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# Mitigating the impacts of COVID-19: failure mode and effect analysis and supply chain resilience (FMEA-SCR) combined model

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## Abstract

**Purpose** – The coronavirus disease (COVID-19) pandemic generated a worldwide financial crisis by impacting several links of the supply chain, however companies can take advantage by quantitatively measuring the disruptive impacts.

**Design/methodology/approach** – This study sought to develop the failure mode and effect analysis and supply chain resilience (FMEA-SCR), a hybrid tool developed using a potential failure mode and effect analysis (FMEA) applied to supply chain resilience (SCR) and taking into account the capability factors and business processes.

**Findings** – In order to validate, the proposed model was applied into two different organizational study cases: an university and a cooperative managing urban solid wastes with recyclable potential (MSWRP). Through the procedures described here any organization can understand and assess in a simplified way the impacts over their supply chain generated by such a crisis.

**Originality/value** – This study synthesizes three different procedures into a single method called FMEA-SCR, allowing organizations to understand and assess in a simplified way, the impacts over their supply chain generated by COVID-19. To this end, it brought together the studies developed by Rajesh and Ravi (2015) and Curkovic *et al.* (2015), on possible causes of disruptions in SC, the capability factors of Pettit *et al.* (2010) used by organizations to mitigate the effects of disruptions, besides Lambert's and Croxton (2005) business processes, thus weaving a method that allows organizations to visualize, analyze and classify the pandemic impacts over their supply chain.

**Keywords** COVID-19, Combined model, Disruption, FMEA, SCR, 3R's, Proof of concept

**Paper type** Research paper

## 1. Introduction

The economy and consequently the supply chain (SC) are impacted by crises, such as the 2008 global financial crisis, which had repercussions in several countries, devastating economies, decimating financial resources and almost collapsing banking systems in several countries (Hausman and Johnston, 2014).

From 2020 to now, the world is experiencing a pandemic generated by the coronavirus disease (COVID-19), and according to Anderson *et al.* (2020), the governments will not be able to minimize both deaths from COVID-19 and the economic impact of viral spread. Keeping



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mortality as low as possible will be the highest priority for individuals; hence, governments must put in place measures to ameliorate the inevitable economic downturn.

Governments sought to develop public policies to reduce the burden of this pandemic on health systems, which is commonly referred to as flattening the curve (Requia *et al.*, 2020). In order to minimize contagion and consequent deaths, several countries have adopted social isolation, which is accomplished by limiting, decreasing or paralyzing the flow of people. This strategy is certainly very effective in reducing mobility on a global scale in the short term, but it also generates a high negative socioeconomic impact in the short and long terms (Iacus *et al.*, 2020).

In countries where the curve has been flattened, such as the United States, Brazil, Russia and India (WHO, 2020), there has also been a gradual reopening of the productive sector, but with several restrictive measures of social distance. Another important aspect is psychological, because even if people are free to start consuming again, they may be afraid of becoming infected.

These characteristics make the environment of demand and the future of SC is uncertain, unlike other events that generated SC demand disruptions, for example, Hurricane Katrina and the 2008 global financial crisis; however, once their effect had ceased, they tended to seek to return to normality. In this context, this recent pandemic has the characteristics of significantly altering consumption habits and changing demand patterns that are completely different from those currently digitally adopted.

It is possible to find ways in which the SC can lighten disruption impacts, one of which is resilience (Hosseini *et al.*, 2019; Yu *et al.*, 2019); that is, models that are applied to the SC enables the recovery of its processes and economic indicators to occur more quickly (Chowdhury and Quaddus, 2015; Suresh Kannan *et al.*, 2016). Supply chain disruption-oriented firms require the ability to reconfigure resources or have a risk management resource infrastructure to develop resilience (Ambulkar *et al.*, 2015).

Several models have been developed and tested with characteristics inherent to the SC disruption phenomenon. Increase in frequency and the serious consequences of past interruptions have resulted in a growing interest in the topic. Economic systems are increasingly prone to complexities and uncertainties. Therefore, making decisions based on consistent information requires risk analysis, control and mitigation (Heckmann *et al.*, 2015).

The SC Responsiveness, Resilience and Restoration (3Rs) dynamism have a significant positive effect on having their financial impacts diminished (Queiroz *et al.*, 2020). Another important aspect is related to the SC regionalization, an effective way to soften the negative impacts of environmental interruptions (Kamalahmadi and Parast, 2017).

Before investing in the SC risk management practices, companies need to identify their technological abilities that influence and impact these practices. Companies that are too immature in their capabilities are unable to implement risk management practices, so more advanced (context-sensitive) approaches are needed, especially in relation to the risk-taking attitude of the decision-maker and in relation to the affected SC environment (Heckmann *et al.*, 2015).

FMEA is a method initially developed for product and process quality management, but with application and great results in various areas such as: development of risk-based improvement selection model within virtual environment; establishment of model on linking risk-based improvement strategy selection with business performance management tool such as balanced scorecard (BSC) and customer relationship management (CRM) and change management model (Sutrisno *et al.*, 2014). Its adaptation to quantify and prioritize scratches allied to the SC disruption is evident but not found in the literature.

