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A strategic approach to safeguard global supply chains against COVID-19 disruptions

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The global system of supply chains has been dramatically disrupted over the last years due to the outbreak of the COVID-19 pandemic. In these current challenging times, this paper proposes a methodological approach for managing dependence and uncertainty in dynamic industrial scenarios. A detailed study of epidemic effects is carried out according to an operational management-based perspective. We proceed by analyzing connections among effects and risks potentially leading to significant supply chain disturbances through a multicriteria approach. Risks and effects are weighted by applying the Analytic Network Process (ANP). Weighted risks are then assumed as criteria for selecting the most suitable contingency strategy. To this aim, the Fuzzy Technique for Order of Preference by Similarity to Ideal Solution (FTOPSIS) is able to rank a set of strategies by addressing and quantifying uncertainty. A case study on the sector of the automotive industry is implemented to validate the proposed methodological approach.

KEYWORDS

ANP, contingency strategies, effects analysis, FTOPSIS, multicriteria decision-making, performance management, supply chain risk

MSC CLASSIFICATION

90B06, 90B50, 90B90, 91B06, 91B74

1 | INTRODUCTION AND LITERATURE REVIEW

1.1 | Context, objectives, and structure of the research

Managing supply chain risks (SCRs) has become an increasingly strategic key factor over the last decade, aimed at pursuing and maintaining business success. Various studies in the existing literature [1–4] have grouped risks into two main categories: Operational risks, coming from disturbances of operations throughout the supply chain in terms of lead time and demand fluctuations; and disruption risks, whose occurrence is mainly due to exogenous reasons such as natural disasters, in our case, a pandemic outbreak [5, 6].

These last types of risks clearly pose an important challenge to managers nowadays, and evaluating uncertainty affecting business scenarios as well as ripple effects propagation is crucial [7, 8]. COVID-19 has been dangerously affecting supply chains of global manufacturers [9, 10], which are significantly vulnerable against disruptions [11], being indicated as a main trigger cause of supply chain disruptions for a huge number of enterprises [12]. In this paper, we are going to mainly focus on COVID-19, but pandemic events are of course not the only cause of severe external disturbances. Another example of exogenous reasons leading to supply chain disruptions may be political instability; let us think for instance of the recent occurrence of the Ukrainian crisis or other similar events. Various works of research have analyzed the impact of different epidemic occurrences on supply chains such as, for instance, influenza [13], Ebola [14], cholera [15], and malaria [16]. However, major effects derived from epidemic outbreaks on supply chains should be further adequately investigated and preferably supported by emerging technologies [17, 18], since enterprises have been adopting poor risk management plans to face them, especially in the immediate period upon the outbreak [19]. Many companies, for instance, have been assuming a passive attitude toward the management of pandemic effects, simply waiting for the situation to come back to normality at hopefully short notice. On the other side, those companies that are more proactively reacting to the pandemic [20] have been encountering countless difficulties in implementing risk management plans at operational levels [21]. It is also necessary to take into account the relationship between fear-uncertainty toward COVID-19 and the adaptation to new managerial procedures [22].

Given these preliminaries, the present paper is a substantial extension of a previous conference contribution [23], which identified and analyzed relevant supply chain risks due to COVID-19, formulated the problem, and gave hints for its solution. In comparison to our previous work, this research study represents a significant step forward in the field of decision-making applied to supply chain risk management, as it expands the risk analysis previously presented, by effectively linking it to the implementation of suitable contingency strategies while also providing a much more thorough literature review. Specifically, from a technical point of view, this research employs a multicriteria decision-making (MCDM) hybrid approach (adding FTOPSIS) that has proven to be highly effective in producing guidelines and solutions for implementing real-world managerial strategies. We lead its practical application by achieving a classification of suitable strategies to mitigate the impact of COVID-19 on supply chain operations based on a thorough analysis of the risks that can arise in supply chains during a pandemic. Furthermore, the proposed decision-making model can handle multiple criteria, including qualitative and quantitative factors, that can have varying levels of importance. The case study of this paper discusses the practical scenario of the automotive industry, yielding positive results in terms of the quality of decision-making. The results of the model can be used to generate practical recommendations and solutions for real-world managerial strategies. The main objectives of the paper are formalized as follows:

1. studying and identifying significant risks related to the effects of COVID-19 on supply chain networks by further extending the literature review previously carried out;
2. analyzing the related risks and their interdependence relationships to establish priorities on mitigation/prevention actions and most influential risks;
3. selecting the most suitable contingency strategy on the basis of companies' needs and by considering the previously analyzed risks as evaluation criteria;
4. developing a real case study in the sector of the automotive industry to test the applicability and effectiveness of the proposed approach.

The research is organized as follows. After the literature review on the main topics of research presented in this section, the identification of the most relevant supply chain risks related to the major effects of COVID-19 is formalized in Section 2 to address the first objective. The second and third objectives are addressed by means of the hybrid MCDM approach presented in Section 3: First, the Analytic Network Process (ANP) is suggested to analyze and weigh risks, and then the Fuzzy Technique for Order of Preference by Similarity to Ideal Solution (FTOPSIS) is applied to rank possible contingency strategies by considering the previously weighted risks as evaluation criteria while simultaneously considering uncertainty affecting evaluations. The obtained ranking will enable the selection of the most suitable strategy on the basis of the specific business context features. A real-world case study on the sector of the automotive industry addressing the fourth objective is developed and solved in Section 4, and, lastly, conclusions are provided in Section 5.

