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Designing supplier selection strategies under COVID-19 constraints for industrial environments

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Abstract

COVID-19 has been impacting worldwide supply chains causing interruption, closure of production and distribution. This impact has been drastic on the supplier side and, as a consequence of disruptions, strong reductions of production have been estimated. Such a circumstance forces companies to propose innovative best practices of supply chain risk management aimed at facing vulnerability generated by COVID-19 and pursuing industrial improvements in manufacturing and production environments. As a part of supply chain strategy, supplier selection criteria should be revised to include pandemic-related risks. This article aims to propose an answer to such a problem. In detail, a comprehensive tool designed as a hybrid combination of multi-criteria decision-making (MCDM) methods is suggested to manage important stages connected to the production development cycle and to provide companies with a structured way to rank risks and easily select their suppliers. The main criteria of analysis will be first identified from the existent literature. Risks related to COVID-19 will be then analysed in order to elaborate a comprehensive list of potential risks in the field of interest. The Best Worst Method (BWM) will be first used to calculate criteria weights. The Fuzzy Technique for Order of Preference by Similarity to Ideal Solution (FTOPSIS) will be then applied to rank and prioritize risks affecting suppliers. The effectiveness of the approach will be tested through a case study in the sector of automotive industry. The applicability of the designed MCDM framework can be extended also to other industrial sectors of interest.

Keywords: COVID-19, Supplier risks, Supplier selection, BWM, FTOPSIS

1. Introduction and literature review

Supplier selection and relation management are strategical issues for effective competition among companies [1]. These topics become more and more complex when it comes to the Low-Frequency-High-Impact (LFHI) risk to supply chains (SCs) [2,3,4,5] related, for instance, to disruptions due to COVID-19 . COVID-19 has been impacting supply chains of global manufacturers on a wide scale [6] and can be reasonably considered as the main trigger cause of SC disruptions for a remarkable number of companies [7]. A recent survey [8] on around 600 US companies reveals that suppliers of the 57% of the surveyed companies are operating at an average 50% of their capacity with consequent longer product lead times and a negative impact on revenue ranging between 5.6%-15%. The literature presents several works on the impact of different epidemic occurrences on SC by discussing, for instance, such outbreaks as influenza [9], Ebola [10], Cholera [11] and malaria [12]. However, according to such authors as Ivanov [5] and Sarkis et al. [13], the effects of epidemic outbreaks on SCs are still to be adequately investigated. Moreover, to the best of the authors' knowledge, no research has been developed so far about COVID-19-related risks and their impact on the problem of suppliers' selection. This is the main reason why the present contribution intends to cover this gap. Indeed, even if the problem of suppliers' selection is not recent, it is considered as one of the most challenging tasks for SC management [14], still requiring the attention of the scientific community.

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The decision-making problem of suppliers' selection involves both qualitative and quantitative factors [15] and the application of Multi-Criteria Decision-Making (MCDM) approaches has been largely proposed to deal with such an issue. Pi and Low [16] propose a supplier evaluation and selection system based on Taguchi loss function and the Analytical Hierarchy Process (AHP). Sevkli et al. [17] use data envelopment AHP to select the best supplier for a TV company. Dai and Blackhurst [18] present an integrated approach making use of the AHP and the Quality Function Deployment (QFD) method. Haq and Kannan [19] propose the fuzzy AHP (FAHP) to better manage uncertainty in the supplier selection process. Chan et al. [20] apply the FAHP to a global supplier selection problem and Chamodrakas et al. [21] use the same method for selecting suppliers in the electronics sector. Azadnia et al. [22] propose an integrated approach between FAHP and a multi-objective mathematical programming making use of a rule-based weighted fuzzy method. Apart from AHP and FAHP, several other MCDM methods have been proposed to solve the problem object of research, i.e. the Fuzzy Technique for Order of Preference by Similarity to Ideal Solution (FTOPSIS) [23] and the DEcision MAking Trial and Evaluation Laboratory (DEMATEL) [24]. A hybrid MCDM approach has been proposed by Streimikiene et al. [25], who combine the TOPSIS method with the multi-objective optimization by ratio analysis plus the full multiplicative form (MULTIMOORA). The authors also stress the effectiveness of the Best Worst Method (BWM) because of its simplicity with respect to other MCDM techniques. For example, Liu et al. [26] combine the BWM with the MULTIMOORA and Kusi-Sarpong et al. [27] present a BWM-based framework aimed at ranking and selecting the most important criteria for sustainable innovations in the supply chain management field.

