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A DECISION SUPPORT MODEL FOR MITIGATING SUPPLY CHAIN RISKS BASED ON A MODIFIED FMEA, MULTI-OBJECTIVE OPTIMIZATION AND MULTI-CRITERIA DECISION-MAKING APPROACH

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Abstract:
Recent years have seen a huge development in the subject of supply chain risk management. In this increasingly uncertain world, the use of practical and effective tools for decision making and risk mitigation has become more necessary than ever. In this research, mitigation strategies for a tier one multinational company operating in the automotive industry and providing an assembly operation to final customer Renault Tanger and Renault SOMACA were prioritized according to their effectiveness, as well as their implementation costs. Based on research in the literature and the opinions of experts in the field. 44 risks and 55 mitigation strategies were identified. FMEA (Failure Modes and Effects Analysis) method was used based on the latest AIAG 2019 edition to filter and identify the risks to be prioritized, we used then a multi-objective optimization approach to identify the mitigation strategies that constitute the Pareto front for each of the risks and finally used the EDAS method for the final ranking of the strategies. Our case revealed that strategies like ensuring elaborating a contingency planning and defining the responsibilities, imposing contractual obligations on subcontractors, applying a flexible supply contract were found to be relevant risk mitigation strategies for the company. Managers interested in mitigating risk can deploy this model to prioritize risk mitigation strategies.

Key words: *risk mitigation strategies, multi-criteria decision making, efficiency, Supply chain risk management, multi-objective optimization*

INTRODUCTION

In the ongoing industry circumstance, numerous ambiguities influence the business working climate. The development of globalization and subcontracting has given development to Supply chain management issues [1]. Present day organizations are overall altogether impacted by continuous and significant changes in innovation, current developments, fast globalization, extraordinary rivalry and worldwide outsourcing, and so forth, which are all driving organizations to confront an increased amount of risk [2].

Supply chains involve several stakeholders, with different environmental, social, economic, and ethical attributes, and are exposed to various risks along all stages [3]. It focuses on incorporating a company's inward processes with the outside climate [4].

Management of risks in Supply chains has acquired expanding consideration throughout the past years [5]. It aims to recognize expected risks, diminish them and mitigate their effects, [6]. It is an orderly cycle to protect mission critical functions by regulating susceptibilities, weaknesses, and dangers all through a supply chain network. The cycle adopts a four-step strategy towards the management of risk (identification, evaluation, treatment, and monitoring) in accordance with the ISO 31000 rules [7]. Those steps are as yet fundamental to the success of supply chains [8]. Supply chain risks are present in all companies doing business. There already exists an enriched collection of supply chain risk management (SCRM) related research works which address the uncertainties in supply chains of different industries by assessing risks from different perspectives [2]. Researchers have been underlining, consequently, the need to build strong supply chains to advance fast recuperation from disruptions [8].

Risk is the effect of uncertainty on objectives, and it is expressed usually in terms of risk sources, potential events, their likelihood, and consequences [9]. It can appear through partners' reactions, when they consider

organizations answerable for troublesome circumstances in the supply chain, prompting reputational damage [3].

Outer emergencies, like the Coronavirus pandemic widespread affect organizations and their supply chains and require a significantly more grounded accentuation on efficient risk management approaches. Other examples of events that caused interruptions can be found below:

- In May 2018, Huawei was recorded in the entity list of the United States commerce department. The upstream supply section was interfered, bringing about the compression of abroad business. Companies that exchanged with Huawei likewise lost significant income sources, and the worldwide technology supply chain experienced a serious blow [10].
- The Brexit increased food supply chain costs, shortages in Northern Ireland general stores, and caused more expenses for producers [11].
- The Suez Canal was blocked after giant container ship gets stuck 2021, The Suez channel is a critical supply route for oil streams from the Persian Bay locale to Europe and North America. About 5% of worldwide exchanged unrefined petroleum and 10 percent of refined oil based goods went through the canal before the pandemic [12].
- Worldwide shortage in PC ships arrives at emergency point, at first the issue was just an impermanent delay in provisions as plants shut down when the Covid pandemic originally hit [13].
- An aggressive battle about containers made transportation costs rocket by 300% [14].
- Since the fall of 2020, that there are significant shortages of steel and treated steel in Europe. The US is likewise more than once revealing that there is a lack of material there [15].
- A report by risk the executive's organization Interos has found, and it cautioned struggle between the Russia and Ukraine could put "thousands" of organizations across the globe in danger. Interos found in excess of 1,100 US-based firms and 1,300 European firms have no less than one direct provider in Russia. In excess of 400 firms in both the United states and Europe have level one suppliers in Ukraine [16].

To date, research has proposed a few separate risk management strategies considering the kinds of risks in supply chains. but few strategies for the entire Supply chain risk management process of an integrated network. This can be explained by the large number of both risk variables and their associated reduction strategies [4]. Basically, a powerful supply chain strategy would permit a firm to execute contingency plans proficiently and effectively when confronted with an interruption [4].

The automotive industry in Morocco has experienced real growth and development over the last ten years thanks to the policy put in place by the Moroccan government. Key area in the public modern strategy, since the 2000s, the vehicle business discharge a two-digit yearly development. It is the first exporting sector, Morocco leads the African automotive industry with a production capacity of 700.000 vehicles a year, the supply chain is currently made of 250 global players serving automotive facilities in 75 global destinations of export [17]. Exports this year will reach 138 billion dirhams (12 billion euros), the current local integration rate is 60%, and the sector employs more than 220k people in the country. Morocco is ambitioning also to be the most competitive platform worldwide [1].

The main purpose of our study is to answer the following questions:

- What are the risks that threaten automotive supply chains?
- How can we prioritize them?
- What are the strategies for risk mitigation in the automotive industry?
- What model is proposed for decision makers to prioritize those strategies and what are the main criteria for selection?

This exploration supplements the current literature on SCRM by proposing a complete structure that works with a viable correspondence of supply chain risks and assessment of mitigation strategies.

It fosters a comprehensive decision support tool by integrating multi-objective optimization and multi-criteria decision-making techniques that empowers companies to manage the supply chain risks in a proficient way. The exploration likewise expects to make reasonable commitments by showing how the proposed system can be utilized by manufacturing companies.

Research sections are coordinated as follow. Section 2 provides a literature review, research approaches on supply chain risk assessment and risk mitigation strategies. Section 3 explains the methodology. In Section 4, an illustration is presented to exhibit its usefulness. In Section 5, the results of the study will be showed. Findings from our case are discussed in Section 5, which additionally gives conclusions and recommends future research directions.

LITERATURE REVIEW

Supply chain risk management and risk identification

One of the most interesting areas of academic research is that of risk management, it is drawing in a lot of consideration from specialists and practitioners. Supply chain risk management can be defined as the intersection of two main areas, risk management and supply chain management. Considering the number of definitions provided in the past, one cannot point to a specific meaning of risk management in supply chain management. Several authors have defined supply chain risk management in different ways.