1.2 | Relevant aspects to supply chain risk management

Since supply chain risk management is deeply affected by vagueness and uncertainty [24], the use of reliable tools is an indispensable support for analysis. MCDM methods have demonstrated to be particularly useful in treating complex problems and uncertain conditions characterized by the presence of vague or missing information such as the field object of the present research. Next, we consider a reduced sample.

The Analytic Hierarchy Process (AHP) has been applied to evaluate risk factors impacting offshore supply chains [25]. The Fuzzy AHP (FAHP) has been proposed to manage uncertainty in risk assessment for the fashion industry supply chain

[26] and in the automotive industry [27]. Moreover, the adoption of hybrid approaches has been recommended to increase the accuracy of the obtained results. For instance, the FAHP has been integrated with the FTOPSIS for supply chain risk analysis in the electronics sector [28]. Again, the FAHP has been combined with the Multi-Objective Optimization on the basis of a Ratio Analysis plus the full MULTIplicative form (MULTIMOORA) for z risks and ranking suppliers [29]. Risk prevention policies have been evaluated by means of the Best Worst Method (BWM) and the TOPSIS technique to make predictions about their influence on the three most important aspects of supply chains, namely supply, demand, and logistics [30]. Another fuzzy-based approach has been proposed in the field of medical treatment supply management [31], in which the Fuzzy VIKOR (acronym of the Serbian translation of "multicriteria optimization and compromise solution") and the FTOPSIS are integrated as a methodological approach.

When it comes to the fundamental stage of supply chain risk identification, it is of utmost importance to thoroughly understand the effects they are related to. With this regard, several studies have been carried out in the literature aiming at formalizing COVID-19 impacts. We have tried to synthesize them and to provide a comprehensive list in Table 1 referring to recent efforts made in such a direction. Thirteen major effects have been analyzed and codified as $E_j (j = 1, \dots 13)$.

Once highlighted these major effects potentially generated by COVID-19, the most significant supply chain risks are identified and formalized in the following section along with a focus on the possible contingency strategies for effective risk management.

2 | COVID-19 SUPPLY CHAIN RISKS MANAGEMENT

The present section is devoted to studying the supply chain under the major constraints posed by COVID-19. To such an aim, we first identify the most critical risks connected to the effects that emerged from the literature review and described in Table 1. At this stage, also potential effects not currently considered in the existing literature are explored. Second, we present a synthetic description of contingency strategies that may be developed within contingency plans for risk management.

2.1 | Risk identification of COVID-19-related effects on supply chains

Despite the impact of COVID-19 on supply chain management has been studied in the literature, it is quite difficult to gain a comprehensive overview of which contingency strategy may be more effective without carrying out a proper process of risk identification. Such evidence mainly depends on uncertainty and subjectivity associated with the impact of the current pandemic outbreak on supply chains [19, 53], and also on the unpredictability of the COVID-19 phenomenon [33]. This is the reason why we herein carry out a study aimed at identifying risks related to COVID-19 effects. To such an aim, extensive brainstorming has been conducted with the participation of a group of experts in the industrial field. The decision-making group was comprised of four stakeholders, each bringing a wealth of expertise to the table, including backgrounds in the automotive industry, risk management, health and safety, and technology. Once assembled, the group initiated a first session with a singular focus: To identify relevant risks related to the COVID-19 pandemic and its effects on their respective industry. The team evaluated specific industrial aspects, including supply chain disruption, operational challenges, and financial impacts, among others. Throughout the session, the team maintained an environment of open communication, active listening, and constructive feedback. Each member was given an equal opportunity to contribute, and all ideas generated during the session were meticulously documented. The team recognized the importance of converting the opinions and ideas gathered during the session into a more structured format. As such, a second session was organized to develop a comprehensive list of specific risks related to the COVID-19 pandemic's effects on their industry. This list served as a critical foundation for the development of effective strategies aimed at managing these risks. Specifically, the following most significant risks have been evaluated:

1. external risks, produced by exogenous sources, that is, external to the company, and, as a consequence beyond control, even though broadly predictable;
2. operation risks, referring to the prospect of loss resulting from inadequate or failed procedures such as workers, policies, or system failures;
3. organizational risks, referring to the potential for loss due to uncertainty including such aspects as material, strategy, reputation, and security;
4. supply-side risks, causing problems to manufacture, information exchange, inventory, and general logistic aspects;
5. demand-side risks, connected to the general performance of order processing, also in terms of delivery processes.

The major identified risks have been linked to the related effects, and two additional effects have emerged from the brainstorming with the industrial experts, which we codify as E_{14} and E_{15}. To the best of the authors' knowledge, these effects have not been taken into account in the existing literature so far, so the presented identification process may be useful to enlarge the current state-of-the-art. These two additional effects are as follows:

- E_{14}, social problems: The tighter sanitary precautions imposed by the governments negatively impact workers from a psychological point of view by increasing their anxiety; for many, the simple fact of going to their workplaces is becoming complicated in such circumstances. We have to add how strategies of manpower cost reduction due to the economic crisis lead to complaints, strikes, and so on.
- E_{15}, lack of cash liquidity: The COVID-19 pandemic has induced a sharp drop in cash-flow for many firms and several companies have become illiquid. Customer demand changes are currently unpredictable and many order

TABLE 1 Literature review on significant effects of COVID-19.

