ISSN 2228-9860 eISSN 1906-9642 CODEN: ITJEA8

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International Transaction Journal of Engineering, Management, & Applied Sciences & Technologies

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A Framework for Identifying and Managing Risk Impact Factors for Disruptions in the Food Supply Chain

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Paper ID: 12A4U

Volume 12 Issue 4

Received 04 January 2021
Received in revised form 18 February 2021
Accepted 25 February 2021
Available online 1 March 2021

Keywords:
Supply chain disruption; SC Risk Variables; ISM; MICMAC analysis; Dependence power; Drive power; Risk wheel; Structural Self Interaction Matrix (SSIM); Risk Mitigation; Risk ranking; Performance measurement; Food supply chain threat.

Abstract

Risk has constantly been an issue in the supply chain. It's a reality inside and out of the four walls of any organization. It's very important to handle anticipated and unexpected risks occurring upstream and downstream in the supply chain. Supply chain disruptions can be outlined as any unforeseen events that disturb the conventional flow of goods. These disruptions eventually will have major negative consequences for the management of operations. This research commences with identifying the different dimensions of the risks associated with the supply chain processes and understanding how these risk factors contribute towards the supply chain performance and its measurement. All these risk variables will be identified by critically reviewing 25 reputed relevant papers and surveying 200 subject matter experts. A contextual relationship between variables is established with the help of Interpretive Structure Modeling (ISM) and eventually the extent of the criticality of those variables is obtained so that these risks will be prioritized. MICMAC analysis will be used further to complement the ISM approach by exploring all the constraints that will help in funneling out the drive power and dependence power of all these risk variables.

Disciplinary: Operations & Logistics (Supply Chain Management).

Cite This Article:

Ray, P., Duraipandian, R., and Sinha, R. (2021). A Framework for Identifying and Managing Risk Impact Factors for Disruptions in the Food Supply Chain. *International Transaction Journal of Engineering, Management, & Applied Sciences & Technologies, 12*(4), 12A4U, 1-11. http://TUENGR.COM/V12/12A4U.pdf DOI: 10.14456/ITJEMAST.2021.84

1 Introduction

Over the past three decades, the supply chain has become increasingly global and complex (Narasimhan, 2009). In the past ten years, supply chain risk has become an increasingly important segment of supply chain management (Sheffi, 2005). Thus, there is a necessity for comprehensive methodologies to grasp the underlying structure constituting the linkage between risk sources, risk occurrences, and effects on performance (Spekman, 2014).

To gain a holistic understanding of how these risk variables affect the supply chain performance management in such a crisis, in-depth quantitative research is required (Sinha, 2004). Focusing on these risks can help organizations recognizing potential critical risk factors and corrective actions to combat these risks (Lockamy, 2010). This research aims to identify the most significant factors in the risks of the supply chain affecting the overall performance of the supply chain processes through literature review, surveys, and interviews. Further, these variables should be measured, and a coherent relationship among them will be quantified by conducting a statistical analysis of these variables through ISM. MICMAC will be used to analyze the drive power and dependency power of these variables.

This research does not only identify the risk variables but also ranks these variables by establishing the interrelationship among these variables and the level of importance of each of the variables. This research will provide the degree of impact for each of these variables and also help in understanding the direct or indirect relationships between the variables by implementing a cross-impact matrix. Moreover, it will also provide managerial implications for decision-making. This study explores the identification of major supply chain risk factors leading to SC problems according to the principles of objectivity, significance, system, and continuity.

2 Literature Review

Supply chain risk management has always been a matter of concern for researchers and practitioners, and despite this, today organizations still lack a risk culture (Lummus, 2001). Risk management has been gaining extensive attention as a critical subject within the field of supply chain management (Juttner, 2005). The failure to effectively and efficiently manage supply chain risk may end in economic and financial losses, leading to reductions in product quality, delivery delays, and loss of customer and supplier trust (Hult, 2017; Hendricks, 2013). Thus, supply chain risk management has become a core issue in coming up with and management of any organization (Finch, 2004). However, organizations that perceive the importance of supply chain risk typically do not apprehend wherever to start to tackle it (Kiser, 2016).

Raiffa (1982), Chopra (2004), and Norman (2004) presented an illustrative list of supply chain risks. Wu (2006) applies the Analytic Hierarchy method (AHP) to calculate the relative weight of every risk issue, which is an indicator of how necessary a risk issue is. Finally, quantitative risk analysis usually depends on simulation approaches like the Monte Carlo technique, Petri Nets, and fault and event trees (Wu, 2008; Kleindorfer, 2005). Building on these studies, Tummala (1994), Hallikas (2002), and Lee (1992) developed a structured Risk Management method (RMP) consisting of the five phases risk identification, risk measuring, risk assessment, risk analysis, and risk management and observation.