A definition from a holistic view has been proposed by [18], They confirmed that it is the implementation of internal tools, techniques and strategies as well as the coordination of internal and external supply chain collaborators for the identification, treatment and monitoring of supply chain risks. Supply chain risk management can be defined as the management through coordination between the different collaborators in the supply chain to ensure profitability and continuity; it is the capacity of the organization to comprehend and deal with its economic, environmental and social dangers inside the supply chain [19]. Risk can have several

definitions depending on the research domain. If we talk specifically about supply chain management, risk is seen for its unwanted results [20, 21], claimed that risk is the potential occurrence of an incident, which may cause the failure to meet the customer need. [22] found that while globalization and internalization may offer opportunities to increase revenues and reduce costs, it may also increase the complexity of supply chains, and thus their vulnerability to risk. [23] confirmed that the field of risk management must be applied both inside and outside of companies in order to identify major events that may affect and address the risk; the objective being the sustainability and achievement of the main objectives of the company.

There are several risks threatening supply chains, which can be segmented into several categories. The first one is that of risks related to human resources that have a direct impact on supply chains, such as the lack of qualified personnel [24], labor disputes and conflicts [25], disasters within the plant [26], theft [27], language and culture problem [1].The second category of risk is that related to end-customer such as inaccurate or variable sales and demand forecasts [28] and uncertainty of supply and demand [29] we can also find the category of risks related to customs such as import and export restrictions and tariffs [30].

The fourth category of risks is that of engineering and process risks, such as the risks related to the capacity [30] and deteriorated production performance [31].The fifth category of risks is related to financial and economic risks, we can mention for example, the impact of inflation and exchange rate changes [32], bankruptcy and insolvency of the supplier [1], cash-flow disruptions [33]. Sixth category is related to infrastructure and IT as bottleneck-congestion of infrastructure [24] or failure of the information infrastructure, breakdowns related to the information system and hacking [31].

The seventh category is related to internal maintenance risks, where we can mention the risks of technical problems on the machines causing their stops [1] as well as the risks related to the high maintenance costs [33].

The category of natural hazards, such as catastrophic events in the plant [1] problems related to extreme weather and natural disasters [33] , can cause huge disruptions to supply chains. The eighth category is problems related to physical flows , such as inventory differences [31] and problems in the logistic equipment [32].

An additional category of risk is political risk, like wars and terrorist attacks [30] as well as political agitation [27]. The tenth category is related to purchasing and suppliers demand , such as the increase in the purchase price of the raw material in the world markets [31] as well as legislative actions on import and global sourcing [25]. Regarding supplier risks, we can specify the risks connected with the assembling capacity of the suppliers [28], dependence on a single source of supply [25] as well as the inflexibility of the source of supply [31]. Finally, we can mention other categories of risks such as external service providers, safety, quality, and management risks.

Failure mode and effects analysis

In order to avoid many incidents with military products in the US, the national standard MIL developed in the past some procedures used for performing a criticality, failure mode and effect analysis. Some major car producers made attention to this phenomenon and wanted to put in place some procedures also.

Since in the automotive industry, there are mass and repeated failures, the OEMs (original equipment manufacturer) were forced to withdraw large quantities of cars to resolve the issues on them , resulting colossal financial losses [34]. Some examples:

- Possible airbag faults forces Toyota to recall 1.7M cars in 2018 [35].
- Certain failure of the fuel system forced the car manufacturer Mazda to recall 42000 cars on 2014 [36].

Starting the year 2019, a significant change in the methodology was carried out, by rejecting the RPN value calculation (Multiplication of Severity*occurrence*detectability) and replacing it by a special table. They determine the actions priority (AP) depending on the parameters S, O, D combinations [34].

In order to assist the suppliers in the development of FMEA, VDA and the AIAG jointly published a FMEA handbook to be used. There are many issues in adopting the reference manual since the new handbook is newly published in June 2019 [37]. As the standard is new, there is little examination or contextual analyses on it. A lot of improvements are constantly made. [34] informed that the main steps of the FMEA method are, first, the planning of actions, then the analysis of the elements interaction, followed by the analysis of the functions impact, the next step is the analysis of the structure refusals followed by the quantitative risk assessment. The two final steps are the improvement of the process and finally the documentation of the results.

The severity, occurrence and detectability determine the action priority. The way to deal with measurement of the actual parameters stays unaltered.

The new proposal uses three levels of priority actions (AP) to prevent the process failure: H (high), M (medium), L(low). Improvement actions are mandatory if the action priority is high, they are necessary if the action priority is medium and recommended if it is low [34].

For IATF certified organization, there is no specific transition period to adopt the 2019 AIAG/VDA FMEA framework. For the new projects, there is a specification from several carmakers to their supplier that they should adopt the new FMEA framework. The table utilized comprise of north of 100 cells and possesses 2 pages of the norm. As an option in contrast to the AP table, a company ought to consider making an AP matrix, for example, the one displayed in

Figure 1 it is a rating method introduced in the AIAG & VDA failure mode and effects analysis – FMEA Handbook. The AP provides a priority level based on severity, occurrence, and detection values, It was developed in order to give more emphasis to severity first, then occurrence, and then detection. Action priority values may be: ‘High’: these items are the highest priority for review and action. ‘Medium’: these

items are medium priority for review and action. 'Low': these items are low priority for review and action.
The AP values are determined based on the values of the Severity, Occurrence, and Detection fields [1].

		Severity 1	Severity 2-3			Severity 4-6				Severity 7-8				Severity 9-10			
Occurrence	8-10	L	L	L	M	M	M	H	H	H	H	H	H	H	H	H	H
	6-7	L	L	L	L	L	M	M	M	M	H	H	H	H	H	H	H
	4-5	L	L	L	L	L	L	L	M	M	M	M	H	M	H	H	H
	2-3	L	L	L	L	L	L	L	L	L	L	M	M	L	L	M	H
	1	L	L	L	L	L	L	L	L	L	L	L	L	L	L	M	H
		1-10	1	2-4	5-6	7-10	1	2-4	5-6	7-10	1	2-4	5-6	7-10	1	2-4	5-6	7-10
		Detection																

Fig. 1 Action priority matrix

Risk mitigation strategies

Several studies have been conducted in the past by different authors around risk mitigation strategies in supply chains. These studies have proposed appropriate strategies for each type of industry, most of the studies have classified the strategies as reactive and proactive. Table 1 represents a synthesis of the strategies discussed previously in the literature.