In view of the problematization, there is a lack of studies that correlate FMEA and SCR with the COVID-19 pandemic impacts in order to create mechanisms for the SC to respond positively and adequately (Queiroz *et al.*, 2020). To integrate disruption and capability factors with SC processes, FMEA is used to analyze the inherent processes and risks (Liu *et al.*, 2019), transforming qualitative aspects into quantitative ones (Curkovic *et al.*, 2015), having obtained qualitative results in risk reduction in several areas (Liu *et al.*, 2019; Maggiulli *et al.*, 2020). Thus, the union of those linked to the FMEA-SCR processes will be demonstrated throughout the article.

Within this context, the research question raised was: are companies technologically capable of providing resilience to their SC? The answer is yes, as technological capabilities have enabled companies to use tools to produce insights into key SC processes (Rajesh, 2017). Thus, it can be said that resilience is a way that the SC can use to better respond to interruptions, which are identified and evaluated using performance indicators (Rajesh, 2016). So, this study proposes a combined methodology that allows organizations to quickly realize the disruptive factors and how the SC can mitigate the impacts generated by COVID-19.

To this end, we analyze: (1) the literature in search of characteristics inherent in the disruption of the SC caused by governmental actions of social isolation linked to the fight against COVID-19; (2) characteristics inherent to SCR that are best suited to soften these impacts, in order to integrate them through the FMEA method, the integrating method called FMEA-SCR, which he considers, was developed, which he considers capacity factors and SC business processes.

We use the proof of concept (Kendig, 2015) to test and validate the FMEA-SCR model presented. This study aims to provide managerial insights and guidelines for practitioners to improve the Responsiveness, Resilience and Restoration (3Rs) of their SCs.

## 2. Literature review

### *2.1 Supply chain resilience – SCR*

The effects generated by SC interruptions can be used as resilience resources by members of the network (Craighead *et al.*, 2007). Since economic systems are increasingly prone to complexity and uncertainty, making informed decisions requires risk analysis, control and attenuation.

Risk in SC can be defined as the potential loss in terms of its target values of efficiency and effectiveness evoked by uncertain developments of its characteristics whose changes were caused by the occurrence of a triggering event. The risks can be divided into: (1) probability and/or adverse outcome; (2) supply risk; (3) deviation from the expected (or still does not present any explicit definition of risk); (4) as an event; (5) a deviation from the expected or objective; or (6) a probability (Heckmann *et al.*, 2015).

Currently, SCs need to meet efficiency-oriented objectives; approaches must take into account the balance of these opposing requirements, for example, the balance of distribution costs and shipping fees or general logistics costs and service level risk. This balance can be achieved by increasing resource investment that can be resilient, presenting a positive result in the repair of productive capacity and SC logistics (Goldbeck *et al.*, 2020).

From another perspective, when analyzing how certain disruptions impact suppliers, it appears that their allocation and reallocation can be helped by models that prioritize critical suppliers, helping to balance SC efficiency and resilience (Hosseini *et al.*, 2019). Thus, it can be concluded that, at least under certain conditions, there may be prioritization of critical resources and that such prioritization would have positive impacts on results.

For example, in a SC analysis related to the 2008 global financial crisis, it was found that it would be possible to develop a proactive, resilient network that could prevent future crises; this interaction was carried out by including members of the chain upstream and downstream (Wang *et al.*, 2018). Thus, it would be possible to use some of these characteristics to mitigate the impacts caused by COVID-19 (Vahid Nooraie and Parast, 2016).

The SCR starts with the identification of the vulnerability factors that cause disruption or change over the SC, shown in Table 1.

| Vulnerability factor | Definition | Sub-factors |
|---|---|---|
| Turbulence | Environment characterized by frequent changes in external factors beyond your control | Natural disasters, Geopolitical disruptions, Unpredictability of demand, Fluctuations in currencies and prices, Technology failures, Pandemic |
| Deliberate threats | Intentional attacks aimed at disrupting operations or causing human or financial harm | Theft, Terrorism/sabotage, Labor disputes, Espionage, Special interest groups, Product liability |
| External pressures | Influences, not specifically targeting he firm, that create business constraints or barriers | Competitive innovation, Social/Cultural change, Political/Regulatory change, Price pressures, Corporate responsibility Environmental change |
| Resource limits | Constraints on output based on availability of the factors of production | Supplier, Production and Distribution capacity, Raw material and Utilities availability, Human resources |
| Sensitivity | Importance of carefully controlled conditions for product and process integrity | Complexity, Product purity, Restricted materials, Fragility, Reliability of equipment, Safety hazards, Visibility to stakeholders, Symbolic profile of brand, Concentration of capacity |
| Connectivity | Degree of interdependence and reliance on outside entities | Scale of network, Reliance upon information, Degree of outsourcing, Import and Export channels, Reliance upon specialty sources |
| Supplier/customer disruptions | Susceptibility of suppliers and customers to external forces or disruptions | Supplier reliability, Customer disruptions |

**Source(s):** Table adapted from Pettit *et al.* (2010)

**Table 1.** Factors that cause disruptions or changes in the supply chain

Once the company is able to determine the risk associated with the factors that may cause change or break, it is important to describe how it can positively react in order to weaken impacts or even obtain competitive advantages.

*2.2 Models and approaches for measuring capability factors in the supply chain*

In a quantitative way, several models were developed trying to visualize SC impacts and how organizations can efficiently work their resources to relieve them, where some models consider suppliers as resources and others as results to be relieved. Below, some of them are presented with the intuition of supporting the construction of a joint model.

To analyze suppliers, López and Ishizaka (2019) used fuzzy cognitive maps (FCM) and analytical hierarchy process (AHP), resulting in the impact of the localization decision on the offshore outsourcing process at SCRM. The sensitivity analysis of the results reveals that a site would improve the SC resilience. This FCM-AHP analysis improved the understanding of academics and professionals about the importance of location criteria and their influence on SCRM capabilities.