The authors (articulated that for enhancing supply chai performance; supply chain risk needs to manage and alignment, adaptability, and agility are the basic ingredients for managing supply chain risks. The metrics and measures are mentioned within the context of the subsequent supply chain activities/processes: (1) Plan, (2) source, (3) make/assemble, and (4) delivery/customer (Tuncel, 2010; Gunasekaran, 2001). For a balanced approach, Maskell (1991) and Kaplan (1992) suggested that corporations should perceive that, whereas monetary performance measurements area unit is necessary for strategic decisions and external reporting, day-to-day control of producing and distribution operations is commonly handled higher with non-financial measures.

2.1 Gap Analysis

Many companies do not focus on Performance Gaps resulting in a lack of competitiveness (Hult, 2017). There has been a deficit of no audit process in the supply chain. Also, there is a gap in Predictive Analytics to assess Supply chain Disruptions. When disruptions occur in the supply chain that demands an immediate response, the company and its customers should have thought about its strategy well beforehand so that they will not be caught off-guard.

3 Methodology

This is quantitative research for gaining an in-depth understanding of the context and relating the same to the wider population in the area of the Supply Chain. This research uses both primary and secondary data. This research is exploratory and correlational in nature.

This research uses Interpretive Structure Modeling (ISM) for the basic streamlining of quantitative analysis. MICMAC analysis will be done to complement the ISM approach.

- To identify and rank the risk variables.
- To establish the inter-relationship among these variables.
- To discuss the managerial inference of the research.

This research is exploratory, aiming to explore all the potential risks affecting the supply chain from various angles.

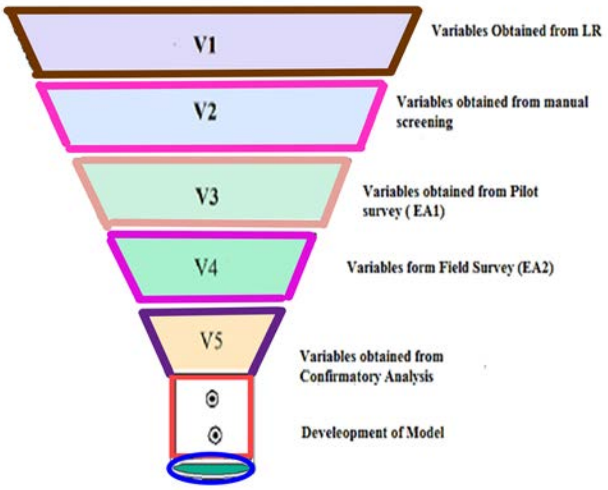

Figure 1: Stages of variables funneling.

The research questions include “What are the risk factors correlated in the supply chain? How are these factors critical to the performance of supply chain processes? What is the level of criticality of these identified risks from the management perspective? What are the drive power and dependency power of these risk variables? How supply chain managers can combat the performance issues by prioritizing the risks?” The researcher has considerably channeled all the risk variables in five different levels to find out the critical supply chain risks. The block diagram (Figure 1) shows how the variables have been funneled.

Figure 2 shows the critical risk variables that impact the supply chain processes.

Figure 2: Research Variables.

3.1 Data Collection

The primary data were collected from questionnaires surveys with open and close-ended questions for Bengaluru, India. For the sampling technique, this research uses Random Sampling and Snowball Sampling. This has been mainly done in-person and online in some cases due to the pandemic Covid-19 outbreak, totaling 200 data. The secondary data includes the variables taken from reputed journals, databases, and physical archive data (25 papers).

4 Analysis, Results, and Discussion

The final variables extracted from the data analysis are finally analyzed through ISM and MICMAC models. The block diagram Figure 3 shows the approach of ISM and MICMAC analysis.

