

# **Modeling of Risk for Agri-food Supply Chain System Sustainability**

TRIPTI



**Bharti School of Telecommunication Technology and Management**

INDIAN INSTITUTE OF TECHNOLOGY DELHI

January 2023

**© Indian Institute of Technology Delhi (IITD), New Delhi, 2023**

# **Modeling of Risk for Agri-food Supply Chain System Sustainability**

*by*

**TRIPTI**

**Bharti School of Telecommunication Technology and Management**

*Submitted*

*In the fulfilment of the requirements for the degree of Doctor of Philosophy*

*to the*



**INDIAN INSTITUTE OF TECHNOLOGY DELHI**

January 2023

## **CERTIFICATE**

This is to certify that the thesis entitled “**Modeling of Risk for Agri-food Supply Chain System Sustainability**” being submitted by Tripti to the Indian Institute of Technology Delhi for the award of the degree of **Doctor of Philosophy (Ph.D.)**, is a record of bonafide research work carried out by her. She has worked under my guidance and supervision and has fulfilled the requirements for the submission of this thesis, which has attained the requisite standard required for Ph.D. degree from the Indian Institute of Technology Delhi. The results presented in this thesis have not been submitted elsewhere for the award of any degree or diploma.

**(Prof. Ravi Shankar)**

Research Supervisor

Department of Management Studies

Indian Institute of Technology Delhi

New Delhi- 110016

## ACKNOWLEDGEMENTS

I was contently employed with a prestigious private firm before I decided to call it quits and make the transition from an ambitious professional career to a challenging research vocation. The transition was easy if you discount the salary; however, the course of research work was not. After gaining several years of professional experience and devoting a comparable number of years toward my research, I have realised that there is no use in debating which career option is better. At the end of the day, one's career choice should not be determined by an opinionated or generalised statement but rather an individual's thoughtful deliberation. What has worked for others may not work for you. In a professional career, the ease of life at the job is heavily influenced by the type of boss one has; likewise, the quality of one's research output is substantially determined by the supervisor one has.

I was fortunate to have a supervisor like Prof. Ravi Shankar (Sir) to whom I am indebted for his sincere guidance and unwavering support. Apart from his good supervisory abilities, I would like to express my kindest appreciation to him for being accessible at all times and for resolving problems encountered right from the conceptualisation of the research plan through the writing of the thesis.

I hold my deepest gratitude and respect for the members of the Students Research Committee (SRC), Dr. Mahim Sagar (Chairman), Dr M.P. Gupta (Internal) and Dr. Nomes Bolia (External) for their invaluable feedback and advises during my research journey. I shall forever remember the immense support and encouragement provided by the faculty members of the Department of Management Studies and Bharti School of Telecommunication, Technology and Management of IIT Delhi.

Family support is essential for a constant dose of motivation to get you going on the research journey. The love and support of my mother (Mrs. Bhagwati Awasthi) and father (Dr. P.K. Awasthi) helped me surmount all obstacles. I would also like to acknowledge my sister (Mrs. Deepti Awasthi) for being there for me at all times.

I would also like to praise my husband and in-laws for believing in me and allowing me to pursue my research work unrestrainedly. I would like to specially mention my daughters Syra

Saanvi and Shreya Saanchi and nephew Shivansh for bringing all the joy and fun throughout the research journey.

Thank You

**TRIPTI**

## **ABSTRACT**

**KEYWORDS:** Agri-food Supply Chain; Sustainability; Risk Drivers and Factors; Risk Assessment; Decision Support System; India.

A nation's economic prosperity is determined by its capacity to provide sufficient quantities of wholesome, high-quality food to its population. Despite the vibrancy of the food industry, all nations, whether established or developing, confront a variety of obstacles that threaten the security, safety, and sustainability of the agri-food supply chain system and operations. Increasing globalisation and complexity of the agri-food supply chain result in the unavailability and inaccessibility of food, making it increasingly challenging to meet the requirements of a rising population. To maintain the security and safety of food, it is vital to evaluate the inefficiencies and variables impacting the agri-food supply chain system. This research study examines the Indian agri-food supply chain system.

The Agri-food supply chain is characterised by long lead times for agricultural product production, seasonality in food production and consumption, variation in product quality and yield, and special handling requirements for food products such as cold storage and perishable nature of food products, all of which make agri-food supply chain system complex and difficult. The existence of segregated and autonomous activities along the agri-food supply chain thwarts joint efforts, resulting in economic inefficiencies and environmental deterioration and having a negative social impact. Risk at all phases of the agri-food supply chain – from harvesting through processing, packing, handling, storage, distribution, and consumption – exacerbates the problem and impacts the system sustainability. The Food and Agriculture Organization estimates that one-third of worldwide food production is wasted or lost each year. These difficulties, taken together, need study in this field to find efficient solutions for managing agri-food supply chain activities to fulfil the rising demand for food and achieve sustainable operation by mitigating the risk impact.

