S14	0.00	0.00	0.00	0.00
S15	0.00	0.00	0.00	0.00
S16	3.66	2.34	0.58	0.00
S17	502,218,990,000.00	0.00	45,199,709,100.00	502,218,990,000.00
S18	0.00	63,230,496,210,000,000,000,000,000.00	10,116,879,393,600,000,000,000,000.00	217,625,316,733,439,000,000,000.00
s_i^+	5,117,873.44	7,951,760,586,605.77	3,180,704,229,798.16	466,503,287,210.18

and (30), respectively. The aforementioned calculations were performed using only Excel spreadsheets.

The ranking of pork suppliers and their respective closeness coefficients $R_i$is shown in Figure 13. Such coefficients were achieved by applying Equation (31). The results evidenced that Sp_1 (R_1 = 0.999999356) and Sp_4 (R_4 = 0.941333333) exceeded largely the performance of Sp_3 (R_3 = 0.600000001) and Sp_2 (R_2 = 0.000000089). Additionally, it can be noted that two pork suppliers presented poor performance records, which dramatically increases the bullwhip effect across the pork supply chain. These findings reflect the need for developing improvement programmes that tackle the current weaknesses of pork suppliers. Therefore, it is necessary to establish the aspects that contribute most to this behaviour. Such aspects can be identified by analysing the distances shown in Tables 15–16. These distances are helpful to determine the advantages (subcriteria/criteria whose separation from A^+ is equal to 0) and disadvantages of each pork supplier (subcriteria/criteria whose separation from A^+ is greater than zero||separation from A^- is equal to 0). We especially targeted the disadvantages of each pork supplier to support bullwhip effect management consistently. For example, Sp_2 should propel the implementation of a business digital platform (S5) to diminish the information distortion and react faster when facing demand changes. In addition, it should implement an R&D department (S8) that helps to diminish the production time per kilogram of pork and consequently decreases the lead time provided to the restaurants. The number of pork products (S10) offered to the restaurants (4) is another signal that evidences the lack of R&D programmes within this company. On the other hand, Sp_2 presents the lowest monthly production capacity (3,400 kg), which restricts its efficient response to the presence of demand peaks. Thus, Sp_2 should establish temporal alliances with other potential suppliers so that the pork supply chain can be better supported when facing demand swings. It is also important to note that Sp_2 does not provide a certain guarantee of quality (S13), which is a clear disadvantage considering the perishable nature of pork products. Another aspect of concern with this supplier is its localization (C6). The average distance between Sp_2 and the restaurants is equal to 91,700 km, which may increase the variability of lead times and transportation costs. If this company wants to continue partnering with the restaurants, new ways of diminishing such uncertainty should be explored including a new localization of its production facilities. Finally, Sp_2 must increase its financial stability because the monthly net profit (S18) observed in Table 11 ($7.500.000) limits the performance of the pork supply chain in terms of inventory level and on-time provision. Alliances with similar companies can be studied to address this problem and increase its competitiveness and sustainability in the supply structure.

Sp_4 was concluded to offer the longest average time of postsale service—S9 (24 hr). Such problem decreases the reliability of customers (restaurants) who expect for compliance with the warranty conditions of after-sales-service. The appropriate management of

TABLE 16 Distance from the negative solution

	Sp 1	Sp 2	Sp 3	Sp 4
S1	0.00	0.00	0.00	0.00
S2	0.00	0.00	0.00	0.00
S3	0.00	0.00	0.00	0.00
S4	199.83	112.40	28.10	0.00
S5	0.00	0.00	0.00	0.00
S6	0.00	0.00	0.00	0.00
S7	0.00	0.00	0.00	0.00
S8	0.00	0.00	0.00	0.00
C4	2,854,486,146,600.00	0.00	6,817,739,639,400.00	45,671,778,345,600.00
S9	73.99	485.23	0.00	485.23
S10	0.09	0.00	0.00	0.09
S11	0.00	130.47	8.15	27.54
S12	0.00	34273914.54	11859486.00	26683843.50
S13	0.00	0.00	22.58	0.00
C6	216651314294554000.00	0.00	162813231196000000.00	202354923346330000.00
S14	0.00	0.00	0.00	0.00
S15	0.00	0.00	0.00	0.00
S16	0.00	0.15	1.32	3.66
S17	0.00	502218990000.00	246087305100.00	0.00
S18	63230496210000000000000000.00	0.00	22762978635600000000000000.00	56029076638093400000000000.00
s_i^-	7951760586603.08	708698.29	4771056360851.37	7485257299551.83

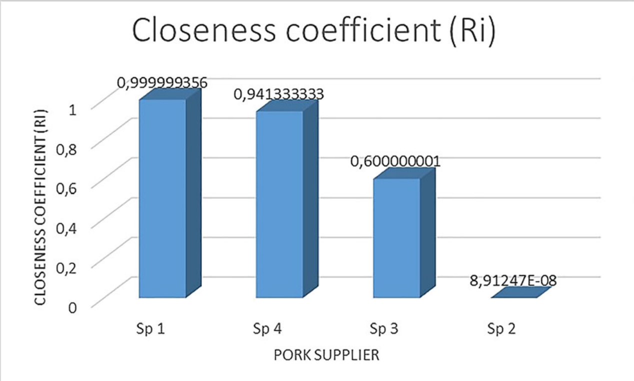


FIGURE 13 The final ranking of pork suppliers

after-sales-service supply chain is then a crucial challenge for pork suppliers upon considering the perishable nature and short life cycle of their products. To address this weakness, Sp_4 should improve its resource planning and upstream coordination as well as increase the forecasting accuracy. Similar to Sp_2, Sp_4 should also improve the production flexibility (S10) by incorporating new pork products that augment the offer diversification and the reaction level to demand changes. It is also suggested to aggressively negotiate with the restaurants to give them everyday low cost in order to control the bullwhip problem caused by pricing conditions (S14).

6 | CONCLUSION

Supplier assessment practices are quite important for companies in the food sector and appears to be the most significant factor for increasing firm competitiveness in a complex food supply chain management. In this respect, companies have to deal with the uncertainty, and it is therefore necessary to search for high-committed suppliers decreasing the bullwhip effect. Particularly, we focus on companies processing and distributing pork meat. Hence, according the above-mentioned considerations, this study aimed to evaluate the performance of pork suppliers based on a hybrid MCDM approach.

The contribution of this research was to identify the main factors and attributes characterizing the pork supply chain, which are relevant to the quality of the final product as perceived by the consumer. The paper provides a holistic perspective of the pork supply chain and can be useful for researchers and practitioners involved in the management of pork product quality and new product development. It is essential to mention that the findings could be associated with the case study. This research study was limited to four pork suppliers in the food industry of Colombia, which may partially explain the outcomes. The aim of further research will be twofold. First, will be investigate the effects of the interactions between the factors on pork chain analysis and consumer satisfaction in other countries and not only in Colombia. Second, fuzzy approaches and environmental criteria will be further considered.

ORCID

Miguel Ortiz-Barrios https://orcid.org/0000-0001-6890-7547

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