ID	Effect description	Explanation	Reference
E_1	Orders canceled by brands and retailers	A lower number of orders can correctly be processed, given the difficulties of reaching the final customers due to the lack of flexible delivery options and peaks of transportation demand.	[32–35]
E_2	Ineffective supplier contingency plans	Components or modules supply may suffer from undetected broken supply chain showing a lack of readiness in responding to perturbation events as well as limited applicability of existing plans.	[33, 34, 36]
E_3	Perturbed supplies	Supplier of critical components can be severely affected and negatively impact production.	[33, 34, 36]
E_4	Perturbed production	The process of raw material supply is less efficient, something that leads to a strong reduction of production rates, to the impossibility of fulfilling orders, and to long-term capacity shortage.	[37, 38]
E_5	Change of delivery and order cycle	Delivery time may be extremely delayed in COVID-19 scenarios and this may significantly affect the whole order cycle.	[39, 40]
E_6	Excessive inventory amount	Excess on inventory could be caused by sudden orders' cancelations or reductions.	[41]
E_7	Shortage of primary resource	The shortage of raw and human resources may lead to possible consequent factory shutdown.	[42, 43]
E_8	Slow shipments and problems with deliveries	The closure of ports during the lockdown period have seriously affected distributors' capability to send goods by causing delivery delays and inflation of related costs.	[19, 44, 45]
E_9	Shortage of Operation, Maintenance, and Surveillance (OMS) workers	One or more OMS workers may be affected by COVID-19 and, consequently, in lockdown areas.	[46, 47]
E_{10}	Impact on relationships with suppliers	Suppliers have been facing strong pressures caused by COVID-19 disruptions in terms of visibility, communication, and flexibility, something that may generally deteriorate the quality of relationships with customers.	[33, 36, 48]
E_{11}	Increased level of job cuts	Multiple job cuts may occur due to reduction of production and demand.	[46, 49]
E_{12}	Impact on international trade	Foreign investors may pull their offers out and, in addition, credit flow from banks and non-banking financial companies may be slowed down or interrupted.	[50, 51]
E_{13}	Unavailable operators due to sickness reasons	One or more operators may be affected COVID-19.	[19, 46, 52]

TABLE 2 Risks identified from the brainstorming sessions and connection with effects.

ID	Risk	Related effects
C_1	External risk	E_3, E_7
C_2	Operation risk	E_4, E_{13}
C_3	Organizational risk	E_2, E_6, E_9, E_{11}, E_{14}, E_{15}
C_4	Supply-side risk	E_8, E_{12}, E_{10}
C_5	Demand-side risk	E_1, E_5

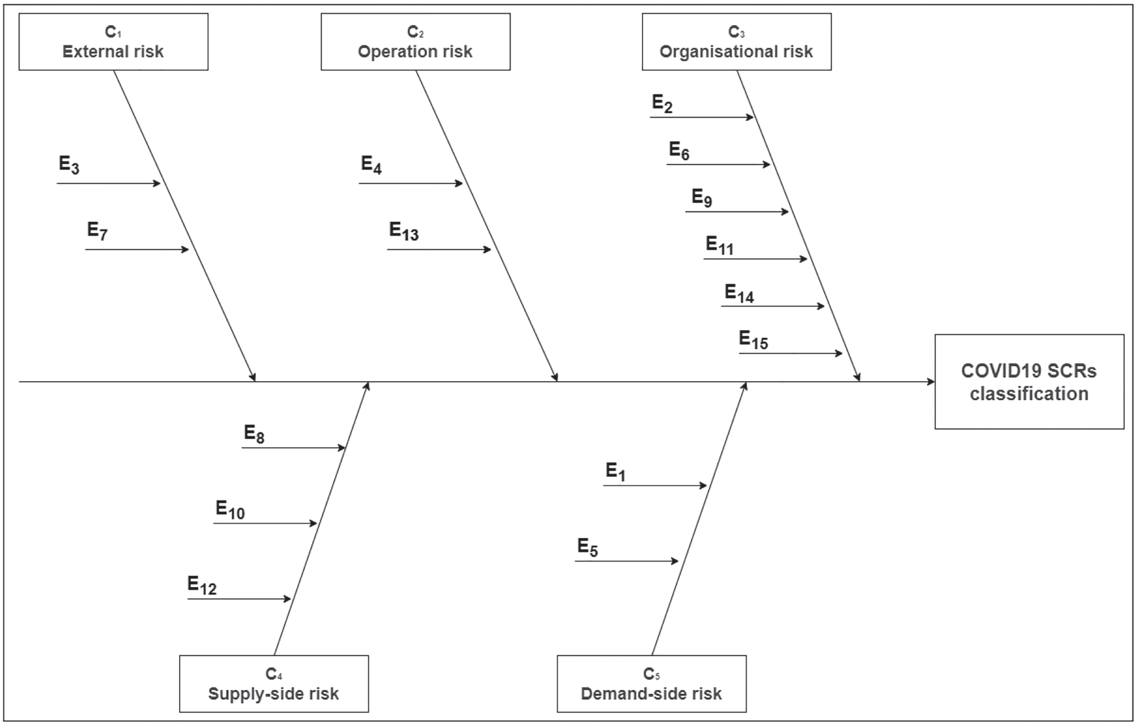

FIGURE 1 Fishbone diagram representing the most critical risks and the related effects.

cancelations have been registered. In addition, delays in payments are becoming the normality at this moment in time.

The final output of the brainstorming process is shown in Table 2. The five major risks have been codified as $C_i(i = 1, \dots 5)$. These risks will constitute the set of evaluation criteria in the following combined MCDM application, while effects $E_j(j = 1, \dots 15)$ will constitute the set of subcriteria for the ANP application. Results are graphically represented through the fishbone diagram shown in Figure 1.