In another study, a combination of learning and supervised machine simulation showed increased delivery reliability through the discovery of critical suppliers (or combinations of suppliers) whose interruption results in diminished adverse performance (Cavalcante *et al.*, 2019).

Regionalization can also be a way to alleviate the negative impacts of SC disruptions (Kamalahmadi and Parast, 2017). Bearing in mind that the dynamism of SC has a significant positive effect on the guidance on SCR interruptions since it is affected by orientation interruptions (Yu *et al.*, 2019).

Another possibility of working capacity in a resilient way is the separation of capacity into: (1) traditional criteria: cost, quality, lead time and quick response; (2) resilient capacity absorption criteria: excess stock, separation location, interdependence, robustness and reliability; (3) adaptation criteria: forwarding and reorganization; and (4) capacity restoration criteria: repair or restoration (Hosseini and Khaled, 2019). To analyze the SCR, Pettit *et al.* (2010) propose a model composed of 14 capability factors, which are subdivided into *n* sub-factors (Table 2).

*2.3 Supply chain processes*

Several models analyze the SC, among them is the SCOR model developed by the Supply Chain Council (SCC), which evaluates four macro processes: (1) Performance – Standard metrics to describe process performance and define strategic goals; (2) Processes – Standard descriptions of management processes and process relationships; (3) Practices – Management practices that produce significantly better process performance; and (4) People – Standard definitions for skills required to perform SC processes (Stewart, 2011).

Besides that, Lambert and Croxton (2005) propose a framework that describes the SC processes, taking specific factors into account, as follows (Table 3).

*2.4 Failure modes and effects analysis (FMEA)*

Quality tools have been used for years to quantify and prioritize quality problems in several areas, for example, in studies conducted on the manufacturing sector using the pure FMEA or mixed with quantitative decision-making methods such as AHP and/or fuzzy logic, as well as in studies that present areas such as the possibility of application as a risk of distribution in SC, waste management and service operations (Sutrisno *et al.*, 2014).

Some studies have also been conducted on COVID-19 in medical areas to prevent contamination risk in laboratories (Maggiulli *et al.*, 2020) and develop protocols for managing inpatients with COVID-19 (Sevastru *et al.*, 2020).

Risk assessment within SC can be performed using FMEA; thus, it is possible to quantify and prioritize the risks in SC (Curkovic *et al.*, 2015), and it is possible to adapt it to SCR, as shown in this work.

Based on the bibliographic survey on SCR and the importance of disruption factors, the term FMEA is sometimes replaced by disruption since the concepts presented list a wide range of causes of disruption in the SC and can be measured in terms of severity, probability of occurrence and mitigation, as shown in Tables 4–6.

## 3. Methodology

In this section, the development of the method is presented by the FMEA-SCR and taking into account the SC capacity factors and processes and aiming to be followed by an organization in order to carry out its position in relation to the disruption of their SC. Some scales are proposed to assess the disruption risk.

Step 1: Identify among the disruptions listed in Table 1: factors that cause disruption or changes in the SC, briefly describe the disruption and assess the severity of the disruption (for both the scale and the qualitative quantitative conversion procedures for the assessment of the severity of the disruption, the scales used in Table 4 are based on studies by Curkovic *et al.*, 2015).

Step 2: To assess the probability of occurrence of the disruption, a FMEA of disruption occurrence degree ranking showing which parameters should be adopted for the

| Capability factor | Definition | Sub-factors |
|---|---|---|
| Flexibility in sourcing | Ability to quickly change inputs or the mode of receiving inputs | Part commonality, Modular product design, Multiple uses, Supplier contract flexibility, Multiple sources |
| Flexibility in order fulfillment | Ability to quickly change outputs or the mode of delivering outputs | Alternate distribution channels, Risk pooling/sharing, Multi-sourcing, Delayed commitment, Production postponement, Inventory management, Rerouting of requirements |
| Capacity | Availability of assets to enable sustained production levels | Reserve capacity, Redundancy, Backup energy sources and communications |
| Efficiency | Capability to produce outputs with minimum resource requirements | Waste elimination, Labor productivity, Asset utilization, Product variability reduction, Failure prevention |
| Visibility | Knowledge of the status of operating assets and the environment | Business intelligence gathering, Information technology, Products, Assets and People visibility, Information exchange |
| Adaptability | Ability to modify operations in response to challenges or opportunities | Fast rerouting of requirements, Lead time reduction, Strategic gaming and simulation, Seizing advantage from disruptions, Alternative technology development, Learning from experience |
| Anticipation | Ability to discern potential future events or situations | Monitoring early warning signals, Forecasting, Deviation and Near-miss analysis, Contingency planning, Preparedness, Risk management, Business continuity planning, Recognition of opportunities |
| Recovery | Ability to return to normal operational state rapidly | Crisis management, Resource mobilization, Communications strategy, Consequence mitigation |
| Dispersion | Broad distribution or decentralization of assets | Distributed decision-making, Distributed capacity and assets, Decentralization of key resources, Location-specific empowerment, Dispersion of markets |
| Collaboration | Ability to work effectively with other entities for mutual benefit | Collaborative forecasting, Customer management, Communications, Postponement of orders, Product life cycle management, Risk sharing with partners |
| Organization | Human resource structures, policies, skills and culture | Learning, Accountability and Empowerment, Teamwork, Creative problem solving, Cross training, Substitute leadership, Culture of caring |
| Market position | Status of a company or its products in specific markets | Product differentiation, Customer loyalty/retention Market share, Brand equity, Customer relationships, Customer communications |
| Security | Defense against deliberate intrusion or attack | Layered defenses, Access restrictions, Employee involvement, Collaboration with governments, Cyber-security, Personnel security |
| Financial strength | Capacity to absorb fluctuations in cash flow | Insurance, Portfolio diversification, Financial reserves and liquidity, Price margin |