Furthermore, in today's business world, globalisation-induced competition, increased food miles as a result of globalisation and trade, heightened consumer awareness of high-quality products and operational transparency, rising population and food demand, and strict government regulations place greater strains on the limited resources required to produce goods and services. A confluence of such forces has resulted in sustainable behaviours being a must rather than a choice. Furthermore, rising demand for food goods to feed a growing population

puts strain on natural resources, necessitating a sustainable approach to natural resource production and consumption, and eliminating agri-food loss at all levels of the agri-food supply chain to achieve system sustainability. As a result, there is a need for a research study that finds potential for enhancing the agri-food supply chain system sustainability, which also helps to achieve the desired sustainable development goals.

This study identified and addressed various research gaps based on the review of the extant literature. In order to comprehend existing risks in the agri-food supply chain (AFSC), this study first built a conceptual framework employing "Soft System Methodology (SSM)" to investigate risk drivers, variables, and potential solutions. The results of SSM usher the scope and direction of future research. Initially, various risk drivers and their associated factors are identified. A conceptual framework validation is then performed to see the impact of the integration of the risk management process and critical success factors on achieving the agri-food supply chain system sustainability, using partial least square- structural equation modelling (PLS-SEM). The result of this analysis, together with the solution output from SSM, stimulated the authors to conduct the study on identifying the critical success factors for agri-food supply chain system sustainability to tackle different risk issues. Therefore, the next section of the research deals with identifying critical success factors (CSFs) of agri-food supply chain system sustainability. Three important theories, "stakeholder theory", "system sustainability" and "theory of critical success factor", have been referred for this work. Post-identification, these CSFs were subjected to statistical reliability analysis using Cronbach's coefficient, followed by the analysis of their inter-relationships using total interpretive structural modelling (TISM).

Further, an attempt is made to analyse the identified risk drivers and factors through risk assessment using a fuzzy analytical process and fuzzy Vlekriterijumsko KOMPromisno Rangiranje (VIKOR) by collecting the response from various stakeholders. This risk assessment provides the rank of various risk factors impacting the system sustainability of AFSC. The research study analysis shows that production risk is the major risk driver that impacted the agri-food supply chain system sustainability and impacted all the three dimensions of sustainability. This prompted the authors to carry out a case study on the production risk in terms of post-harvest loss and evaluate and quantify the various factors causing the losses. The case study was performed in the Narmadapuram district of Madhya Pradesh State. The extent of post-harvest losses was evaluated by multiple linear regression

analysis and problem faced index (PFI). Based on review of the literature, discussions with the subject experts and through risk analysis results; a decision support system framework using the DIKW hierarchy was proposed for risk mitigation.

This research work contributes to the existing literature on the sustainable AFSC, and gives management implications to practitioners and policy suggestions to the government and policymakers, and captures advances in the field. The thesis serves as a road map for practitioners working with agri-food supply chain system challenges, allowing decision-makers to assure the security of safe and nutritious agri-food to all at an affordable price and in a sustainable manner. The research study's shortcomings are discussed and potential future research paths.

## सार

**कीवर्ड:** कृषि-खाद्य आपूर्ति श्रृंखला; वहनीयता; जोखिम चालक और कारक; जोखिम आकलन; निर्णय समर्थन प्रणाली; भारत।

किसी राष्ट्र की आर्थिक समृद्धि उसके नागरिकों को पर्याप्त मात्रा में सुरक्षित, उच्च गुणवत्ता वाला भोजन उपलब्ध कराने की क्षमता से निर्धारित होती है। खाद्य उद्योग की जीवंतता के बावजूद, सभी राष्ट्र, चाहे स्थापित हों या विकासशील, विभिन्न प्रकार की बाधाओं का सामना करते हैं जो कृषि-खाद्य आपूर्ति श्रृंखला प्रणाली और संचालन की सुरक्षा, सुरक्षा और स्थिरता को खतरे में डालती हैं। कृषि-खाद्य आपूर्ति श्रृंखला के बढ़ते वैश्वीकरण और जटिलता के परिणामस्वरूप भोजन की अनुपलब्धता और दुर्गमता बढ़ रही है, जिससे बढ़ती जनसंख्या की आवश्यकताओं को पूरा करना तेजी से चुनौतीपूर्ण हो गया है। भोजन की सुरक्षा और सुरक्षा को बनाए रखने के लिए, कृषि-खाद्य आपूर्ति श्रृंखला प्रणाली को प्रभावित करने वाली अक्षमताओं और चरों का मूल्यांकन करना महत्वपूर्ण है। यह शोध अध्ययन भारतीय कृषि-खाद्य आपूर्ति श्रृंखला प्रणाली की जांच करता है।