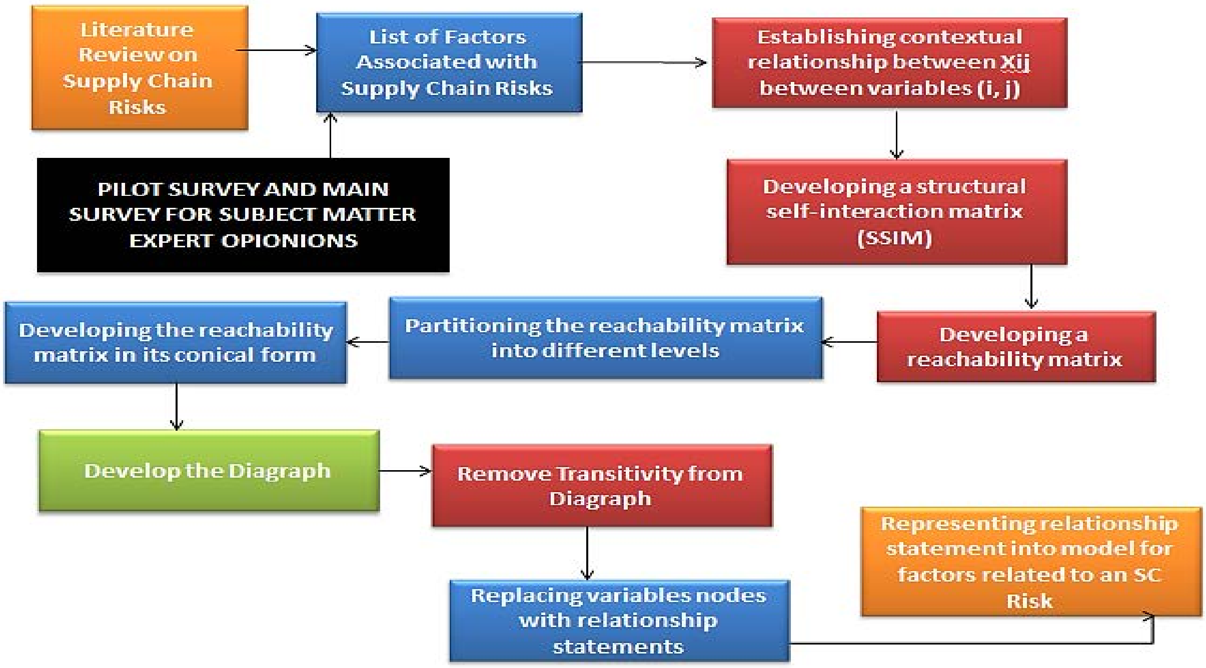

Figure 3: ISM and MICMAC Approach.

Figure 3, the various steps involved in the ISM Modeling used in this research are as follows:

STEP 1: Identification of Elements Relevant to the Problem

Table 1, from the final confirmatory factor analysis; these elements are taken as an input to the model. These elements are the threat that has been confirmed from the confirmatory factor analysis. The coding is done in this step to help the visualization of the matrix easier.

Table 1: Assigned threat coding to the threats.

Risks or Threats	Corresponding codings
In-Transit Storage Conditions	1
In-Transit Delay	2
Supplier Reliability	3
Poor Quality	4
Inventory Fluctuations	5
Operations Downtime	6
IT failure	7
Data Error	8
Credit Risk	9
Trade Agreement Inflation	10

STEP 2: Establishing the Relationship between These Elements

Based on the input data collected from the experts, the relationship has been established and the maximum count on the relationship is taken as the final input to the matrix, Table 2, where I - Row wise representation and J - Column wise representation.

Table 2: Establishing relationships between elements.

Based on Experts Input the relationship matrix has arrived		J									
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
I	**1**	O	V	V	V	O	O	O	O	O	O
	2	A	O	V	A	O	V	O	A	O	O
	3	A	A	O	X	X	O	O	O	O	O
	4	A	V	X	O	O	O	O	O	V	V
	5	O	O	X	O	O	O	O	A	O	O
	6	O	A	O	O	O	O	V	O	O	O
	7	O	O	O	O	O	A	O	O	O	O
	8	O	V	O	O	V	O	O	O	O	O
	9	O	O	O	A	O	O	O	O	O	O
	10	O	O	O	O	A	O	O	O	O	O

STEP 3: Creating Structural Self Interaction Matrix (SSIM)

This SSIM matrix designates the pair-wise relationship among elements of the system. This matrix is checked for transitivity. The relationship between each of the elements is then converted into the matrix as Boolean. The input is then taken in the matrix as follows: **V and X** as 1 and **O and X** as 0, see Table 3.

Table 3: Establishing SSIM matrix.