**Source(s):** Table adapted from Pettit *et al.* (2010)

**Table 2.** Capability factors for supply chain resilience

probability of occurrence of disruption, the scales used in Table 5 are based on studies by Curkovic *et al.* (2015).

Step 3: Evaluate the possibility of assuaging the disruption. In this study, two different ways were pointed out: the SC capability factors and business processes. These are

| Specific factors | Description | Strategic sub-processes | Operational sub-processes |
|---|---|---|---|
| Customer relationship management | Provides the structure for how relationships with customers are developed and maintained. Cross-functional customer teams tailor product and service agreements to meet the needs of key accounts and segments of other customers | 1. Review Corporate and Marketing Strategy<br>2. Identify Criteria for Categorizing Customers<br>3. Provide Guidelines for the Degree of Differentiation<br>4. Identify Opportunities with the Accounts<br>5. Develop the Product/ Service Agreement | 1. Differentiate Customers<br>2. Prepare the Account/ Segment Management Team<br>3. Internally Review the Accounts in the Product/ Service Agreement<br>4. Develop Framework of Metrics<br>5. Develop Guidelines for Sharing Process Improvement<br>6. Implement the Product/ Service Agreement Benefits with Customers<br>7. Measure Performance and Generate Profitability Reports |
| Customer service management | Provides the firm's face to the customer, a single source of customer information and the key point of contact for administering the product service agreements | 1. Develop Customer Service Strategy<br>2. Develop Response Procedures<br>3. Develop Infrastructure for Implementing Responses Procedures<br>4. Develop Framework for metrics | 1. Recognize Event<br>2. Evaluate Situation and Alternatives<br>3. Implement Solution<br>4. Monitor and Report |
| Demand management | Provides the structure for balancing the customers' requirements with supply chain capabilities, including reducing demand variability and increasing supply chain flexibility | 1. Determine Demand Management Goals and Strategy<br>2. Determine Forecasting Procedures<br>3. Plan Information Flow<br>4. Determine Synchronization Procedures<br>5. Develop Contingency Management System<br>6. Develop Framework of Metrics | 1. Collect Data/Information<br>2. Forecast<br>3. Synchronize<br>4. Reduce Variability and Increase Flexibility<br>5. Measure Performance |
| Order fulfillment | Includes all activities necessary to define customer requirements, design a network and enable the firm to meet customer requests while minimizing the total delivered cost | 1. Review Marketing Strategy, Supply Chain Structure<br>2. Define Requirements for Order Fulfillment<br>3. Evaluate Logistics Network<br>4. Define Plan for Order Fulfillment<br>5. Development Framework of Metrics | 1. Generate and Communicate Order and Customer Service Goals<br>2. Enter Order<br>3. Process Order<br>4. Handle Documentation<br>5. Fill Order<br>6. Deliver Order<br>7. Perform Post Delivery Activities and Measure Performance |

*(continued)*

**Table 3.**
Supply chain processes

| Specific factors | Description | Strategic sub-processes | Operational sub-processes |
|---|---|---|---|
| Manufacturing flow management | Includes all activities necessary to obtain, implement and manage manufacturing flexibility and move products through the plants in the supply chain | 1. Review Manufacturing, Sourcing, Marketing, and Logistics Strategies<br>2. Determine Degree of Manufacturing Flexibility 4. Measure Performance<br>3. Determine Push/Pull Boundaries<br>4. Identify Manufacturing Constraints and Determine Capabilities<br>5. Development Framework of Metrics | 1. Determine Routing and Velocity through Manufacturing<br>2 Manufacturing and Materials Planning<br>3. Execute Capacity and Demand Requirement |
| Supplier relationship management | Provides the structure for how relationships with suppliers are developed and maintained. Cross-functional teams tailor product and service agreements with key suppliers | 1. Review Corporate, Marketing, Manufacturing and Sourcing Strategies<br>2. Identify Criteria for Categorizing Suppliers<br>3. Provide Guidelines for the Degree of Customization in the Product/Service Agreement<br>4. Develop Framework of Metrics<br>5. Develop Guidelines for Sharing Process Improvement Benefits with Suppliers | 1. Differentiate Customers<br>2. Prepare the Supplier/ Segment Management Team<br>3. Internally Review the Supplier/Supplier Segment<br>4. Identify Opportunities with the Suppliers<br>5. Develop the Product/Service Agreement and Communication Plan<br>6. Implement the Product/ Service Agreement<br>7. Measure Performance and Generate Supplier Cost/ Profitability Reports |
| Product development and commercialization | Provides the structure for developing and bringing to market new products jointly with customers and suppliers | 1. Review Corporate, Marketing, Manufacturing and Sourcing Strategies<br>2. Develop Idea Generation and Screening Processes<br>3. Establish Guidelines for Cross-functional Product Development Team Membership<br>4. Identify Product Rollout Issues and Constraints<br>5. Establish New Product Project Guidelines<br>6. Develop Framework of Metrics | 1. Define New Products and Assess Fit<br>2. Establish Cross-functional Product Development Team<br>3. Formalize New Product Development Project<br>4. Design and Build Prototypes<br>5. Make/Buy Decision<br>6. Determine Channels<br>7. Product Rollout<br>8. Measure Process Performance |