The main contribution of this research to the state of the art consists in designing an integrated MCDM tool capable to simultaneously take into account the diverse importance of relevant criteria as well as the potential impact of significant risks on core industrial processes related to production. As already underlined, similar hybrid approaches are promoted and commonly adopted in the practice what shows the suitability of the methodological combination to face complex decision-making problems in the field of interest. Particularly, the present paper aims to support the suppliers' selection problem by contemplating risks related to COVID-19 through an integrated MCDM approach making use of the BWM and the FTOPSIS. BWM has been chosen for its simplicity in calculating criteria weights, guaranteeing the possibility to be applied in a flexible way in any business context. Furthermore, FTOPSIS appears to be a valuable technique for representing practical real-life situations. Eliciting crisp numerical values may indeed be difficult, especially in such processes permeated by uncertainty as risk assessment. To the best of the authors' knowledge, the proposed methodological combination has not been previously used to solve the practical problem under analysis. In such a direction, the implementation of effective strategies for suppliers' selection within industrial companies positively influences production and general performance, being strictly related to the industrial improvements of many aspects connected to engineering and manufacturing as well as associated production environments.

The integrated MCDM approach will be eventually applied to a real-world case study in the sector of automotive industry. In any case, the application of the designed framework can be extended to other industrial fields. The research is organized as follows. Section 2 presents the processes of criteria selection and risks identification as a part of supplier selection strategy. Section 3 describes the designed MCDM approach by providing details about the chosen methodologies. Section 4 shows an applicative real case in the sector of automotive industry and section 5 closes the work.

2. Main elements for implementing a suppliers' selection strategy during the COVID-19 pandemic

The present section is first focused on the elaboration of a comprehensive criteria list. In particular, criteria that have been mainly used for suppliers' selection in the existent literature will be analysed and synthetized. Secondly, a supplier risk analysis contemplating COVID-19 outbreak will be performed.

2.1. Main criteria selection

As highlighted by Kuo et al. [28] and by Rezaei et al. [29], preliminary analyses on criteria are fundamental for achieving quality and effectiveness in the process of suppliers' selection. We are going to report those criteria we have chosen for our study along with the related motivations.

- C_1, price/cost [30,31,32]: this criterion includes such aspects as unit price, pricing terms, exchange rates, taxes, and discount. It also contemplates cost as a monetary evaluation of spent efforts, materials, resources, time and utilities, as well as occurred risks and foregone opportunities in terms of goods and/or service delivery.
- C_2, quality [33,34]: this criterion evaluates suppliers' capability of meeting quality specifications including such aspects as features (material, size, design, durability), variety, manufacturing (production lines, manufacturing techniques, machines and plants), system management and continuous improvement.
- C_3, delivery performance and reliability [31,34]: this criterion refers to the respect of specific delivery scheduling including lead-time, on-time performance, fill rate, returns management, location and transportation.
- C_4, reputation [32,34]: this criterion represents the extent to which suppliers are fair, honest and concerned about relationships with their buyers.

2.2. Suppliers' risks identification

We have already underlined as supply chains worldwide are currently facing new types of constraints due to COVID-19, never considered before within contingency management plans. Indeed, risks related to the pandemic around the world are still not well defined nor fully analysed in the existent literature. We are going to perform a suppliers' risk analysis by involving a group of stakeholders from a representative sector, that is the automotive industry, successively used as case study. Several brainstorming sessions and meetings have been organized, being the related output obtained by using the 6M method and graphically presented in Figure 1.