2.2 | Contingency strategies for managing supply chain risks

We have already underlined as SCR management plays a fundamental part in guaranteeing competitiveness and effectiveness of business processes and companies. Several contingency strategies have been analyzed in the literature to face supply chain disruptions. We describe next the five main strategies developed in such a direction and codify them as $S_i(i = 1, \dots 5)$. These strategies will constitute the set of alternatives to be ranked by means of the FTOPSIS application.

- S_1, stability: Ability to return to a pre-disturbance state and ensure business continuity [54, 55];
- S_2, robustness: Ability to withstand a disruption (or a series of disruptions) while maintaining the planned performance [56, 57];
- S_3, resilience: Ability to withstand a disruption (or a series of disruptions) and quickly recover the original performance [5, 58];
- S_4, agility: Capability of the supply chain to adapt or respond quickly to the dynamic and unpredictable business environment [59];
- S_5, viability: Ability to meet demand and keep competitiveness for surviving in a changing environment [53].

Next, among the described contingency strategies, we select the one representing the best option for facing COVID-19 effects on supply chain networks.

3 | INTEGRATED MCDM APPROACH

This section is aimed at providing methodological details about the techniques proposed in the present paper. As already explained, we are going to face the problem of contingency strategy selection on the basis of a previous analysis of risks related to COVID-19. Specifically, the ANP is herein proposed as a risk assessment tool. The risks identified in the previous sections will be processed in relation to their related subcriteria and the weights expressing their relative importance will be calculated. The obtained vector of criteria weights will be used among the input data necessary for the consequent FTOPSIS application. Risks will be considered as evaluation criteria to establish the contingency strategy representing the best trade-off for risk management optimization.

The reasons why these two methodologies have been chosen among the plethora of existing MCDM techniques to carry out the present analysis are explained next.

- The ANP enables solving complex decision-making problems by breaking them down into a suitable hierarchical structure in which independence associated with elements can be evaluated, which plays an important part in making final decisions [60].
- Despite its more complex computational application [61], ANP outperforms other methods applied in practice for calculating weights, such as, for example, AHP or BWM, for which relationships of dependence are not taken into account, potentially leading to arguable results.
- ANP has been proven to be quite effective in the field of supply chain risks while observing the cause-effect relationships evidenced as intrinsic risk features [62].
- FTOPSIS has been successfully applied in the supply chain management field [63] and the use of fuzzy logic is considered to be valuable in getting realistic evaluations [64].
- To the best of the authors' knowledge, the proposed integrated approach has not been implemented before for managing the problem of contingency strategy selection under risk conditions considering COVID-19. In this direction, the implementation of this framework can represent a novel approach to deal with a currently urgent topic of research.

3.1 | The ANP to analyze and weight risks

The ANP, first implemented by Thomas Saaty [65] as a follow-up of the AHP technique [66], is a useful tool commonly applied to evaluate sets of decision-making elements (called nodes in the method context). Its purpose is to produce a vector of weights by considering the possible interdependences among the nodes, which are categorized into clusters (viz., criteria, subcriteria, and alternatives) to build the hierarchical structure of the decision-making problem, whose general goal has been specified previously (see [67] among others). Specifically, weights of alternatives are calculated with respect to criteria and subcriteria, weights of subcriteria with respect to criteria, and, lastly, criteria weights are determined with respect to the main goal. In the present paper, however, the ANP application is conducted only to evaluate criteria (i.e., main risks) and subcriteria weights (i.e., effects). We are indeed suggesting a hybrid procedure so that alternatives (i.e., strategies) are treated by means of the FTOPSIS procedure. The ANP technique is implemented by performing the following six stages consecutively.

1. Representing the decision-making problem by means of a hierarchical structure, clearly defining clusters and nodes. Once the structure has been fixed, relations of interdependence among the nodes (that may occur among nodes belonging to the same clusters and also among nodes belonging to different clusters) have to be established. At this stage, opinions provided by a decision-making team of experts in the field of the problem may highlight any possible relation.
2. Building the influence matrix, in which relations identified during the previous stage are formalized. Specifically, the influence matrix is a square block matrix, whose size equals the total number of nodes, whose blocks correspond to the identified clusters, and whose entries a_{ij} are equal to 1 if a relation of dependence between element j over element i exists, and 0 otherwise. This matrix acts as a template for the non-zero elements of the matrix described next.
3. Building the unweighted supermatrix (following the non-zero-entry structure of the influence matrix) by pairwise comparing those nodes for which a relation of dependence has been identified ($a_{ij} = 1$), and by calculating weights for the corresponding elements in each cluster (the AHP may be applied to calculate those weights). We herein specify that, in our case, comparisons have to be performed: (1) Between pairs of criteria, (2) between pairs of criteria and subcriteria, and (3) between pairs of subcriteria. The calculated weights will be the entries of the unweighted supermatrix. The sums of the columns of the unweighted supermatrix must equal the number of clusters for which comparison has been performed.
4. Producing the weighted supermatrix by means of a normalization procedure. The sums of the columns of the weighted supermatrix will be equal to one and, in such a way, the matrix gets stochastic.

5. Obtaining the limit matrix by raising to powers the weighted matrix. All the columns of the limit matrix are equal, each one of them representing the global priorities, which will have to be eventually normalized in relation to each cluster to produce meaningful information.
6. Formalizing the final vectors of weights, which embody the interdependencies accumulated throughout the successive powering of the weighted matrix. Elements with associated higher values should be preferred and, in any case, will have major prominence in leading the decision-making process.