Table 1

Risk mitigation strategies proposed in the literature

Author	Strategies treated
[38]	Increase flexibility; Apply the buffer strategies: Increase security stock level; Increase alignment, adaptability and agility; Increase Supply chain agility and information sharing.
[39]	Increase Supply chain agility and information sharing, trust, and collaborative relationships;
[40]	Apply the multi-sourcing strategy; Find alternative supply sources; Implement backup production; Increase flexibility; Supplier selection improvement
[41]	Multiple suppliers; Flexible Supply contract; Supplier selection; Postponement; Responsive pricing; Flexible production or manufacturing; Control strategies; Robust supply chain strategies; Increase supply chain capacity through enhanced partnership.
[42]	Information sharing implementation
[43]	Fine-tune supply chain design; Supply base strengthening; Supply contract flexibility; Dynamic assortment planning; Centralize demand; Capacity flexibility; Process standardization; Agile operations; Manufacturing flexibility; Risk hedging; Enhance visibility; Cross-training of employees; Product flexibility via postponement; Vindicate product ranges; Inventory flexibility; Logistics flexibility; Dynamic revenue management; Silent product rollover; Proliferate customer accounts; Responsive pricing strategies; Using insurance; Vindicate product ranges
[44]	Dropping specific products, geographical markets, supplier and or customer organizations; Vertical integration; Increased stockpiling and the use of buffer inventory; Maintaining excess capacity in productions, storage, handling or transport; Imposing contractual obligations on suppliers; Joint efforts to improve SC visibility and understanding; Joint efforts to share risks-related information; Joint efforts to prepare SC continuity plans; Postponement; Multiple sourcing; Localized sourcing
[45]	Adoption of industry 4.0 technologies; Supply chain collaboration; Shared responsibility
[46]	Increasing capacity; Redundant suppliers; Increasing inventory; Increasing responsiveness; Increasing flexibility; Aggregating demand; Increasing capability
[47]	Contingency planning; Speculation; Product bundling; Dynamic pricing; Information sharing; Demand switching
[48]	Manufacturing flexibility; The application of lean tools; Dedicated machinery; Narrow product lines; Postponement of final Assembly; Safety stock inventory; Excess capacity; Bridging strategies develop close relationships, monitor, cooperate, exchange information, and conduct joint activities with their supply chain network partners; Developing cooperative relationships with supply chain network partners; The sharing of strategic and transactional information.
[49]	Buffering; Bridging strategies
[50]	Cooperating to mitigation risks; Increase the ability to efficiently respond or adapt to change; Enhance the operational capability to reconstitute itself after disruption; Stimulate the ability to respond effectively to the changing dynamics in the market; Change order quantities between suppliers; Enhance the ability to develop in a constantly changing business environment
[51]	Predictive analysis tools for SCRM; Use risk indices to monitor risks continuously; Risk reporting and governance procedures in place; Dissemination of risk management practices through manuals; Inventory levels are visible throughout supply chain (SC); Demand information is visible throughout SC; Transportation visibility across the SC; Command group to analyze end-to-end operations; Maintain Organizations emergency plans; Keep control of the organization at all times; Defined contingency plan responsibilities; Post-event analysis and lessons learned; Defined meeting to share KPI; Partners priority on cost and delivery matches; Customers priority on delivery; Defined communication network protocol; Supplier ordering processes match with us; Cost pressure is borne by suppliers only; We educate our suppliers on SC risks; Our suppliers keep inventories for us; Risk and reward are shared
[52]	Developing agility; Multiple green sourcing and flexible capacity; Trust, coordination, and collaboration; Alignment of economic incentives and revenue sharing; Strategic risk planning for green objectives; Information sharing and visibility; Surplus green inventory; Hazard management and adoption of safety standards; Transferring and sharing of risks; Postponement; Flexible and multimodal transportation
[53]	Postponement; Strategic stock; Flexible supply base; Make-and-buy; Economic supply incentives; Flexible transportation; Revenue management; Dynamic assortment planning; Silent product rollover; Flexible supply contracts; Flexible manufacturing process
[54]	Add capacity; Add inventory; Have redundant supplier; Increase responsiveness; Increase flexibility; Aggregate or Pool Demand; Increase capability; Have More customer accounts

cont. Table 1

[55]	Collaboration with key suppliers; Sharing knowledge and resources; Finding universal source of suppliers; Faith and integration among the partners; Robustness; Resilient strategy; Lean strategy; Agile strategy; Flexible strategy
[56]	Avoidance; Investment in development activities; Control strategy; SC integration; External flexibility and internal flexibility; Redundant resources; Save additional inventory: safety stock; Supply chain collaboration; Risk-information-sharing mechanism; Proactive approach by avoidance; Securing, tracing the transportation media and cooperating with reliable supplier to reduce the need for inspection; Multiple sourcing strategies: supplier development activities; Redundancy resources and additional inventory; Constant interaction with suppliers and Supplier development activities; Cooperating with many suppliers and keeping the prices confidential and signing legal contracts with suppliers; Signing risk-sharing contract with suppliers; Consideration of global and economic factors in forecasting process; Postponement and shifting production and demand quantity across different products; Educating customers about what the company has done for the quality assurance to neutralize the rumors; Selecting 'safe' locations; Enforcing security; Identifying vulnerability of disasters and developing emergency plans; Ability to use flexible ways of transportation; Maintaining multiple facilities with flexible; redundant resources .
[57]	Avoidance; Postponement; Speculation; Hedging; Control; Sharing or transferring; Avoidance

Multi-criteria decision making and EDAS method

Multi-criteria decision making is a mathematical technique used in several decision-making practices; it is a field of research that involves the analysis of different possible choices in a specific field. It is likewise a process of showing up at the best proper solution from a bunch of accessible alternatives corresponding to a set of assessment criteria. Multi criteria decision making methods have been examined by different researchers and has been distributed in various scientific journals and proposed techniques for solving different problems in areas of supply chain management, finance, sustainable development, construction, economics, operations [58].

The Evaluation Based on Distance from Average Solution is a new method that is very efficient to prioritize alternatives [59]. It was proposed and further extended EDAS method for multi criteria decision making by [60]. The distance of alternatives from an average solution is determining the desirability of them in this method. We can differentiate between two measures of dealing with the attractiveness of the alternatives, the first one is the positive distance from average (PDA), and the second is the negative distance from average (NDA). They show the difference between each alternative and the average solution.

The assessment of the choices is made by higher values of PDA and lower values of NDA, it represents that the solution is better than average solution. The Evaluation Based on Distance from Average Solution technique's computational system with m parameters and n alternatives can be summed up in seven stages as follows [60] :

Step 1 Selection of the most important criteria that describe alternatives.

Step 2: Construction of the decision-making matrix X based on formula (1):

$$\mathrm{X} = \left[X_{\mathrm{ij}}\right]\mathrm{n} \cdot \mathrm{m} = \begin{bmatrix} X_{11} & X_{12} & \ldots & X_{1m} \\ X_{21} & X_{22} & \ldots & X_{2m} \\ \vdots & \vdots & \vdots & \vdots \\ X_{m1} & X_{n2} & \ldots & X_{nm} \end{bmatrix} \quad (1)$$

X_{ij} signifies the performance value of *i* th alternative on *j* th criterion.