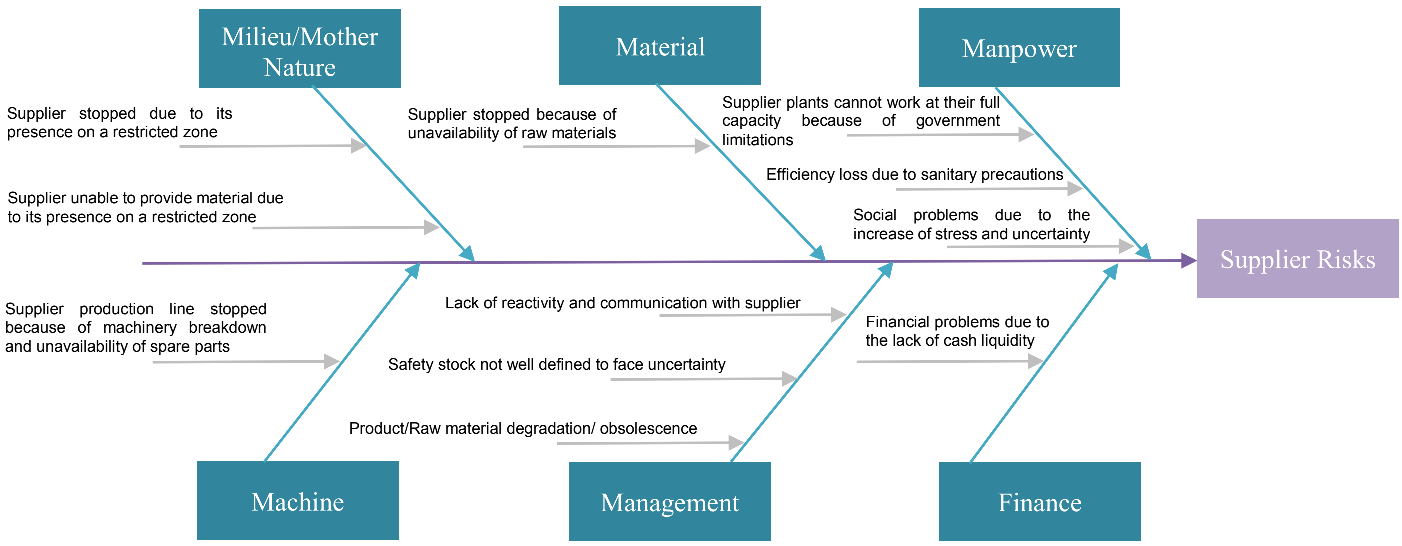

Fig. 1. 6M supplier risks identification

3. MCDM integrated approach

As previously explained, we aim to design an integrated and dedicated tool to enhance production environments by focusing on such a fundamental issue as supply chain management. Structuring and implementing effective strategies for suppliers' selection within industrial companies has indeed a direct influence on all the stages of industrial production. The combination of decision-making methods herein developed can represent a flexible tool to manage important stages connected to the production development cycle, being the evaluation of suppliers fundamental for manufacturing management, even more in the current context affected by COVID-19. In this section we are going to present the integrated MCDM approach. The BWM will be used to calculate criteria weights whereas the FTOPSIS will be applied to rank and prioritize suppliers on the basis of the related previously identified risks.

3.1. The Best Worst Method for weighting criteria

BWM was developed by Rezaei [35] for solving MCDM problems and, in particular, determining the mutual importance of criteria. The existent literature tends to prefer BWM to AHP, being the first one time saving for guaranteeing better results [35,36]. The steps to obtain weights by using the BWM are described next.

- **I STEP**: determining the set of evaluation criteria. Let $C = (C_1, C_2, C_3, \dots, C_n)$ be the set of n criteria. The involved decision-maker(s) will identify, among the elements of the set, the best criterion (most desirable, most important) named B and the worst criterion (least desirable, least important) named W. The following pairwise comparisons will be based on these two criteria.
- **II STEP**: obtaining vector A_B. Vector A_B is obtained by determining the preference of the best criterion over other criteria by means of a 9-points scale. The so-called resultant Best-to-Others vector will be:

  $$A_B = (a_{B1}, a_{B2}, \dots, a_{Bn}), \quad (1)$$

  where a_{Bj} $(j = 1, \dots, n)$ indicates the preference of the best criterion B over criterion j. $a_{Bj} \in (1, \dots, 9)$, where $a_{Bj} = 1$ indicates that B and j have attributed the same importance and $a_{Bj} > 1$ indicates that B is more important than j. The element a_{BB} has associated an evaluation equal to 1.
- **III STEP**: obtaining vector A_W. Vector A_W is achieved by determining the preference of the worst criterion over the other criteria by means of a 9-points scale. The so-called resultant Worst-to-Others vector will be:

  $$A_W = (a_{W1}, a_{W2}, \dots, a_{Wn}), \quad (2)$$

  where a_{Wj} $(j = 1, \dots, n)$ indicates the preference of the worst criterion W over criterion j. $a_{Wj} \in (1, \dots, 9)$, where $a_{Wj} = 1$ indicates that W and j have attributed the same importance and $a_{Wj} > 1$ indicates that W is more important than j. The element a_{WW} has associated an evaluation equal to 1.
- **IV STEP**: finding the optimal weights. Optimal weights for criteria are the ones where, for each pair w_B/w_j and w_j/w_W, we have $w_B/w_j = a_{Bj}$ and $w_i/w_W = a_{jW}$. To satisfy these conditions for all j, the following problem should be solved:

  $$min\, max_j \left\{ \left| \frac{w_B}{w_j} - a_{Bj} \right|, \left| \frac{w_j}{w_W} - a_{jW} \right| \right\}, \quad (3)$$

  being $\sum_j w_j = 1$ and $w_j \geq 0$ for all j. The problem (3) can be expressed as:

  $$\left| \frac{w_B}{w_j} - a_{Bj} \right| \leq \varepsilon, for\ all\ j, \quad (4)$$

  $$\left| \frac{w_j}{w_W} - a_{jW} \right| \leq \varepsilon, for\ all\ j, \quad (5)$$

  being $\sum_j w_j = 1$ and $w_j \geq 0$ for all j. The optimal weight $(w_1^*, w_2^*, \cdots, w_n^*)$ and $\varepsilon^*$are obtained.
- **V STEP**: calculating the Consistency Ratio, CR. The element ε^* will be used to get the Consistency Ratio by means of the following equation:

  $$CR = \frac{\varepsilon^*}{CI}, \quad (6)$$

  being CI the Consistency Index, obtained according to the value of A_{Bw} by using the scale reported in Table 1.

Table 1. CI scale [35]

A_{Bw}	1	2	3	4	5	6	7	8	9
CI (max ε)	0.00	0.44	1.00	1.63	2.30	3.00	3.73	4.47	5.23

As it is possible to note, the higher the value of ε^*, the higher the consistency ratio and the lower the reliability of comparisons. This is the reason why CR values close to zero indicate good comparisons.

3.2. The Fuzzy Technique for Order of Preference by Similarity to Ideal Solution for ranking supplier risks

The steps required to apply the FTOPSIS method [37] are synthesised in the following.

- **I STEP**: defining the fuzzy decision matrix $\tilde{X}$ of input data:

$$\tilde{X} = \begin{bmatrix} \tilde{x}_{11} & \cdots & \tilde{x}_{1n} \\ \vdots & \ddots & \vdots \\ \tilde{x}_{m1} & \cdots & \tilde{x}_{mn} \end{bmatrix}. \quad (7)$$

The generic fuzzy number $\tilde{x}_{ij}$ represents the rating of alternative i under criterion j. In the present case, we take into account triangular fuzzy numbers (TFNs), characterized by ordered triples:

$$\tilde{x}_{ij} = (a_{ij}, b_{ij}, c_{ij}), \quad (8)$$

- **II STEP**: weighting and normalising the previously defined matrix with relation to each criterion. Matrix $\tilde{X}$ must be normalized and weighted with relation to different criteria, and the obtained result is a matrix called $\tilde{U}$, which components are obtained as follows:

$$\tilde{u}_{ij} = \left(\frac{a_{ij}}{c_j^*}, \frac{b_{ij}}{c_j^*}, \frac{c_{ij}}{c_j^*}\right) \cdot w_j,\ j \in I', \quad (9)$$

$$\tilde{u}_{ij} = \left(\frac{a_j^-}{c_{ij}}, \frac{a_j^-}{b_{ij}}, \frac{a_j^-}{a_{ij}}\right) \cdot w_j,\ j \in I'', \quad (10)$$

I' being the subset of criteria to be maximized, I'' the subset of criteria to be minimized, w_j the relative importance weight of criterion j and c_j^* and a_j^- calculated as:

$$c_j^* = \max_i c_{ij} \quad \text{if } j \in I', \quad (11)$$

$$a_j^- = \min_i a_{ij} \quad \text{if } j \in I'' . \quad (12)$$

- **III STEP**: computing distances between each alternative and the fuzzy ideal solutions A^* and A^-:

$$A^* = (\tilde{u}_1^*, \tilde{u}_2^*, \dots, \tilde{u}_n^*), \quad (13)$$

$$A^- = (\tilde{u}_1^-, \tilde{u}_2^-, \dots, \tilde{u}_n^-), \quad (14)$$

where $\tilde{u}_j^* = (1,1,1)$ and $\tilde{u}_j^- = (0,0,0)$, $j = 1 \dots n$. In detail, distances between each alternative and these points are computed through the vertex method [37], for which the distance $d(\tilde{m}, \tilde{n})$ between two TFNs $\tilde{m} = (m_1, m_2, m_3)$ and $\tilde{n} = (n_1, n_2, n_3)$ is the crisp value:

$$d(\tilde{m}, \tilde{n}) = \sqrt{\frac{1}{3}[(m_1 - n_1)^2 + (m_2 - n_2)^2 + (m_3 - n_3)^2]}. \quad (15)$$