3.2 | The FTOPSIS for contingency strategy selection

The MCDM method FTOPSIS was developed by Chen [68] as an extension of the traditional TOPSIS [69] under a fuzzy environment. As pointed out in [70], traditional TOPSIS is widely applied in practice as a methodology able to rank even huge numbers of alternatives on the basis of their crisp ratings on different quantitative and/or qualitative criteria. However, in practical real-life situations, input evaluations required by the technique are often affected by uncertainty so the use of fuzzy numbers represented by linguistic variables is certainly more realistic. Eliciting crisp numerical values may indeed be difficult, especially in processes permeated with uncertainty, such as risk management.

As already highlighted, FTOPSIS is proposed in the present paper for ranking contingency strategies on the basis of the main risks herein considered as evaluation criteria and previously weighted by means of the ANP. Specifically, FTOPSIS is based on the concept of distances between each alternative and the fuzzy positive and negative ideal solutions. The best alternative among the set of evaluated contingency strategies will be that one characterized by its shortest distance from the fuzzy positive ideal solution and its larger distance from the fuzzy negative ideal solution.

A description of the FTOPSIS implementation may be found elsewhere, for example, in [71].

4 | REAL CASE STUDY ON THE AUTOMOTIVE SECTOR

We apply now the proposed integrated MCDM approach to a real case study in the field of the automotive industry. We aim to rank strategies and eventually select the one that will demonstrate to be the most effective in facing COVID-19 effects on supply chains. One has to note that the chosen field of application is extremely complex, critical, and vulnerable under current conditions, having been particularly affected by the pandemic outbreak. It has been reported how sales

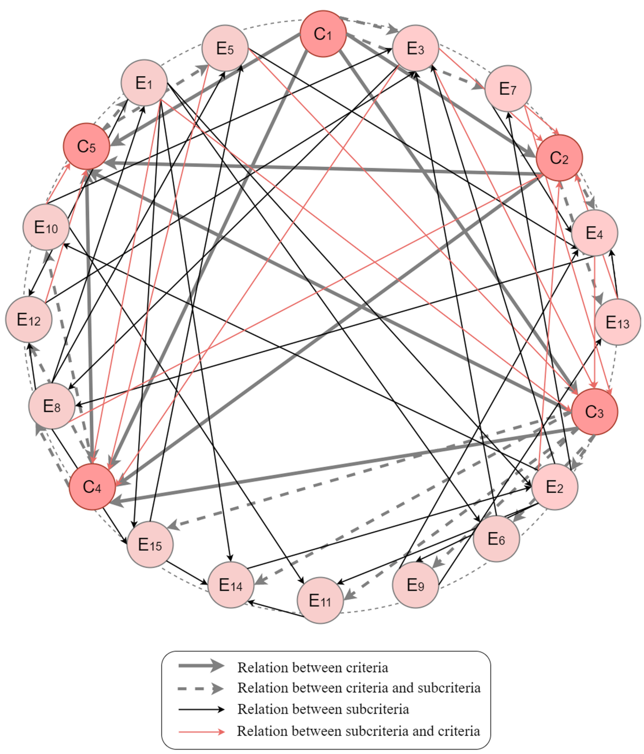

FIGURE 2 Relationships of dependence bonding criteria and subcriteria. [Colour figure can be viewed at wileyonlinelibrary.com]

referring to this sector have dramatically decreased over the last year with respect to the previous year. Such a reduction in profit has hugely impacted the financial health of the automotive business, so several companies are facing the drastic decision of reducing their workforce. Moreover, management strategies are completely changing in the automotive sector due to severe financial problems, and spending restrictions have been adopted worldwide, in many cases causing painful project cancelations.

For these reasons, we believe that our approach may be beneficial for the automotive industry. Its application, nonetheless, may also be extended to other business sectors.

TABLE 3 Unweighted matrix produced within the ANP procedure.

	G	C_1	C_2	C_3	C_4	C_5	E_3	E_7	E_4	E_{13}	E_2	E_6	E_9	E_{11}	E_{14}	E_{15}	E_8	E_{12}	E_{10}	E_1	E_5
G	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C_1	0.29	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	1.00	0.00	0.00	1.00	0.00	0.00	0.00
C_2	0.13	0.25	0.00	0.50	0.00	0.00	0.30	0.50	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00
C_3	0.07	0.25	0.00	0.00	0.00	0.00	0.30	0.50	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.50	0.50
C_4	0.19	0.25	0.50	0.25	0.00	1.00	0.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.50	0.50
C_5	0.32	0.25	0.50	0.25	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	1.00	0.00	0.00
E_3	0.03	0.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.11	1.00	0.00	0.00	0.00	0.00	0.00	1.00	0.46	0.00	0.00
E_7	0.06	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.34	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
E_4	0.07	0.00	0.80	0.00	0.00	0.00	0.00	1.00	0.00	1.00	0.00	0.00	0.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00
E_{13}	0.07	0.00	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
E_2	0.02	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.09	0.19	0.00
E_6	0.02	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.00
E_9	0.04	0.00	0.00	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
E_{11}	0.07	0.00	0.00	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.46	0.00	0.00
E_{14}	0.14	0.00	0.00	0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.88	0.00	0.00	0.00	0.23	0.00
E_{15}	0.16	0.00	0.00	0.45	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.00	0.00	0.40	0.00
E_8	0.07	0.00	0.00	0.00	0.71	0.00	1.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
E_{12}	0.04	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.15	0.00	0.00	0.11	0.00
E_{10}	0.06	0.00	0.00	0.00	0.19	0.00	0.00	0.00	0.00	0.00	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
E_1	0.12	0.00	0.00	0.00	0.00	0.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.42	0.00	0.00	0.00	0.00
E_5	0.03	0.00	0.00	0.00	0.00	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.13	0.11	0.00	0.00	0.00	0.00

TABLE 4 Weighted matrix produced within the ANP procedure.