(*continued*)

**Table 3.**

| Specific factors | Description | Strategic sub-processes | Operational sub-processes |
| --- | --- | --- | --- |
| Returns management | Includes all activities related to returns, reverse logistics, gatekeeping and avoidance | 1. Determine Returns Management Goals and Strategy<br>2. Develop Avoidance, Gatekeeping and Disposition Guidelines<br>3. Develop Returns Network and Flow Options<br>4 Develop Credit Rules<br>5. Determine Secondary Markets<br>6. Develop Framework of Metrics | 1. Receive Return Request<br>2. Determine Routing<br>3. Receive Returns<br>4. Select Disposition<br>5. Credit Consumer/Supplier<br>6. Analyze Returns and Measure Performance |

**Table 3.**

**Source(s):** Adapted from Lambert and Croxton (2005)

| Degree | Description | Median rating |
| --- | --- | --- |
| Very high | When a potential failure mode affects safe operation of the product and/or involves nonconformance with government regulations. May endanger people or product. Assign “9” if there will be a warning before disruption, assign “10” if there will not be a warning before disruption | 10–9 |
| High | When a high degree of customer dissatisfaction is caused by the disruption. Does not involve safety of people or product or compliance with government regulations. May cause disruption to subsequent processes/operations and/or require rework | 8–7 |
| Moderate | When a moderate degree of customer dissatisfaction is caused by the disruption. Customer is made uncomfortable or is annoyed by the disruption. May cause rework or result in damage to equipment | 6–5 |
| Minor | When a disruption is not likely to cause any real effect on subsequent processes/ operations or require rework. Most customers are not likely to notice any disruption. Any rework that might be required is minor | 4–3 |
| Low | When a disruption will cause only slight annoyance to the customer | 2–1 |

**Source(s):** Adapted from Curkovic *et al.* (2015)

**Table 4.** FMEA disruption severity degree ranking

described in Tables 2 and 3, so one should identify the capability factor, analyze its definition, describe the subprocesses, demonstrate the mitigation potential and describe the procedure that will be performed. In relation to the SC process, it is necessary to describe how your intervention will be and what its mitigation potential will be afterward.

To check the quantification of the data, for both, scales to soften the risk of constant disruption were called FMEA – risk mitigation degree ranking (Table 6), with the same scale being applied for both factors. To maintain the detection calculation, the result was divided by two. The Level of Prevention Disruption of Supply Chain (LPDSC) is calculated as follows (Equation (1)).

$$\begin{aligned} \text{LPDSC} = & \ (\text{Impact of Disruption x Probability of Causing Problems}) \\ & - (\text{Score Capability Factor Score x SC process Score}) \end{aligned} \tag{1}$$

Table 6 shows the FMEA risk mitigation degree ranking:

| Chance | Description | Probability | Median rating |
|---|---|---|---|
| Very high | Disruption is almost inevitable | 1 in 2<br>1 in 3 | 10–9 |
| High | Process is "similar" to previous processes with a high rate of disruption | 1 in 8<br>1 in 20 | 8–7 |
| Moderate | Process is "similar" to previous processes which have occasional disruption | 1 in 80<br>1 in 400<br>1 in 2,000 | 6–5 – 4 |
| Low | Process is "similar" to previous processes with isolated disruption | 1 in 15,000 | 3 |
| Very low | Process is "similar" to previous processes with very isolated disruption | 1 in 150,000 | 2 |
| Remote | Process is "similar" to previous processes with no known disruption | 1 in 1,500,000 | 1 |

**Source(s):** Adapted from Curkovic *et al.* (2015)

**Table 5.** FMEA disruption occurrence degree ranking

| Degree | Degree in % | Description | Median rating |
|---|---|---|---|
| Detection is not possible | 0 | Control method(s) cannot or will not detect the existence of a disruption | 10 |
| Very low | 0–50 | Control method(s) probably will not detect the existence of a disruption | 9 |
| Low | 50–60<br>60–70 | Control method(s) has a poor chance of detecting the existence of a disruption | 8–7 |
| Moderate | 70–80<br>80–85 | Control method(s) may detect the existence of a disruption | 6–5 |
| High | 85–90<br>90–95 | Control method(s) has a good chance of detecting the existence of a disruption | 4–3 |
| Very high | 95–100 | Control method(s) will almost certainly detect the existence of a disruption | 2–1 |

**Source(s):** Created by authors

**Table 6.** FMEA risk mitigation degree ranking

### *3.1 FMEA-SCR application*

Taking into account the information described in Tables 1–6, in this work, the combined model was applied to an educational institution and a cooperative for the collection of recyclable materials.

The first organization analyzed is a higher education organization with more than 100 years of history, founded in 1909. In 2020, the university will have 13 campuses, 32,000 students, 2,500 teachers and 1,200 administrative technicians. Its performance in teaching is linked to technical, technological, undergraduate and graduate courses.