Then, aggregating with respect to the whole set of criteria, the related distances of each alternative i from A^* and A^- are:

$$d_i^* = \sum_{j=1}^n d(\tilde{u}_{ij}, \tilde{u}_j^*) \ \ i = 1 \dots n, \quad (16)$$

$$d_i^- = \sum_{j=1}^n d(\tilde{u}_{ij}, \tilde{u}_j^-) \ \ i = 1 \dots n. \quad (17)$$

- **IV STEP**: calculating the closeness coefficient CC_i:

$$CC_i = \frac{d_i^-}{d_i^- + d_i^*} . \quad (18)$$

To get the final ranking it is necessary to sort the values of the closeness coefficient related to each alternatives in a decreasing way.

4. Case study on automotive industry

The present case study refers to an automotive company based on the North of Morocco. Due to supply chain disruptions caused by COVID-19, the company faced the breakdown of its core activities for a six-weeks period, without available suppliers and without having established a proper plan to face the emergency. In the difficult attempt to progress from the current circumstances, the company is now aimed at revising its previous suppliers' strategy by integrating risks related to COVID-19 within management plans. The present application provides a structured methodology to support the company management in such a direction.

First of all, the BWM is herein applied to weight the evaluation criteria described in subsection 2.1 (C_1, price/cost; C_2, quality; C_3, delivery performance and reliability; C_4, reputation). After consultation with the team of managers from the company, the best criterion results to be C_3 (delivery performance and reliability), the worst criterion being C_1 (price/cost). Preference judgments about the best criterion to the others have been collected as well as evaluations related to the preference of the remaining criteria to the worst criterion. Evaluations attributed from the company decision-making team are reported in Table 2 along with the vector of weights.

Table 2. Evaluations of preference and criteria weights

Best/Worst	**C_1**	**C_2**	**C_3**	**C_4**
C_3 (to others)	4	1	1	2
(others to) **C_1**	1	3	4	2
Weights	0.10	0.33	0.38	0.19

The value of ε^* for the performed comparisons is equal to 0.0476, indicating that results can be considered as reliable. Once calculated the vector of criteria weights, we are going to proceed with the FTOPSIS application. In particular, the eleven major risks connected to suppliers (Figure 1) have been codified as follows: R_1, supplier stopped due to its presence on a restricted zone; R_2, supplier unable to provide material due to its presence on a restricted zone; R_3, supplier stopped because of unavailability of raw materials; R_4, supplier production line stopped because of machinery breakdown and unavailability of spare parts; R_5, lack of reactivity and communication with supplier; R_6, safety stock not well defined to face uncertainty; R_7, product/raw material degradation/obsolescence; R_8, supplier plants cannot work at their full capacity because of government limitations; R_9, efficiency loss due to sanitary precautions; R_{10}, social problems due to the increase of stress and uncertainty; R_{11}, financial problems due to the lack of cash liquidity.

The mentioned risks have been evaluated with relation to three different suppliers (Table 3) and linguistic evaluations have been translated to TFNs (Table 4) as a part of input data of the FTOPSIS application.

The final rankings of risks are reported in Table 5 for each supplier. These results are important to proceed with the final supplier selection. It is immediate to derive as risk R_{11} is higher for the first supplier, risk R_7 is higher for the second supplier and risk R_9 is higher for the third supplier.