	G	C_1	C_2	C_3	C_4	C_5	E_3	E_7	E_4	E_{13}	E_2	E_6	E_9	E_{11}	E_{14}	E_{15}	E_8	E_{12}	E_{10}	E_1	E_5
G	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C_1	0.14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.50	0.50	0.00	0.00	0.33	0.00	0.00	0.00
C_2	0.07	0.13	0.00	0.25	0.00	0.00	0.15	0.25	0.00	0.50	0.00	0.00	0.00	0.00	0.00	0.00	0.50	0.00	0.00	0.00	0.00
C_3	0.04	0.13	0.00	0.00	0.00	0.00	0.15	0.25	0.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.25
C_4	0.10	0.13	0.25	0.13	0.00	0.50	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.25
C_5	0.16	0.13	0.25	0.13	0.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.50	0.00	0.00
E_3	0.02	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.11	1.00	0.00	0.00	0.00	0.00	0.00	0.33	0.23	0.00	0.00
E_7	0.03	0.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.34	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
E_4	0.03	0.00	0.40	0.00	0.00	0.00	0.00	0.50	0.00	0.50	0.00	0.00	0.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.50
E_{13}	0.03	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
E_2	0.01	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.50	0.00	0.00	0.00	0.05	0.09	0.00
E_6	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00
E_9	0.02	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
E_{11}	0.03	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.23	0.00	0.00
E_{14}	0.07	0.00	0.00	0.15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.50	0.00	0.88	0.00	0.00	0.00	0.12	0.00
E_{15}	0.08	0.00	0.00	0.22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.16	0.00	0.00	0.20	0.00
E_8	0.04	0.00	0.00	0.00	0.36	0.00	0.50	0.00	0.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
E_{12}	0.02	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.00	0.00	0.06	0.00
E_{10}	0.03	0.00	0.00	0.00	0.09	0.00	0.00	0.00	0.00	0.00	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
E_1	0.06	0.00	0.00	0.00	0.00	0.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.21	0.00	0.00	0.00	0.00
E_5	0.01	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.13	0.05	0.00	0.00	0.00	0.00

4.1 | ANP application

This subsection presents the application of the ANP technique to calculate risk weights by simultaneously taking into account relationships of dependence among them and also those links bonding risks with effects and effects with each other. SCRs are indeed deeply interconnected [62, 72].

Figure 2 graphically formalizes these relations for the identified sets of risks and effects.

The unweighted matrix has been obtained from the established relations of influence, specifically by pairwise comparing those nodes for which a link has been identified (Table 3). We have used the AHP to determine the priorities shown in the unweighted matrix, whose columns have been normalized to sum one to get the weighted matrix of Table 4.

The limit matrix has been eventually obtained by raising the weighted matrix to successive powers until achieving convergence. By performing a normalization operation of any of these (identical) columns, it is possible to express the final vector of criteria weights. The values of any of the columns of the limit matrix are shown in Table 5 with relation to risks and effects. Their weights expressed in percentages are also indicated.

Results derived from the ANP procedure show as prominent importance is attributed to supply-side and demand-side risks. Operation and organizational risks have associated weights representing intermediate importance, while COVID-19 effects referring to external risk have the lower weights for selecting the most suitable contingency plan.

After having calculated the risks weights and analyzed their relations of influence with the related effects potentially affecting business contexts in the COVID-19 era, we apply now the FTOPSIS to select, among the five strategies discussed in Section 2.2, that contingency strategy representing the most suitable trade-off to minimize COVID-19-related risks and, consequently, the negative impact of the related effects. We further underline that risks will be considered as evaluation criteria for the FTOPSIS application, and the weights calculated through the ANP will be treated as a part of the input data.

4.2 | FTOPSIS application

In this subsection, we present the FTOPSIS application for ranking the strategies. The five analyzed contingency strategies have been evaluated under the five evaluation criteria representing risk conditions, which are going to be minimized when applying the technique. Input evaluations collected in Table 6 have been attributed by involving a decision-making

TABLE 5 Risks and effects weights.

Risk	Limit matrix value	% Weight	Effect	Limit matrix value	% Weight
C_1	0.0484	10.68%	E_3	0.0346	60.65%
			E_7	0.0225	39.35%
C_2	0.0894	19.71%	E_4	0.0680	84.54%
			E_{13}	0.0124	15.46%
C_3	0.0732	16.13%	E_2	0.0430	23.36%
			E_6	0.0031	1.70%
			E_9	0.0070	3.79%
			E_{11}	0.0179	9.72%
			E_{14}	0.0676	36.71%
			E_{15}	0.0455	24.72%
C_4	0.1254	27.65%	E_8	0.0960	70.82%
			E_{12}	0.0172	12.66%
			E_{10}	0.0224	16.52%
C_5	0.1172	25.83%	E_1	0.0669	74.88%
			E_5	0.0225	25.12%

TABLE 6 Input linguistic evaluations for the FTOPSIS application.