The second organization analyzed is a cooperative, which has two basic types of recyclable material input. The material comes from companies called large generators because the volume of recyclable material generated is high. Another source of recyclable material comes from homes, where the cooperative conducts selective collection door-to-door. The cooperative has a contract with the municipal government under which it receives a fee for each residence served. The sale of the collected material is made to companies in neighboring cities or neighboring states, and the city gives in to the cooperative (Fidelis and Colmeneiro, 2018; Fidelis *et al.*, 2020).

## 4. Results and discussion

For the purpose of validating the proposed combined model, two organizational cases will be presented, showing the complete analysis of the FMEA-SCR.

Regarding the first organization analyzed in March 2020, the institution entered a lockdown, ending all of its teaching, administrative and research and extension activities in person. Administrative work was carried out remotely and with restrictions on the movement of people in research laboratories. Undergraduate classes were maintained remotely for two weeks and were interrupted after this period. The academic calendar was paralyzed after this period, but with the extension of actions linked to isolation, the university created a new regulation for the development of undergraduate and graduate classes and in August, teaching activities were carried out in a non-presence manner.

The analysis of this process was performed through the proposed tool FMEA-SCR, where the disruptions are described as well as the internal and external factors of the organization that can be used to mitigate them. The FMEA-SCR analysis intends to demonstrate how the institution can work within the internal factors of the organization and factors linked to the supply chain to mitigate the impacts of the pandemic.

Table 7 presents the FMEA – SCR application applied to the case study at the university.

In the study case related to the university, it can be seen that the first impacts generated by COVID-19 are linked to disruption factor turbulence since there was an interruption in classroom teaching activities from March 2020 to February 2022.

The choice is related to the fact that the university is part of a supply chain, not in the classic model of SC (product manufacturing), but as a teaching service provider in the following sense of SC links: book suppliers, equipment (computers, video resources, software), laboratory maintenance equipment, consumer materials (reagents, office supplies) and at the focal company: students, teachers, and academic community; and downstream companies that receive professionals trained by this university that can directly affect the performance of a country's economy, research results (published scientific articles), including vaccine development.

Given this and the strong impact caused by the disruption of activities in this chain, since in Brazil, some universities only returned to their face-to-face activities in 2022, this chain was chosen for analysis as it was highly impacted by the disruption caused by COVID-19.

This caused a major break in the university's teaching, research and extension activities. The main consequence of the interruption is the possible dropout of students, which is described in Table 7 in its second line. To mitigate this impact, the institution approved a new regulation for non-face-to-face distance classes, using the capability factor adaptability and along the supply chain, worked with the process of SC (CRM), making use of its network contacts with students (email, lives on YouTube, mobile apps) to explain the procedures that would be performed to maintain teaching activities.

Teaching activities (online classes) were maintained, reducing student evasion. The remote mode of teaching (live classes and/or recorded by professors) was carried out, and as a consequence, the university was able to maintain its academic calendar even during the periods (2020–2021) in which the university was closed.

Continuing the disruption analysis, it was possible to verify that despite their potential impact, since it presents a high risk and a high probability of causing problems, the actions that can be taken by the organization are aimed at mitigation through the adaptability factor, where the organization can create a new regulation, using its relationship network with its students to assist in the approval of the regulation, as well as build a new form of teaching called synchronous teaching, which in turn is responsible for mitigating some impacts that refer to the departure of students and the cancellation of a new entry of students in two semesters.

| Disruption factor | Disruption description | Risk | Impact | Disruption impact | Problems probability | Capability factor | Capability | Mitigation potential | How it will occur | Ability factor Score | SC process | Mitigation potential | How it will occur | Ability factor score | LPDSC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Turbulence | Shutdown of classroom teaching activities | Noncompliance with the academic calendar | Damage in relation to new calendars and the inability of students entering the second semester of 2020 and the first semester of 2021 | 7 | 7 | Adaptability | Developing non-presence classes | High, due to the maintenance of teaching activities | The calendar resumed with non-presence classes | 5 | Customer Relationship Management | Approval of a new teaching regulation that allows non-presence lessons | Contact with students' class representatives directly with students | 5 | 24 |
| Turbulence | Shutdown of classroom teaching activities | Withdrawal of students | Due to stoppage, students may withdraw from the course | 9 | 9 | Adaptability | Developing non-presence classes | Medium, because some students do not adapt to non-presence classes | The calendar resumed with non-presence classes | 5 | Customer Relationship Management | Approval of a new teaching regulation that allows for non-presence lessons | Contact with students' class representatives directly with students | 5 | 24 |
| Supplier/customer disruptions | Difficulty in obtaining the supply of some inputs for continuing scientific research | Research interruption | Stopping scientific research | 3 | 4 | Flexibility in sourcing | Search for a new base of suppliers that can meet the demand | Low, due to the existence of few suppliers and because it is a state-owned company, the need for specific purchasing procedures | Searches informational database for new suppliers with existing contracts | 3 | Supplier Relationship Management | Low due to the existence of few suppliers registered in the informational database | Search with the informational supplier base | 2 | 6 |
| Resource limits | Decrease in resources due to the decrease in the number of students enrolled | Inability to perform basic services combined with research and extension teaching activities | Decrease in quality of teaching, number of research and extension activities | 9 | 9 | Adaptably | Developing non-presence classes | Medium, because some students do not adapt to non-presence classes | The calendar resumed with non-presence classes | 5 | Customer Relationship Management | Approval of a new teaching regulation that allows non-presence classes | Contact with students' class representatives directly with students | 2 | 71 |
| Resource limits | Decrease in resources due to decrease in the number of students enrolled | Inability to perform basic services combined with research and extension teaching activities | Decrease in quality of teaching, number of research and extension activities | 9 | 9 | Adaptability | Search for new research notices aimed at developing research and extension activities linked to COVID-19 | Medium, due to the small number of researchers with expertise in the health area | Dissemination of research and extension notices linked to COVID-19 | 3 | Supplier Relationship Management | Search the source agencies for specific public notices for Covid-19 | Search with the promotion and dissemination agencies with the academic community | 3 | 72 |

**Source(s):** Created by authors

**Table 7.** FMEA – SCR applied to the university

The highest FMEA-SCR factors are linked to the limited resources, tending to decrease the number of students and consequently decreasing the resources to be invested in research and extension projects.