SS.IM		J									
		1	2	3	4	5	6	7	8	9	10
I	1	0	1	1	1	0	0	0	0	0	0
	2	0	0	1	0	0	1	0	0	0	0
	3	0	0	0	1	1	0	0	0	0	0
	4	0	1	1	0	0	0	0	0	1	1
	5	0	0	1	0	0	0	0	0	0	0
	6	0	0	0	0	0	0	1	0	0	0
	7	0	0	0	0	0	0	0	0	0	0
	8	0	1	0	0	1	0	0	0	0	0
	9	0	0	0	0	0	0	0	0	0	0
	10	0	0	0	0	0	0	0	0	0	0

STEP 4: Creating Reachability Matrix (RM)

From Step 3 to Step 4, all the transitivity checks have been carried out in the matrix and allocated 1 to all the diagonal elements to arrive at the reachability matrix.

STEP 5: Partitioning of Reachability Matrix

Table 4 shows the calculated driver power and the dependence power of each of the variables.

Table 4: Calculating Driver and Dependence Power.

Partition of RM		J										Driver Power
		1	2	3	4	5	6	7	8	9	10	
I	1	1	1	1	1	0	0	0	0	0	0	4
	2	0	1	1	0	0	1	0	0	0	0	3
	3	0	0	1	1	1	0	0	0	0	0	3
	4	0	1	1	1	0	0	0	0	1	1	5
	5	0	0	1	0	1	0	0	0	0	0	2
	6	0	0	0	0	0	1	1	0	0	0	2
	7	0	0	0	0	0	0	1	0	0	0	1
	8	0	1	0	0	1	0	0	1	0	0	3
	9	0	0	0	0	0	0	0	0	1	0	1
	10	0	0	0	0	0	0	0	0	0	1	1
Dependence Power		1	4	5	3	3	2	2	1	2	2	

Dependence power is the sum of each of the columns and driving power is the sum of the rows.

STEP 6: Diagraph Formulation

After removing all the transitivity from the RM, we formulate the di-graph as shown in Figure 4, between the elements to understand the threats driver power and dependence power in the power map.

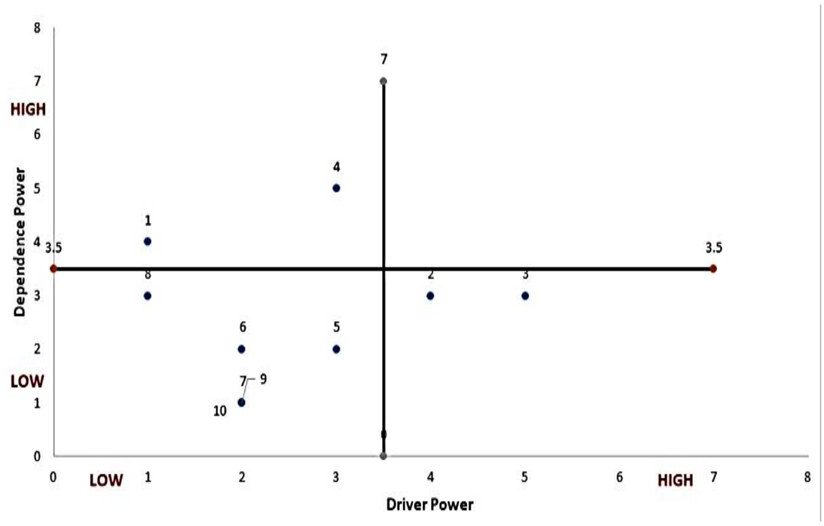

Figure 4: Formulation of digraph: Threat driver power & dependence power map.

From the ISM and MICMAC analysis, the map obtained has four quadrants which are given by the RISK model:

- Low driver and Low dependence power (Quadrant 1)
- Low driver and High dependence power (Quadrant 2)
- High driver and Low dependence power (Quadrant 3)
- High driver and High dependence power (Quadrant 4)

Quadrant 1 – insight from the RISK model:

Trade Agreement Inflation, Credit Risk, IT failure, Operations Downtime, and Inventory Fluctuations, and Data error are the elements that are put in this quadrant.

Quadrant 2 – insights from the RISK model:

In-storage conditions and poor quality are the elements that are part of this quadrant.

Quadrant 3 – insights from the RISK model:

In-transit delay and Supplier reliability

Quadrant 4 – insights (there are no elements which are found in this quadrant)

It is found that the in-storage conditions, in-transit delays, supplier reliability, poor quality, inventory fluctuations, and operations downtime are linked to the performance; data error and IT failure are related to IT-KM, and credit risk and trade inflation is related to the market.