Table 3. Linguistic evaluations of risks for each supplier

	Supplier 1				Supplier 2				Supplier 3			
Risk	C_1	C_2	C_3	C_4	C_1	C_2	C_3	C_4	C_1	C_2	C_3	C_4
R_1	VH	L	H	M	M	L	L	H	H	M	VH	L
R_2	VH	M	H	M	L	L	H	M	H	L	M	H
R_3	VH	M	VH	H	H	L	M	M	VH	VH	VH	H
R_4	H	L	H	H	H	L	L	M	H	H	H	M
R_5	M	L	H	M	M	L	M	L	M	L	H	H
R_6	H	M	M	M	M	L	H	M	VH	L	L	M
R_7	H	M	H	M	H	H	M	H	M	M	M	L
R_8	M	M	H	H	M	M	H	M	L	L	M	H
R_9	M	M	H	L	M	L	H	M	H	H	VH	M
R_{10}	H	L	M	M	M	M	H	M	M	M	M	VH
R_{11}	VH	H	VH	H	H	L	H	H	H	L	M	M

Table 4. Fuzzy numbers corresponding to linguistic evaluations

Evaluation	Fuzzy Number
Very high impact (VH)	(9, 10, 10)
High impact (H)	(7, 9, 9)
Medium impact (M)	(3, 5, 7)
Low impact (L)	(0,1, 3)
Very low impact (VL)	(0, 1, 1)

Table 5. FTOPSIS results

	Supplier 1		Supplier 2		Supplier 3	
Risk	CC_i	**Ranking position**	CC_i	**Ranking position**	CC_i	**Ranking position**
R_1	0.1316	10th	0.1215	5th	0.1049	6th
R_2	0.1613	5th	0.1215	6th	0.1049	7th
R_3	0.1902	2nd	0.0884	9th	0.2084	1st
R_4	0.1498	7th	0.0559	11th	0.1754	3rd
R_5	0.1435	8th	0.0721	10th	0.1381	4th
R_6	0.1331	9th	0.1215	7th	0.0559	11th
R_7	0.1629	4th	0.1587	1st	0.0986	9th
R_8	0.1898	3rd	0.1482	2nd	0.1049	8th
R_9	0.1550	6th	0.1215	8th	0.1843	2nd
R_{10}	0.1035	11th	0.1482	3rd	0.1360	5th
R_{11}	0.2175	1st	0.1381	4th	0.0884	10th

The first qualitative consideration consists in coupling these results with the specific needs of the company in terms of risk management. For example, if financial aspects are of crucial importance for the company, the third supplier will be certainly excluded, and so on. On the whole, when risks have the same importance for the company, it is possible to proceed to the selection as suggested next. By observing the whole set of CC_i values of Table 4, they vary from 0.0559 as a minimum value to 0.2175 as a maximum value, the last one expressing maximum risk condition. Such a range can be divided into three ordered classes of same width (equal to 0.1616) respectively expressing acceptable, medium and high risk conditions. We suggest to select the supplier with associated the lower number of risks belonging to the higher class. These considerations have been formalized in Table 6, from which the selection of the second supplier is recommended.

Table 6. Risk classes obtained from CC_i values

Class	Supplier 1	Supplier 2	Supplier 3
High risk ($0.2175 \leq CC_i \leq 0.1636$)	R_3,R_8,R_{11}		R_3,R_4,R_9
Medium risk ($0.1636 < CC_i \leq 0.1097$)	R_1,R_2,R_4,R_5, R_6,R_7,R_9	R_1,R_2,R_6,R_7, R_8,R_9, R_{10}, R_{11}	R_5,R_{10}
Acceptable risk ($0.1097 < CC_i \leq 0.0559$)	R_{10}	R_3,R_4,R_5	R_1,R_2,R_6, R_7,R_8,R_{11}

Results suggest as implementing actions aimed at strengthening robustness of supply chain would be beneficial for effectively managing almost all the relevant risks related to Supplier 2, in particular risks R_1, R_2, R_6, R_9, R_{10}. This would have a positive influence on supply chain performance and, in a medium-long term horizon, the integration of additional supplier(s) may be contemplated as a diversification strategy.

5. Conclusions

This contribution faces the problem of suppliers' selection strategy under risks related to COVID-19. After establishing relevant criteria and identifying those risks mainly impacting on suppliers' management, we propose a MCDM approach making use of the BWM and the FTOPSIS techniques. The first method aims to get criteria weights, whereas the second one ranks risks connected with suppliers including important aspects related to the COVID-19 outbreak. Our approach has been applied to a real case study on the sector of automotive industry and results confirm its applicability by leading towards the selection of the suitable supplier. The analysed company has eventually implemented the decision-making framework as a part of its own management plan. We specify that the applicability can be extended also to other industrial sectors to support production environments by means of the dedicated design of process management and organization in hazardous scenarios. As future developments of this research, the practical implementation of actions aimed at strengthening the robustness of supply chain, like for example multiple sourcing or chain shortening, may be contemplated for managing the main risks evaluated for the selected supplier.

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