The organization used its capability factor with the synchronous procedure and also used the SC process of customer relationship management to mitigate students' departure impacts. However, it does not have a significant impact, given the tendency of the organization to lose students. As an example, consider the case of new classes of MBA courses that have not been launched, as in most cases there was no time to prospect internally for synchronous activities.

This same disruption generates losses in relation to the maintenance and prospection of new research and extension projects with the university. Thus, there was a significant damage to research activities since many researchers were paralyzed as they depended on manpower to carry out tests and analyses.

The fact that research activity is directly linked to teaching activity is one of the factors causing such an impact since the students who are linked to scientific initiation, master's and doctoral activities, for the most part, live in cities other than the university headquarters, so they returned to their hometowns, maintaining academic activities but interrupting activities related to search.

The capability factor used to mitigate this impact, adaptability through the search for a database and changes in research and extension projects to meet the demands of development agencies on COVID-19, proved to be limited since the university had research lines linked to engineering and the demand was for studies related to the health area. The SC process used to mitigate the impact, supplier relationship management, which aims to seek from partners the maintenance of resources, also proved to be limited.

Thus, the organization was able to mitigate some impacts with its internal and external factors, but the disruption factor's turbulence tends to pose a greater risk since it was not found within its capability factor or SC process, resulting in actions capable of completely mitigating the risks caused by the disruption.

Risk factors were classified according to severity and probability. The aspects of impact mitigation for the SC disruption take into account several capacity factors and processes that, if an organization has developed them, can serve as a basis to mitigate the impacts generated by the pandemic, thereby enhancing the 3 R's of SC.

The first analysis was carried out in a targeted manner and predicts that a large-oriented brainstorm will be carried out, where each disruption factor is presented: turbulence; deliberate threats; external pressures; resource limits; sensitivity; connectivity; vendor or customer interruptions.

An analysis of all the disruptive factors allows the company to think about how COVID-19 can impact its several SC links from the perspective of quantitatively measuring them, and this procedure takes place in the second phase. In a high-impact disruption context, resource reconfiguration fully mediates the relationship between SC disruption orientation and firm 3Rs.

In a low-impact disruption context, SC disruption orientation and risk management infrastructure have a synergistic effect on developing firm resilience (Ambulkar *et al.*, 2015).

Table 8 presents the FMEA-SCR results applied to the recyclable materials company, considering capability factors and SC processes.

The second case analyzed is linked to the reverse supply chain of recyclable materials.

The link chosen to be analyzed is responsible for the collection and separation of urban solids with recyclable potential, and the company is the focal company of the study, a cooperative that follows recyclable materials, performing the residential urban collection of recyclable materials and large generators (companies that generate recyclable materials). It separates these materials into more than 40 different types of categories, presses and markets. The main services provided are the collection, the protection of the environment and

**Table 8.** FMEA – SCR applied to the cooperative

| Disruption factor | Disruption description | Risk | Impact consequence | Disruption impact | Probability of causing problems | Capability factor | Capability factor description | Mitigation potential | How it will occur | Score capability factor | SC process | How it will occur | Mitigation potential | SC process score | LPDSC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Resource limits | Large generators reduced the availability of material | Medium | Decrease in cooperative income | 9 | 9 | Adaptability | Increased collection of recyclable material from individuals | High | Increased collection result in lack of material from large generators | 9 | Demand Chain | Increased demand from another customer segment | high | 9 | 40,5 |
| Turbulence | Decrease in prices of recyclable materials | High | Decrease in sales price and accumulation of material | 9 | 9 | Market Position | Establish long-term contracts | Low | Seeking that former customers keep the amount paid | 2 | Customer Relations Manager | Check with old customers to maintain contracts | low | 2 | 79 |
| External pressures | Lower prices for new materials | High | Buyers tend to decrease the amount paid for recycled material | 9 | 9 | Dispersion | Search new markets to distribute products | High | Increased collection result in lack of material from large generators | 9 | Demand Chain | Increased demand from another customer segment | high | 9 | 0 |
| Resource limits | Decrease in materials from large generators | Medium | Decrease in cooperative income | 9 | 4 | Market Position | Use campaigns with new large generators | Low | High prices of PPE's | 2 | Demand Chain | Check with public agents the availability of PPE's | low | 2 | 32 |
| Sensitivity | Risk of contagion of members | High | Decreased workforce and health risk | 9 | 9 | Adaptability | Increase workplace ventilation, distribution of Personal Protective Equipment | Low | PPE distribution and increased ventilation | 1 | Customer service Manager | Campaign to public awareness to not discard masks with the recyclable material | low | 2 | 79 |
| Deliberate Threats | Increasing informal waste pickers | Low | Decreased income and increased conflicts with waste generators | 3 | 3 | Adaptability | Possibility to attract new members | Low | Active search with informal waste pickers | 2 | Customer Service Manager | Instruct generators about the risks in informal collection | low | 2 | 5 |

**Source:** Created by authors

the improvement of working conditions through the income generation and improvement in the working conditions of the members. To this end, it sells its services to public and private organizations, and its products are marketed to industries belonging to the reverse and traditional supply chains.