Step 3: Determine the average solution according to all criteria, shown as follows in formula (2) and (3):

$$\mathrm{AV} = \left[AV_{\mathrm{j}}\right]1 \cdot \mathrm{m}, \quad (2)$$

where:

$$AV_{\mathrm{j}} = \frac{\sum_{\mathrm{In}=1}^{n} x_{\mathrm{Lp}}}{n} \quad (3)$$

Step 4: Calculation of the PDA and the NDA matrixes according to the type of criteria (beneficial and non-beneficial), shown as follows in formulas (4), (5), (6), (7), (8) and (9):

$$\mathrm{PDA} = PDA_{\mathrm{ij}}\mathrm{n} \times \mathrm{m} \quad (4)$$

$$\mathrm{NDA} = NDA_{\mathrm{ij}}\mathrm{n} \times \mathrm{m} \quad (5)$$

if *j* th criterion is beneficial,

$$PDA_{\mathrm{ij}} = \frac{\max[O_i X_{\mathrm{ij}} - AV_{\mathrm{p}})]}{AV_f} \quad (6)$$

$$NDA_{\mathrm{ij}} = \frac{\max[Q[AV_j - X_{[j}])}{AV_f} \quad (7)$$

and if *j* th criterion is non-beneficial,

$$NDA_{\mathrm{ij}} = \frac{\max[Q[AV_j - X_{[j}])}{AV_f} \quad (8)$$

$$NDA_{\mathrm{ij}} = \frac{\max[Q[AV_j - X_{[j}])}{AV_f} \quad (9)$$

where:

PDA_{ij} and NDA_{ij} denote the positive and negative distance of *i* th alternative from average solution in terms of *j* th criterion, respectively.

Step 5: Determination of the weighted sum of PDA and NDA for all alternatives based on formulas (10) and (11):

$$SP_{\mathrm{i}} = \sum_{j=1}^{m} w_j \times PDA_{ij} \quad (10)$$

$$SN_{\mathrm{i}} = \sum_{j=1}^{m} w_j \times NDA_{ij} \quad (11)$$

where:

w_{i} represents the weight of *j* th criterion.

Step 6: Normalization of the values of SP and SN for all alternatives based on formulas (12), (13):

$$NSP_{\mathrm{i}} = \frac{SP_P}{\max[SP_i P_{N_R}} \quad (12)$$

$$NSN_{\mathrm{i}} = 1 - \frac{SN_R}{\max[SN_i)} \quad (13)$$

Step 7: Calculate the appraisal score (AS) for all alternatives based on equation (14):

$$AS_{\mathrm{i}} = \frac{1}{2(NSP_{\mathrm{i}} + NSN_{\mathrm{i}})}, \quad (14)$$

where:

$0 < AS_{\mathrm{i}} < 1$.

Step 8: Ranking the choices based on the decreasing values of appraisal score (AS). The alternative with the highest AS is the best choice among the candidate alternatives.

Multi-objective optimization and front pareto method

Computational models describing the behaviour of complex physical systems are often used in the engineering design field to identify better or optimal solutions with respect to previously defined performance criteria. It ought to be desirable to optimize the objective functions at the same time, but generally, they are in rivalry with one another, and the optimization process needs to look for the best ideal trade off solution [61]. A large portion of the real-life optimization issues are multi-objective. Tools for the assurance and the examination of the choices coming from a multi-objective design optimization issue are very important [62].

A considerable number of optimization algorithms have been proposed to solve this task in the current literature [62], the possible applications are vast and can help improve the performance of the process from different perspectives, or at least give the decision makers the tools to decide what is the best compromise solution between objectives at conflict [63].

The primary goals in multi-objective optimization problem solution are to preserve non-dominated points in the objective space and associated solution points in the decision space [61].

Multi-objective optimization refers to the application of mathematical programming techniques to the solution of optimization problems in which more than one objective function must be maximized or minimized. The solution to multiple objectives is difficult; instead, the concept of Pareto dominance is usually adopted. This way, instead of obtaining a single solution, a set of Pareto optimal solutions are obtained. To obtain these solutions, two main approaches can be used; the first one consists in classical methods, such as scalarization-based methods, for example, weighted sum or goal programming. The second type of methods uses metaheuristics techniques [63].

Multi-objective problems are those problems where the goal is to optimize simultaneously k objective functions designated as: f_1 (x), f_2 (x), . . . , f_k (x) and forming a vector function F(x): [61] found below in formula (15):

$$\mathrm{F(x)} = \begin{bmatrix} f_1(x) \\ f_2(x) \\ \vdots \\ f_k(x) \end{bmatrix} \tag{15}$$

A decision maker must choose one or more solutions by selecting one or more vectors. the decision maker usually selects an acceptable solution belonging to the Pareto front. Identifying a set of Pareto optimal solutions is thus a key point for the decision maker's selection of a compromise solution satisfying all the objectives as better as possible. These functions form a mathematical description of performance criteria which are usually in conflict with each other.

A solution x ∈ Ω is Pareto optimal with respect to Ω if and only if there is no x' ∈ Ω for which v = F (x') = (f_1(x'), . . ., f_k(x')) dominates u = F(x) = (f_1(x), . . ., f_k(x)). The phrase Pareto optimal is taken to mean with respect to the entire decision variable space unless otherwise specified. In words, this definition says that x∗ is Pareto optimal if there exists no feasible vector x which would decrease some criterion without causing a simultaneous increase in at least one other criterion [61].

METHODOLOGY

Our methodology combines a set of qualitative and quantitative methods whose main goal is to obtain the best strategies that supply chain managers and decision makers can adopt to mitigate their risks. This methodology is the first of its kind that will bring together a modified FMEA technique, with multi-objective optimization and multi-criteria decision making. Below are the different steps followed to reach the expected results:

Step 1: Identification of risks:

We based ourselves on a set of risks identified through a literature review and validated by two persons, a supply chain manager, who is responsible for the entire supply chain, from procurement of the raw material, making the internal production plan and schedule, managing the internal physical flow and also ensuring contact with the two customers Renault Tanger and SOMACA ,there is also an academic with a rich background in supply chain management of the region , we will mathematically designate these risks by R_i.

In our illustration, where we will apply our model to the case of a multinational Tier 1 company providing assembled parts for the carmaker Renault, they are specialized in the production of an assembled braking systems parts. We will start by identifying the risks, applying the FMEA AIAG 2019 methodology, which will enable us to identify the risk factors where we need to implement strategies to mitigate them. We defined the different risk categories by browsing the entire supply chain. The risks proposed to the decision maker in our illustration of the chosen methodology are those on the Table 2.