Plans/criteria	C_1 External risk	C_2 Operation risk	C_3 Organizational risk	C_4 Supply-side risk	C_5 Demand-side risk
S_1, stability	VH	VL	H	VH	VH
S_2, robustness	VL	L	L	VL	H
S_3, resilience	L	H	M	L	M
S_4, agility	M	VH	VL	M	L
S_5, viability	VL	VH	M	VL	VL

group of supply chain experts, by means of the following linguistic variables: VL, very low risk; L, low risk; M, medium risk; H, high risk; VH, very high risk.

Linguistic variables have been translated to Triangular Fuzzy Numbers (TFNs) (Table 7), whose scale is graphically represented in Figure 3. Table 8 presents the normalized values of the fuzzy input matrix.

The final step of the FTOPSIS application consists in calculating the closeness coefficient CC_i for each alternative S_i, by means of which the final ranking will be drawn up. These coefficients are given in Table 9 for each strategy, where also values obtained in two supplementary scenarios are presented. These various scenarios have been considered to perform a sensitivity analysis aimed at testing the robustness of the final solutions and validating the final ranking of the five contingency strategies under the considered risk conditions.

Scenarios considering light perturbations of the obtained criteria weights are as follows:

- Scenario 1 (basis scenario): The weights are those obtained from the ANP application. This scenario will serve to build a comparison with values obtained in the other scenarios.
- Scenario 2: With respect to the weights obtained from the ANP application, we keep the same value for risk C_1, while increasing the values of C_2 and C_3 by 0.05 and decreasing the values of C_4 and C_5 by 0.05.
- Scenario 3: With respect to the weights obtained from the ANP application, we keep the same value for C_1, while increasing the values of C_2 and C_3 by 0.10 and decreasing the values of C_4 and C_5 by 0.10.

TABLE 7 Fuzzy input matrix.

Plans/criteria	C_1			C_2			C_3			C_4			C_5		
S_1	7	9	9	1	1	3	5	7	9	7	9	9	7	9	9
S_2	1	1	3	1	3	5	1	3	5	1	1	3	5	7	9
S_3	1	3	5	5	7	9	3	5	7	1	3	5	3	5	7
S_4	3	5	7	7	9	9	1	1	3	3	5	7	1	3	5
S_5	1	1	3	7	9	9	3	5	7	1	1	3	1	1	3

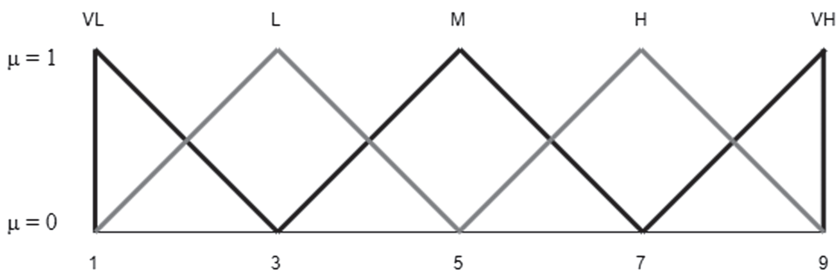

FIGURE 3 Scale for translating linguistic variables to TFNs.

TABLE 8 Fuzzy weighted matrix.

Plans/criteria	C_1			C_2			C_3			C_4			C_5		
S_1	0.01	0.01	0.02	0.07	0.20	0.20	0.02	0.02	0.03	0.03	0.03	0.04	0.03	0.03	0.04
S_2	0.04	0.11	0.11	0.04	0.07	0.20	0.03	0.05	0.16	0.09	0.28	0.28	0.03	0.04	0.05
S_3	0.02	0.04	0.11	0.02	0.03	0.04	0.02	0.03	0.05	0.06	0.09	0.28	0.04	0.05	0.09
S_4	0.02	0.02	0.04	0.02	0.02	0.03	0.05	0.16	0.16	0.04	0.06	0.09	0.05	0.09	0.26
S_5	0.04	0.11	0.11	0.02	0.02	0.03	0.02	0.03	0.05	0.09	0.28	0.28	0.09	0.26	0.26

TABLE 9 Closeness coefficient values and rankings by varying criteria weights.

	Scenario 1		Scenario 2		Scenario 3	
Plans	CC_i	Ranking position	CC_i	Ranking position	CC_i	Ranking position
S_1	0.0537	5th	0.0611	5th	0.0685	4th
S_2	0.1151	2nd	0.1173	1st	0.1194	1st
S_3	0.0729	4th	0.0684	4th	0.0639	5th
S_4	0.0814	3rd	0.0825	3rd	0.0836	3rd
S_5	0.1190	1st	0.1061	2nd	0.0932	2nd