4.1 Supply Chain Risk Assessment

According to the researcher of Aberdeen, over 80% of supply chain management executives reported that their corporation's intimate supply chain disruptions at intervals the past twenty-four months and these provide glitches and had adversely impacted their companies' client relations, revenues, time-to-market cycles, sales, and overall wholesales. They additionally found that only half of the enterprises have established metrics and procedures for assessing and mitigating supply chain risks and lots of acquisition corporations lack ample market intelligence, skills, and knowledge systems to effectively predict and mitigate supply chain risks.

Keeping this in mind, one Framework has been developed which consists of Disruption Predicators. The Primary Reporting view of this framework is known as Risk Wheel, Figure 5.

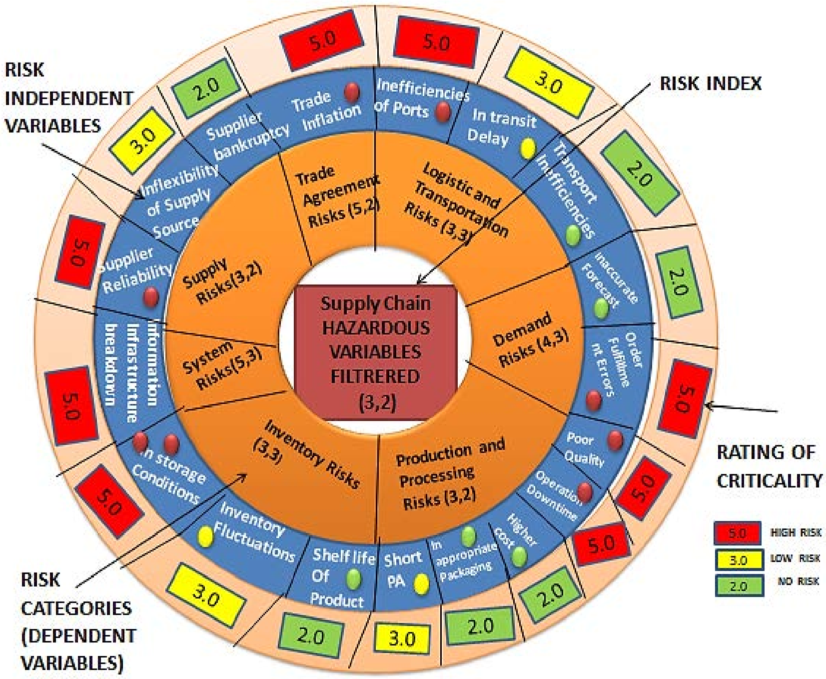

Figure 5: Risk wheel.

A Risk Wheel has been created as a primary reporting view of the supply chain risk system. Figure 1 shows the diagnostic view, accessible for any demographic and any level of drill down. At the centre of the wheel lies the risk index for Supply Chain Risks.

The second ring shows the risk categories and the items with red color-coded are critical to supplying chain risks. This can be used to recognize the critical driving risk factors.

The primary detailed view of the system is the "Risk Wheel". Figure 4 shows the diagnostic view. This view is basically available for any kind of demographic and any level of drill down. The center of the wheel is the Risk Index for the demographic (Supply Chain Risk) and the outer, the risk indicators. Each item or independent variable is color-coded. Red (high risk), Yellow (low risk), green (no risk). This report can be used to understanding the base factors about the factors that are driving risk.

Table 5: Risk FMEA and the counter-measure matrix.

Potential Critical Food Supply Chain RPN	S	O	D	RPN	Potential Impact	Potential Risk Mitigation Steps
Inefficiencies of Ports	2	37	2	148	Port Resilience Port Strike Congestion Collisions Operations Breakdown Affects Supply Chain Resilience	Using Integrated Centers for Transshipment, Storage, Collection, and Distribution (TSCD) Identifying Substitute Ports and proper Forecasting
Supplier Reliability	4	21	3	252	Impacts Responsiveness Inconsistent Performance Increased Costs	Sourcing Necessary Capabilities Avoiding Potential Risks Enhancing Management Control
Order fulfillment errors	5	36	2	360	Lost Inventory Increased Shipping Costs Increased Labor Hours Results in Discounting Items Business Reputation impacted.	Demand seamless integration Enable end-to-end order visibility. Enable exception-based order management. Proper Demand Forecasting. Switching to Modern Warehouse Management System
Operations Downtime	5	35	2	350	Lost Production Financial Losses Long-term damage to company's name. Immediate pain in the form of lost productivity and opportunities. Wasted labor. Depleted Inventory	Increase and Improve Staff Communication. Track Manufacturing Downtime Carefully. Investing in Preventive Maintenance. Upgrading Manufacturing Equipment Conducting Risk Audit
Poor Quality	4	31	2	248	Cost of Poor Quality Increased Freight Costs Increased Freight Costs Chargebacks Lost Sales Unsatisfied Customer Increased Financial Risks Hindered Performance	Enhancing the customer value of the end product. Reducing the total cost of the product Define Performance Indicators Set Target values Performance-based Logistics
Information infrastructure breakdown	5	37	1	185	SC operational inefficiency Unstable network of relationships Reduced IT capabilities Hindered Technological Functionalities Impact industrial production, public services, and communications	Regularly update software to the latest versions. Identify Threats, Make a Plan, and Learn from Mistakes. Back-up Critical Data Invest in Security Training for Employees.
Trade Inflation	3	16	3	144	Rising Transportation Costs Truck-Driver Shortages Huge Tariffs Trade Turbulence Lost Purchasing Power	Internal and External Collaboration Build Strong Supplier Relationships Blocking Inflationary Prices Transferring or sharing the risk with Supplier Deflecting the Price Increased Operating by building up inventory or making products in-house.