Table 2

Risk proposed to the decision maker

Category of risk	Potential defects
Human resources	Lack of qualified personnel (R1); Worker's strike – Union Problems (R2); Labour disputes – Conflicts (R3); Theft (R4); Culture problem: Language and culture (R5)
Customs	Import and export restrictions and customs tariffs (R6); Problem with the customs information system (R7)
Financial	Bankruptcy and insolvency of the supplier (R8); Financial strength of customers. (R9); Cash-flow disruptions (R10);
IT	Failure of the Information Infrastructure and breakdowns related to the information system; hacking (R11)
Legal	Compliance with long-term or short-term contracts (R12);
Maintenance	Failure; breakdown of a machine or equipment. (R13); Risk related to infrastructures, means and buildings (Logistics equipment) (R14);
Management and strategy	Ineffective management strategy (R15)
Natural	Catastrophic events in the plant (R16)
Political	Political issue – agitation (R17)
Quality	Quality risks (Defects per million; Supplier quality) (R18)
Security	Unsafe working conditions (R19)
Reception of material	Damaged packaging (R20); Difference in quantity received (R21)
Material Storage	Damaged packaging after internal handling (R22); Damaged packaging during shipment (R23); Non-respect of traceability Material (R24)
Inventory and Material Handling	Raw material or finished product inventory variance (R25)
Shipping	Lack of identification and loss of internal or external label (R26); Content; container error (R27); Invoicing error (R28);
Transport	Customer truck delay (R29); Supplier truck delay (R30); Vessel capacity and canal overload (R31);
EDI	Incorrect integration of the customer's EDI (call-offs not visible) (R32); Absence of ASN shipping notice (R33);
Supply side	Unsecured supplier requirements due to a capacity problem (R34)
Customer demand	Fluctuating and inaccurate forecasting (R35)
Capacity	Risks related to the capacity study (R36); Production performance (R37)
System	SAP information system not functional (R38); Network is not available (R39); Access to files and data in the common network not possible (R40)
Packaging	Customer packaging not available to ensure quantities (R41); Alternative packaging not available (R42)
Service providers	Poor logistics service providers (customs, storage providers) (R43); Ports issues and infrastructure (R44);

Step 2: Identify the values of severity, occurrence, and detectability for each risk.

For each of the risk identified and shared previously R_i, the target of this step is to obtain, its main value for severity, occurrence, and detectability. The decision maker will provide that information based on the tables below:

Table 3 represents respectively the rating standards for severity, occurrence, and detectability.

Table 3

Severity, occurrence and detectability table

	Severity table [64]	*Occurrence table [65]*	*Detectability table [66]*
Ranking	**Effect**	**Effect**	**Effect**
1	None – not applicable	Nearly impossible – not applicable	Almost certain
2	Very minor	Very remote	Very high
3	Minor	Remote	High
4	Low	Very low	Moderately high
5	Moderate	Low	Moderate
6	Significant	Moderate	Low
7	Major	Moderately high	very low
8	Extreme	High	Remote
9	Serious	Very high	Very remote
10	Hazardous	Nearly certain	Absolute uncertainty – not applicable

We can mathematically design the values of each of the three components, occurrence, severity, detectability by O_i, S_i, D_i.

Step 3: Identify AP values based on the priority action table.

This step consists in deducting the AP value: Either "L", "M", "H" depending on the values O_i, S_i, D_i determined previously,

The AIAG VDA 2019 standard, has implemented a decision support table that allows decision makers to identify the action priority value of each risk. The Figure 1 represents the decision support table used to define the action priority.

Step 4: Selection of the risks with "High" and "Medium" notations.

In this step, our main objective is to filter only the risks that have a notation equal to "high" or "medium". Those are only the risks that will be treated in the next steps, the strategies that will be implemented will have to impact only on those risks. Since the risks with 'Low' value are considered not very harmful for the supply chains, the FMEA AIAG VDA method propose to not take them into consideration, the focus needs to be done on the others.

The risks with 'high' or 'medium' values can be mathematically designed by: R_i.

Step 5: Identify reactive and proactive strategies based on a literature review, validate their relevance with an expert in the field: S_i.

The main objective in this step is to propose to the decision maker, a large choice of the different strategies that could be implemented, the base to find those strategies is the literature review, they were also discussed by an academic and an expert in the domain to ensure them utility. The strategies proposed to the decision maker are the ones in the Table 1.

Step 6: Identify the selection criteria for identification strategies.

Two parameters impact on the selection of an appropriate strategy: the first one is the 'cost', this means the cost of implementing a strategy, it can vary from a few euros to a large amount of money in the case of a material investment on equipment, machines, or even services; Manufacturing and logistics companies have a quarterly, annual, or even long-term investment budget. It is limited by the financial capacity of the company and its cash-flow situation, managers are very reticent and demanding concerning the choice of investments to be put in place, it should be very judicious; A wrong choice can cause financial problems for the company and penalize it in relation to the competition. For our case, we are going to allow to the decision maker to identify regarding its entity, the relative cost to each proposed strategy, we consider mathematically that by: $Cost_{jk}$,

where: j represents the treated risk, k represents the mitigation strategy.

The second parameter for selecting proactive and reactive strategies is their effectiveness; a strategy may be effective against one risk and maybe less effective against other risks.

In order to understand the effectiveness of the proposed strategies, the DM must choose between the values in the Table 4 found below.

Table 4

Effectiveness rating scores

Class	Level
10	Extremely high
9	Very high
8	Between high and very high
7	High
6	Between Moderate and High
5	Moderate
4	Between Low and Moderate
3	Low
2	Between Very Low and Low
1	Very Low

A high effectiveness rating is assumed to indicate that the strategy is highly effective relative to the risk under consideration. This is mathematically represented by: Eff_{jk}, where j represents the treated risk.

k: represents the mitigation strategy.

Step 7: For each risk, for each of the identified strategies, determine a value for cost and efficiency.

Once the evaluation factors have been determined, the decision maker should then be asked to determine, for each risk, the appropriate values for the cost and effectiveness factors $Cost_{jk}$ et Eff_{jk}.

We will therefore have j equivalent tables for each risk treated.

Step 8: Deduce the best strategies for each risk: Pareto optimal solutions.

Once we obtain the tables from the DMs, then the next step is to select the best strategies S_{if} that have an impact on each of the risks R_j.

To do this, we will use the methods of objective multi optimization and the Pareto optimal solutions section which are the choices that constitute the Pareto front. This step will allow us to deduce the set of best strategies.

Step 9: Select only strategies with a lower implementation cost than the total budget.

Once the expanded list of implementation strategies is obtained, the DM is asked to present the total budget dedicated, we will designate this budget by: ß.

For all the strategies that constitute the Pareto front, their adequate cost must not exceed the total cost of the budget ß.

Consequently, strategies that do not respect this rule will be deleted.

Step 10: Calculate the weighted average of the 'cost' and 'efficiency' values, only for the strategies that constitute the Pareto front.