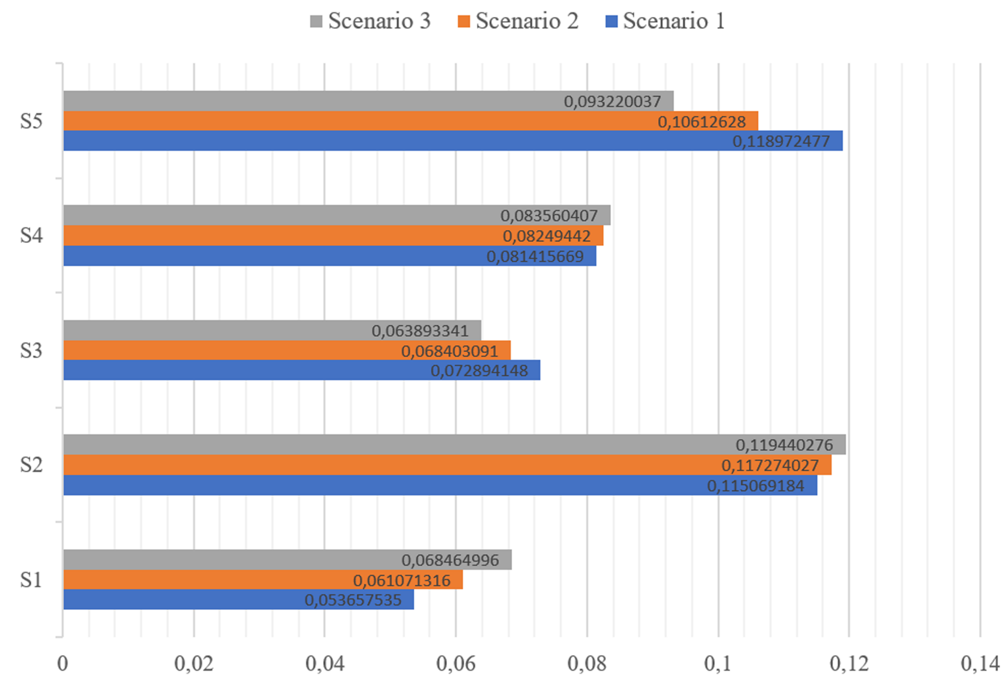

FIGURE 4 Sensitivity analysis on CC_i values by varying criteria weights. [Colour figure can be viewed at wileyonlinelibrary.com]

Results obtained by performing the sensitivity analysis are graphically synthesized in Figure 4, which offers various information for final discussion.

We can observe as, on the whole, CC_i values are subjected to low variations when changing the criteria weights, which confirms the global robustness of the obtained rankings for the supply chain risk strategies.

4.3 | Results discussion and managerial insights

In the basis scenario (when criteria have associated the same weights from the ANP procedure), the most suitable contingency strategy to face COVID-19 appears to be strategy S_5 (viability). In both the second and third scenarios, when progressively increasing the importance of operation and organizational risks while decreasing the weights associated with supply-side and demand-side risks, the best strategy results to be S_2 (robustness).

The obtained results are logical since the viability strategy is a particularly effective way to face phenomena characterized by a high degree of uncertainty, such as COVID-19. This strategy aims to reinforce contingency plans at a wider level and generally improve the responsiveness of companies. When it comes to the robustness strategy, it aims to build a more efficient and solid supply chain system capable to manage the impacts of the COVID-19 outbreak. We recommend choosing either viability or robustness as the contingency strategy depending on the importance that companies prefer to attribute to criteria weights.

Furthermore, strategy S_4 (agility) keeps the third position by varying criteria weights. Strategies S_1 (stability) and S_3 (resilience) are placed at the end of the ranking. Specifically, resilience occupies the last position in the third scenario, while stability occupies the last position in the first and second scenarios. A stability strategy may be the less suitable to face COVID-19 impacts since this pandemic requires important changes to be quickly implemented on contingency plans with a consequent impact on how the company could survive in such circumstances.

The final selection of strategy carried out in Scenario 1 (basis scenario) hence suggests the selection of the viability strategy as the most suitable alternative in the automotive sector. However, the robustness strategy can be selected to be eventually implemented if the company prefers attributing more importance to the minimization of operation and organizational risks. We specify that these results are valid in the business field selected for the proposed case study. Of course, they may be different by varying input evaluations according to other specific needs of a company. In any case, the methodological framework herein proposed can be applied to any sector to lead toward the selection of the best contingency strategy and can also be easily implemented by just collecting and treating evaluations provided by suitable decision-making groups.

5 | CONCLUSIONS

The COVID-19 pandemic is negatively impacting the performance of worldwide supply chains. In such an uncertain and precarious context, the present paper proposes an MCDM framework dealing with the decision-making problem of selecting the most suitable contingency strategy aimed at minimizing risk conditions and negative effects derived from COVID-19. The research need is clear since many companies are struggling from a managerial point of view to cope with the current situation. Specifically, a set of possible strategies studied in the literature have been treated as decision-making alternatives to be evaluated under criteria represented by significant risks connected to supply chain management.

First, the ANP is used to calculate risks' weights on the basis of various interdependences, and also by taking into account relationships existing with regard to the occurrence of potential COVID-19 effects. Effects have been explored by leading a detailed literature review by means of which 13 effects have been identified. With the help of experts in the industrial field, we were able to derive two further effects, that may contribute to state-of-the-art literature on the subject. Second, on the basis of the relative importance attributed to risks, a final ranking for contingency strategies has been obtained by applying the FTOPSIS technique, which is known to efficiently manage uncertainty affecting input evaluations, herein collected in terms of linguistic variables.

The approach has been practically applied to the automotive sector by means of a real-world case study. We note here that the ANP is a procedure based on subjective evaluations, and that the calculated weights have been considered as input data in the FTOPSIS application. This is the reason why we have implemented a necessary sensitivity analysis on risk weights. If supply-side and demand-side risks are more important for companies since they prefer to minimize the impact of the related effects, implementing the viability strategy may be beneficial. The robustness strategy is recommended, however, when companies associate higher importance to such aspects as operation and organizational risks, as a result of the related effects being potentially more dangerous for their business performance.

We lastly underline that these results are valid for the analyzed case study in the field of the automotive sector. They can obviously change depending on the business field and the use case analyzed. However, the proposed framework keeps its methodological validity and can be applied to any context just by adapting input evaluations.

CONFLICT OF INTEREST STATEMENT

This work does not have any conflicts of interest.

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