Thus, the cooperative for recyclable materials and its main impactful links of the supply chain are: downstream industries that have as their raw material recyclable materials; upstream populations; large generators that recently used the collection service; city hall (the service contractor); and the environment, since if the service is not performed, the destination of waste will be the landfill.

Regarding the application of the FMEA-SCR to this second case study, initially the analysis is performed in an oriented manner and provides that a large oriented brainstorm is performed, where each disruptive factor is presented, namely: turbulence; deliberate threats; external pressures; resource limits; sensitivity; connectivity; and supplier/customer disruptions.

The turbulence factor was the first identified; of course, COVID-19 causes the disruption in SC, but when analyzing the other breaking factors, it appears that there were disruptions in relation to suppliers and consumers of the cooperative; in short, all factors allowed disruptions to be analyzed, described and quantified as to their impact and probability of occurrence.

Analysis of all factors related to possible disruptions in the SC allows the company to think of how COVID-19's pandemic can impact the SC links, and from the same perspective, one can quantitatively measure their impact.

Once the disruption factor is identified, the company can view how the various capability factors can be used to mitigate impacts. This procedure happens in the second phase.

So an analysis of the capability factors can be performed, taking into account each set of capabilities: flexibility in supply; flexibility in order to fulfill; capacity; efficiency; visibility; adaptability; anti-culture; recovery; dispersal; collaboration; organization; market position; financial security and soundness. Its analysis allows an organization to understand, quantify and minimize its effects. Thus, the company can visualize how they can be used as internal resources (dimensions).

Another capability that can be cited (but it does not suit this case study) is information technology (IT), since organizations increasingly rely on it to improve the supply chain process. However, evidence suggests that investment in IT *per se* does not guarantee enhanced organizational performance. This capability can serve as a catalyst for transforming IT-related resources into higher value for a firm (Wu *et al.*, 2006).

The analysis was carried out also taking into account the following SC processes: customer relationship management, customer service management, demand management, fulfillment of orders, manufacturing flow management, supplier relationship management, product development and commercialization and returns management. It was through this association analysis that the organization visualized and identified actions related to the SC processes that could be used to alleviate the impacts of disruptions, this procedure was also quantified.

In summary, the main points analyzed were: the disruption factor, of which the most impacted the recycling chain, were turbulence (LPDSC score 79), sensitivity (LPDSC score 79) and rearness (LPSSc score 40.5).

The disruption had a high degree of impact on almost all the factors analyzed, but some impacts were mitigated, such as the external factor. Pressures, which were mitigated by the SC process, generated an increase in demand from large generators due to the increased materials generated. By great generators, it also draws attention to the disrupton sensitivity factor: the risk of contamination, since there has been an increase in the number of masks used by people to prevent COVID-19 contamination.

The union between a supply chain factor and a process has a multiplier weight, since the combination of these two elements can drive a reaction of the company within the SC in order to mitigate the disruption factors.

When major disruptions occur, many supply chains tend to break down and take a long time to recover. However, not only can some supply chains continue to function smoothly but also they continue to satisfy their customers before and after a major disruption. A robust strategy will enable a firm to manage regular fluctuations efficiently under normal circumstances, regardless of the occurrence of major disruptions (Tang, 2007).

So, a robust strategy will help a firm sustain its operations during a major disruption. Through the data analysis presented (Tables 7 and 8), it is possible to clearly understand which disruptions are impacting the SC. Through the procedure described here, the organization can verify which factors can be used to soften the disruption's impacts.

The result regarding the LPDSC is at the discretion of the organization and classifies the elements of disruptions; capability factors and processes together, clearly exposing which would have the greatest impact and also the lowest risk.

A FMEA-SCR hybrid tool was present by taking into account business processes and risk mitigation factors, so they are unified, described and quantified, summarizing the information collected in a single table that allows activities to be prioritized by the companies. Thus, the company can identify the disruptions with the greatest impact on their supply chain and seek actions to minimize or avoid the impacts of such a pandemic crisis.

## 5. Conclusions

This study synthesizes three different procedures into a single method called the FMEA-SCR, allowing organizations to understand and assess in a simplified way the impacts on their SC generated by COVID-19. To this end, it brought together the studies developed by Rajesh and Ravi (2015) and Curkovic *et al.* (2015) on possible causes of disruptions in SC, the capability factors of Pettit *et al.* (2010) used by organizations to mitigate the effects of disruptions and Lambert's and Croxton's (2005) business processes, thus weaving a method that allows organizations to visualize, analyze and classify the pandemic impacts over their supply chain.

To validate the combined model, it was applied to two different organizational proofs of concept, allowing the description, analysis and quantification in a wide and detailed way of the impacts caused by COVID-19, as well as the classification according to criteria of criticality. The simplicity of the method allows even organizations without a large organizational structure to use it and achieve favorable results to alleviate disruption impacts.

For future work, other forms of decision-making analysis can be studied, such as the analytic hierarchy process (AHP), analytic network process (ANP), fuzzy logic DEMATEL and disruption analysis network (DA_NET) methods, which have already proven useful in combination with the FMEA and SCR in other scenarios.

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