For this step, the main objective is to calculate the average of the 'cost' and 'efficiency' values for each of the strategies that constitute the Pareto optimal solutions. For example, for certain risk 'Rx', if 'S1' and 'S2' constitute the front pareto solutions and are the best solutions, then we calculate the mean of 'cost' and 'efficiency' only for those two strategies, this will allow us to derive a single table, including all proposed strategies and appropriate cost and efficiency values.

Step 11: For each of the strategies identified via the Pareto front, identify the gravity coefficient.

In step 8 and 9, the strategies that have the best impact on each of the risks have been determined. The results may indicate that the same strategy can have an impact on one risk, two risks or even more. The same strategy can be very useful for a type 'H' or type 'M' risk or both.

For the choice of the strategies to be implemented, and to differentiate between the risks with an action priority 'Medium' and those with 'High'. We have developed an additional parameter which is the gravity coefficient. The proposed mathematical formula for the 'Gravity coefficient' is the one on formula (16) found below:

$$Coeff_{Sjf} = \alpha \cdot N\mathrm{br}\,(M_{\mathrm{Sif}}) + \beta \cdot N\mathrm{br}\,\left(H_{\mathrm{Sjf}}\right), \qquad (16)$$

where: $\alpha < \beta$.

Step 12: Deduce the final table including the filtered strategies.

Once the values of the gravity coefficients have been calculated for each of the strategies, they will be gathered in a single table; including the filtered strategies, the average

of the efficiency values, the average of the cost values, the gravity coefficient values.

Step 13: Application of the EDAS method to obtain the final ranking of the best strategies to apply for risk mitigation. The last step is to deduce the final ranking of the best strategies to implement for the studied case. The input element of the EDAS method is the table obtained after step 12. First, we need to determine the average solution AVj according to all the criteria as per the formula in the equation (3).

Then, we will calculate The PDA and calculate the NDA based on equations (6) (7) (8) (9).

The weighted sum of PDA is obtained from the average Matrix:

For the weights of the three parameters, we will designate 0.33 for each of the parameters since we have three criteria in the total: 'cost', 'efficiency' and 'coefficient AP'. Then, the weighted sum of NDA is obtained from the Average Matrix.

The normalized values of SP_i and SN_i for all alternatives is calculated based on equations (10) and (11), those are used as input to calculate the appraisal score AS_i for all alternatives. The alternatives are ranked according to the decreasing values of AS_i The alternative with the highest AS_i is the best choice among the alternatives.

RESULTS OF RESEARCH

We started our illustration with the identification of the risks, (Table 2); For each identified risk, we asked the decision maker to designate a value of 'Severity', 'Occurrence' and 'Detectability'.

Table 5 below shows the different values obtained for each of the risks; these allow us to deduce the values of the priority action, only the risks with 'High' and 'Medium' values will be treated in the following steps, the risks with action priority value equal to 'Low' will be neglected.

The list of proposed strategies for implementation and mitigation of risks was then identified and is shown in Table 6 below, this is ensuring summarizing of the main strategies adapted to the supply chain and industrial context.

Table 5

Action priority values

Process Operation; Requirement	Risks or Potential defects	S	O	D	Action Priority
Human resources	Lack of qualified personnel	7	6	3	H
	Worker's strike – Union Problems	8	4	1	M
	Labour disputes – Conflicts	3	6	3	L
	Theft	4	3	4	L
	Culture problem: Language and culture	2	2	1	L
Customs	Import and export restrictions and customs tariffs	7	3	3	L
	Problem with the customs information system	7	5	5	H
Financial	Bankruptcy and insolvency of the supplier	9	2	6	M
	Financial strength of customers	9	2	6	M
	Cash-flow disruptions	10	3	2	L
IT	Failure of the Information Infrastructure and breakdowns related to the information system; hacking;	7	7	4	H
Legal	Compliance with long-term or short-term contracts	8	2	1	L
Maintenance	Failure; breakdown of a machine or equipment	6	7	2	M
	Risk related to infrastructures, means and buildings (Logistics equipment)	6	6	2	M
Management and strategy	Ineffective management strategy	8	2	3	L
Natural	Catastrophic events in the plant.	9	2	2	L
Political	Political issue – agitation	9	2	2	L
Quality	Quality risks (Defects per million; Supplier quality)	7	8	7	H
Security	Unsafe working conditions	6	2	1	L
Raw material reception	Damaged packaging	5	7	1	L
	Difference in quantity received	5	6	4	M
Internal storage	Damaged packaging after internal handling	5	4	5	L
	Damaged packaging during shipment	7	4	2	H
	Non respect of traceability Material	7	4	5	H
Inventory and Material Handling	Raw material or finished product inventory variance	6	6	6	M
Shipment	Lack of identification and loss of internal or external label	6	4	5	L
	Content; container error	8	6	5	H
	Invoicing error	7	4	4	H
Transport	Customer truck delay	3	8	1	L
	Supplier truck delay	5	9	1	M
	Vessel capacity and channel overloading	6	3	3	L
EDI	Incorrect integration of the customer EDI (call-offs not visible) to the system	5	2	1	L
	absence of the shipping notice (ASN)	7	4	5	H
Supply side (Procurement)	Capacity problem with the supplier	9	10	4	H
Customer demand	Fluctuating and inaccurate forecasting	6	7	2	M

cont. Table 5

Capacity	Risks related to the capacity study	9	4	3	H
	Production performance	6	3	3	L
System	SAP information system not functional	6	2	1	L
	Network not available	5	2	1	L
	Access to files and data in the common network not possible	4	2	1	L
Packaging	Customer packaging not available	4	4	3	L
	Alternative packaging not available	7	4	3	H
Service providers	Bad logistics service providers (Customs, storage providers)	5	7	2	M
	Ports issues and infrastructure	6	5	3	L