The average of all these rankings has been taken to decide the final criticality of the variables. For Instance, Inventory Risks have three independent variables: In Storage Conditions (given a ranking of 5); Inventory Fluctuations (given a ranking of 4), and Shelf life of the Product (given a ranking of 3). Taking an average of (5, 4, 3), the final ranking for Inventory Risks has been assigned as 3.

The Inventory risks (3, 3) imply that according to the survey, Inventory risk has an average ranking of 3 and an occurrence of 3. The occurrences have been calculated by taking the average occurrences by all the respondents. Similarly, the criticality and the occurrences have been calculated for all the risk categories. And finally, the Risk Index for the supply chain has been calculated by taking aside all the averages of the occurrences and all the averages of critical rankings. The final risk index (3, 2) has been calculated for the supply chain risks.

This view takes into consideration the indicator scores by applying them to potential risk events that will end in a supply chain disruption. This is often a relative measure used to order the factors according to the potential of the supply chain disruption.

A risk Failure Modes and Effects Analysis (FMEA) and the counter-measure matrix shown in Table 5 have been suggested that organizations can use to create a contingency chart for the critical variables funneled from the Risk wheel. The Risk Priority Number (RPN) has been calculated for all of these risks based on inputs from the survey using the formula:

$$RPN = Severity\ (S) * Occurrence\ (O) * Detectibility\ (D) \qquad (1).$$

5 Proposing the Threat Agent Risk Assessment Model

The researcher proposes a model for the industry, called the Threat Agent Risk Assessment Model. It has the following stages that would help the industry to work towards the risk. It contains a stepwise suggested framework that the researcher believes that the industry should follow aligning to the strategic plan of the Organisation

To DAMP the risks in the supply chain (Detect Assess Measure Prevent), the steps would involve

- Identification of the Threat Agents and assessing the Impacts of the Threats.
- An annual analysis would show the degree of impact of these risks.
- Perform ISM and MICMAC analysis to identify the interdependency of the risks.
- The researcher suggests exploring the Performance Sustainability Index, Traceability Index, Risk Index as may be required for the food value chain
- A Risk Wheel analysis followed by an FMEA on the Main Threat agents with mapping their Severity, Occurrence, and Detectability of Risk factors may prove useful for the stakeholders
- Developing Audit systems in the food supply chain while looking at its important variables of Performance, Information Knowledge and Market may prove to be very important. An integrated audit framework with several parameters would be useful to understand.

This study is carried out in Bengaluru, India only and there can be variations in the risk variables for others.

6 Conclusion

This research will help in optimizing supply chain processes as all the possible critical risk variables could be figured out, their interdependencies and level of criticality will be known, and then the corrective mitigation measures which need to be taken can be obtained. This will also help in reducing the overall costs of the supply chain processes. The proposed Risk wheel can act as a diagrammatic Kanban card for continuous improvements for organizations. Organizations can use Risk models such as the Risk Wheel to assess, prioritize and mitigate the risks. The findings of this study could provide the necessary point of view for the management to implement the best risk mitigation practices to improve the performance of food supply chain management. The research would bring clarity on increase the safety and security of FMCG products to customers. This also provides a framework for performance measurements which will bring onboard the much-required lack of governance and integrated checkpoints.

7 Availability of Data and Material

Information can be made available by contacting the corresponding author.

8 Acknowledgment

The authors acknowledge Mr. Hari Om Harsh for his support in data collection and analysis.

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