Table 6

Risk mitigation strategies proposition

Strategy Number	Strategy
1	Apply the buffer strategies: Increase security stock level, buffer inventory
2	information sharing (Supply chain agility strategy increasing)
3	Trust (Supply chain agility strategy increasing)
4	Collaborative relationships (Supply chain agility strategy increasing)
5	Apply the multi-sourcing and looking for alternative supply sources
6	Looking for a back-up production solution and manufacturing flexibility to reduce lead time
7	Efficient Supplier selection and storage providers
8	Apply a flexible supply contract
9	Looking for a plan B production plant
10	Increase supply chain capacity through enhanced partnership
11	Fine-tune Supply chain design:
12	Supply base strengthening
13	Dynamic assortment planning
14	Centralize demand (advanced warehouse or factory)
15	Increase the capacity and manufacturing flexibility by working on the manufacturing process
16	Process standardization
17	Apply Agile operations: Agility can be imparted through flexible operations, which aids in delivering new products with shorter lead times.
18	Risk hedging: Common pool of inventory
19	Cross-training of employees: Employees for one job are trained to perform other jobs too.
20	Enhance visibility: Information distortions can be reduced by increasing the visibility of capacity and inventory
21	Increase inventory and storage flexibility.
22	Using insurance.
23	Dropping geographical markets.
24	Apply vertical integration
25	Imposing contractual obligations on suppliers
26	Imposing contractual obligations on subcontractors
27	Joint efforts to prepare SC continuity plans.
28	Localized sourcing
29	Apply industry 4.0 technologies
30	Elaborate a contingency planning and define the responsibilities
31	Application of lean tools
32	Postponement of final assembly
33	Proliferate customer accounts
34	Vindicate product ranges
35	Inventory flexibility: Decentralize inventory for products with stable demand and centralize inventory for products with uncertain demands.
36	Develop relationships with supply chain network partners
37	Use risk indices to monitor risks continuously
38	Risk reporting and governance procedures in place
39	Dissemination of risk management practices through manuals
40	Make sure that inventory levels are visible throughout supply chain
41	Post-event analysis and lessons learned
42	Defined meeting to share KPI
43	Our suppliers keep inventories for us: Increase the days on hand to 2 weeks.
44	Logistics flexibility: Implementing flexibility in routing increases responsiveness of products by changing the modes of transportation quickly
45	Make-or-buy analysis
46	Economic supply incentives
47	Aggregate or pool demand: Risk pooling

cont. Table 6

48	Maintaining multiple facilities with flexible; redundant resources
49	Apply ASN with suppliers.
50	Supplier development activities
51	Signing risk-sharing contract with suppliers
52	Postponement and shifting production and demand quantity across different products
53	Safe locations selection.
54	Identifying vulnerability of disasters
55	Poka-Yoke set-up
56	Conduct rotating inventories

Once the risks with 'High' and 'Medium' ratings are determined, the extended list of risks is also identified, The DMs were then asked to determine, for each risk: a 'cost', 'efficiency' value for each of the identified strategies, we obtained these values for each of the 22 selected risks (only M & H) and then identified which are the dominant solutions for each of the risks, the Table 7 below represents these.

Table 7
Dominant pareto solutions for each risk

Potential defects	Strategy number
Bad logistics service providers (Customs, storage providers)	7, 26, 36
Substitution packaging not available	8, 10, 43, 56
Risks related to the capacity study	6, 13,15
Fluctuation of customer forecast and sudden demand	4
Unsecured suppliers need due to a capacity problem	5, 25
Absence of the shipping notice (ASN)	20, 36
Delayed truck supplier	7, 26
Invoicing error	38, 39
Content; container error	30, 55
Raw material or finished product inventory variance	8, 43
Lack of qualified personnel	4, 19, 30
Worker's strike - Union Problems	30
Problem with the customs information system	4, 20, 26, 28
Bankruptcy and insolvency of the supplier	25, 51
Financial strength of customers.	33
IT	17, 30, 39, 41
Failure; breakdown of a machine or equipment.	6, 10
Risk related to infrastructures, means and buildings especially Logistics equipment	26
Quality risks	1, 8
Difference in quantity received	25, 43
Damaged packaging during shipment	38, 55, 56
Non respect of material traceability	11

We then proposed a table for the aggregation of the cost values and efficiency for each of the strategies constituting a Pareto solution by calculating the mean its value for each risk, we also added a dedicated column calculating the gravity coefficient based on equation (16). Table 8 below represents this.

Table 8
Aggregation of cost, efficiency values and calculating the gravity coefficient for each risk

Strategy Number	Risks impacted by these strategies	Cost	Efficiency	Aggregated cost	Aggregated efficiency	Gravity Coeff
1	Quality risks	10000	8	10000	8	2
4	Lack of qualified personnel	100	5	100	6,33	
	Fluctuating and inaccurate forecasting	100	8			
	Problem with the customs information system	100	6			
5	Capacity problem with the supplier	5000	9	5000	9	2
6	Failure; breakdown of a machine or equipment.	50000	9	50000	9	3
	Risks related to the capacity study	50000	9			
7	Bad logistics service providers (Customs, storage providers)	100	8	100	8	2
	Supplier truck delay	100	8			
8	Raw material or finished product inventory variance	100	8	100	7,66	5
	Alternative packaging not available	100	8			
	Quality risks	100	7			
10	Alternative packaging not available	100	8	100	8	3
	Failure; breakdown of a machine or equipment	100	8			
11	Non respect of Material traceability	100	7	100	7	2
13	Risks related to the capacity study	100	6	100	6	2
15	Risks related to the capacity study	5000	8	5000	8	2
17	IT	600	6	600	6	2
19	Lack of qualified personnel	3600	9	3600	9	2
20	Absence of the shipping notice (ASN)	1000	8	1000	7,5	4
	Problem with the customs information system	1000	7			

cont. Table 8

25	Bankruptcy and insolvency of the supplier	100	8	100	8	4
	Capacity problem with the supplier	100	8			
	Difference in quantity received	100	8			
26	Bad logistics service providers (Customs, storage providers)	100	8	100	7,75	5
	Problem with the customs information system	100	6			
	Supplier truck delay	100	8			
	Risk related to infrastructures, means and buildings especially Logistics equipment	100	9			
28	Problem with the customs information system	100	6	100	6	2
30	Content; container error	100	7	100	6	7
	IT	100	5			
	Lack of qualified personnel	100	5			
	Worker's strike - Union Problems	100	7			
33	Financial strength of customers	100	8	100	8	1
36	absence of the shipping notice (ASN)	100	6	100	7	3
	Bad logistics service providers (Customs, storage providers)	100	8			
38	Damaged packaging shipment	100	6	100	7	4
	Invoicing error	100	8			
39	Invoicing error	100	8	100	6,5	4
	IT	100	5			
41	IT	100	5	100	5	2
43	Raw material or finished product inventory variance	100	8	100	8	4
	Difference in quantity received	100	8			
	Alternative packaging not available	100	8			
51	Bankruptcy and insolvency of the supplier	100	8	100	8	1
55	Damaged packaging in the shipment	4000	8	4000	8,5	4
	Content; container error	4000	9			
56	Damaged packaging in the shipment	100	6	100	7	4
	Alternative packaging not available	100	8			

Based on the table above representing the aggregate values of 'costs' and 'efficiency' for each strategy. We then followed the steps of the EDAS method to deduce the different rankings.

The valuation factor 'cost' is non-beneficial, because the higher its value, the more it means additional expenses for the company, which has a negative impact on its budget and financial performance. The evaluation factor 'efficiency' is beneficial, as the higher its value, the more successful the strategy is in mitigating the risks in question.

The gravity type evaluation factor is considered beneficial, because the higher its value, this means the strategy in question impacts: Many risks but also with higher 'high' and 'medium' ratings. We also denote each of the three parameters by a weight equivalent to 0.33 due to the similar importance of the three parameters. We applied then the steps of the EDAS method based on the equations from (1) until (14). This allowed us to derive the values below for each of the strategies mentioned found on the Table 9 below.

Table 9

NSN, NSP and AS values

NSP	NSP Value	NSN Value	AS Value
1	0,0537	0,8298	0,442
4	0,7101	0,9929	0,852
5	0,1148	0,9362	0,525
6	0,1148	0,0000	0,057
7	0,4740	0,9787	0,726
8	0,7435	1,0000	0,872
10	0,4740	1,0000	0,737
11	0,4203	0,9776	0,699
13	0,4203	0,9687	0,694
15	0,0537	0,9362	0,495
17	0,3478	0,9687	0,658
19	0,1148	0,9660	0,540
20	0,4580	1,0000	0,729
25	0,6189	1,0000	0,809
26	0,7486	1,0000	0,874
28	0,4203	0,9687	0,694
30	1,0000	0,9900	0,995
33	0,4740	0,9574	0,716
36	0,4203	0,9989	0,710
38	0,5652	0,9989	0,782
39	0,5652	0,9944	0,780
41	0,4203	0,9597	0,690
43	0,6189	1,0000	0,809
51	0,4740	0,9574	0,716
55	0,2292	0,9787	0,604
56	0,5652	0,9989	0,782

The 'Appraisal scores' values allowed us to derive the final ranking of strategies that impact on the risk mitigation found on the Table 10 below.

Table 10

Final ranking of the strategies

Strategy Number	Strategy	AS Value	Final Ranking
30	Elaborate a contingency planning and define the responsibilities	0,995	1
26	Imposing contractual obligations on subcontractors	0,874	2
8	Apply a flexible supply contract	0,872	3
4	Collaborative relationships (Supply chain agility strategy increasing)	0,852	4
25	Imposing contractual obligations on suppliers	0,809	5
43	Our suppliers keep inventories for us: Increase the days on hand to 2 weeks.	0,809	6
38	Risk reporting and governance procedures in place	0,782	7
56	Conduct rotating inventories	0,782	8
39	Dissemination of risk management practices through manuals	0,780	9
10	Increase supply chain capacity through enhanced partnership	0,737	10
20	Enhance visibility: Information distortions can be reduced by increasing the visibility of capacity and inventory	0,729	11
7	Efficient Supplier selection and storage providers	0,726	12
33	Proliferate customer accounts	0,716	13
51	Signing risk-sharing contract with suppliers	0,716	14
36	Develop relationships with supply chain network partners	0,710	15
11	Fine-tune Supply chain design	0,699	16
13	Dynamic assortment planning	0,694	17
28	Localized sourcing	0,694	18
41	Post-event analysis and lessons learned	0,690	19
17	Apply Agile operations	0,658	20
55	Poka-Yoke set-up	0,604	21
19	Cross-training of employees.	0,540	22
5	Apply the multi-sourcing and looking for alternative supply sources	0,525	23
15	Increase the capacity and manufacturing flexibility	0,495	24
1	Apply the buffer strategies: Increase security stock level, buffer inventory	0,442	25
6	Looking for a back-up production solution and manufacturing flexibility to reduce lead time	0,057	26

Given that the allocated budget is 50,000 euros, we can deduce that all the strategies mentioned in Table 8 can be applied except the last one strategy 6. The sum of all strategies from strategy 30 to strategy 1 is not surpassing 50000 euros.

DISCUSSION AND CONCLUSION

This examination has endeavoured to measure the viability of different risk mitigations approaches considering a practical point of view. Mitigation strategies, based on its effectiveness, costs and impact were sorted utilizing consolidated methodologies of FMEA (failure mode effective analysis), multi-objective optimization and multi criteria decision making method EDAS. This methodology was tested in the context of a multinational company that operates in the automotive sector. Our case was based on 44 risks identified in the literature and on 55 mitigations strategies.

We began our case by applying the new FMEA AIAG 2019 methodology, which allowed us to filter out the risks on which to focus for risk mitigation, after identifying resilient strategies based on a literature review, the decision maker was asked to mention for each risk, the cost and efficiency related to each of the strategies, this allowed us to deduct the solutions that constitute the Pareto front. Only strategies with a lower implementation cost than the total budget were selected.

Then we calculated the weighted average of the 'cost' and 'efficiency' values, and that only for the strategies that constitute the Pareto front and after we identified the gravity coefficient. After this, we deduced the final table including the filtered strategies and applied the EDAS method to obtain the final ranking of the best strategies to be applied for risk mitigation.

The results obtained demonstrated that the company need first to develop a contingency planning and define the responsibilities between the various employees and departments, it must also renegotiate its contracts with the various subcontractors, Especially the carriers, storage providers and the supplier of consumable packaging, we learned that the carriers cause frequent delays in deliveries without being penalized, the renegotiation of contracts with them will force them to pay high compensation;

To improve the flexibility of supply, the company must negotiate with its suppliers of the percentages of variation in its favour, that a percentage exceeding the 20%, in the rise as in the fall must be imposed to the suppliers, that will make the risk of supply shortage less high, it must also create real relations of collaboration with the suppliers by increasing the mutual confidence.

In case of suppliers' failure to deliver the demanded quantities, the company will have to charge shortage costs and penalize the suppliers (labor costs, energy), the awareness of its costs by the suppliers will make them more rigorous in terms of ensuring the deliveries. The next strategy to implement is to impose on the suppliers to increase their safety stock in finished product in two weeks instead of one week, this will minimize the supply risks.

Other strategies may be less interesting, such as the application of multi-sourcing, we learned from the logistics manager that the suppliers of this company are imposed by the final assembly car manufacturer, or suppliers who are part of the same parent group, the application also of additional buffer stock is not suitable for this company. It is a strategy that is not feasible according to the decision maker, because taking into consideration the context of global disruption in electronic chips, this company is delivered depending on a system of shortage allocation, where the difficulty of constituting an additional security stock.

The least important strategy for this company is looking for a back-up production solution, we understood from the manager that it has enormous capacity in terms of production, additional machines are not exploited at 100%.

This illustration reflects an instantaneous image of this multinational company, this image takes into account a number of parameters, including specific suppliers (a long-term contract has been signed with them to supply this company in series, which makes their substitution highly unlikely), there's also the factor of a certain situation of goods availability, the critical importance of goods and many others. It is therefore important for decision-makers to define an appropriate frequency for applying this methodology, considering any changes that may occur, since a change in parameter will imply a change in the level of risk. it also means that the application of this methodology is not fixed in time. it is a living exercise.

The limitations of this work may be the number of risks treated as well as the number of strategies, each company can choose the risks that are best suited to their context as well as the choice of more specific mitigation strategies. This model can be implemented in different types of industries, such as in aeronautics, food industry or even pharmaceutical. Researchers can experiment and make a comparison between the different cases.

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