कृषि-खाद्य आपूर्ति श्रृंखला कृषि उत्पाद उत्पादन के लिए लंबे समय तक, खाद्य उत्पादन और खपत में मौसम, उत्पाद की गुणवत्ता और उपज में भिन्नता, और खाद्य उत्पादों के लिए विशेष हैंडलिंग आवश्यकताओं जैसे कोल्ड स्टोरेज और खाद्य उत्पादों की खराब होने वाली प्रकृति, सभी की विशेषता है। इनमें से कृषि-खाद्य आपूर्ति श्रृंखला प्रणाली को जटिल और कठिन बनाते हैं। कृषि-खाद्य आपूर्ति श्रृंखला के साथ पृथक और स्वायत्त गतिविधियों का अस्तित्व संयुक्त प्रयासों को विफल करता है, जिसके परिणामस्वरूप आर्थिक अक्षमताएं और पर्यावरणीय गिरावट और नकारात्मक सामाजिक प्रभाव पड़ता है। कृषि-खाद्य आपूर्ति श्रृंखला के सभी चरणों में जोखिम - कटाई से प्रसंस्करण, पैकिंग, हैंडलिंग, भंडारण, वितरण और खपत के माध्यम से - समस्या को बढ़ाता है और सिस्टम स्थिरता को प्रभावित करता है। खाद्य और कृषि संगठन का अनुमान है कि हर साल दुनिया भर में एक तिहाई खाद्य उत्पादन बर्बाद हो जाता है या नष्ट हो जाता है। इन कठिनाइयों को एक साथ लेकर, भोजन की बढ़ती मांग को पूरा करने और जोखिम प्रभाव को कम करके स्थायी संचालन प्राप्त करने के लिए कृषि-खाद्य आपूर्ति श्रृंखला गतिविधियों के प्रबंधन के लिए कुशल समाधान खोजने के लिए इस क्षेत्र में अध्ययन की आवश्यकता है।

इसके अलावा, आज की कारोबारी दुनिया में, वैश्वीकरण-प्रेरित प्रतिस्पर्धा, वैश्वीकरण और व्यापार के परिणामस्वरूप खाद्य मील में वृद्धि, उच्च गुणवत्ता वाले उत्पादों और परिचालन पारदर्शिता के बारे में बढ़ी हुई उपभोक्ता जागरूकता, बढ़ती जनसंख्या और भोजन की मांग, और सख्त सरकारी नियम, खाद्य पदार्थों पर अधिक दबाव डालते हैं। वस्तुओं और सेवाओं के उत्पादन के लिए सीमित संसाधनों की आवश्यकता होती है। इस तरह की ताकतों के संगम के परिणामस्वरूप टिकाऊ व्यवहार एक विकल्प के बजाय जरूरी हो गया है। इसके अलावा, बढ़ती आबादी को खिलाने के लिए खाद्य वस्तुओं की बढ़ती मांग प्राकृतिक संसाधनों पर दबाव डालती है, प्राकृतिक संसाधन उत्पादन और खपत के लिए एक स्थायी दृष्टिकोण की आवश्यकता होती है, और सिस्टम स्थिरता प्राप्त करने के लिए कृषि-खाद्य आपूर्ति श्रृंखला के सभी स्तरों पर कृषि-खाद्य हानि को समाप्त करती है। नतीजतन, एक शोध अध्ययन की आवश्यकता है जो कृषि-खाद्य आपूर्ति श्रृंखला प्रणाली स्थिरता को बढ़ाने की क्षमता पाता है, जो वांछित सतत विकास लक्ष्यों को प्राप्त करने में भी मदद करता है।

इस अध्ययन ने वर्तमान साहित्य की समीक्षा के आधार पर विभिन्न शोध अंतरालों की पहचान की और उन्हें संबोधित किया। कृषि-खाद्य आपूर्ति श्रृंखला (एएफएससी) में मौजूदा जोखिमों को समझने के लिए, सबसे पहले, इस अध्ययन में "सॉफ्ट सिस्टम मेटाडोलॉजी (एसएसएम)" का उपयोग करते हुए, जोखिम चालकों, कारकों और संभावित समाधानों का पता लगाने के लिए एक वैचारिक ढांचा विकसित किया गया है। एसएसएम का आउटपुट आगे के शोध करने के लिए गुंजाइश और दिशा प्रदान करता है। प्रारंभ में, विभिन्न जोखिम चालकों और उनसे जुड़े कारकों की पहचान की जाती है। आंशिक न्यूनतम वर्ग-संरचनात्मक समीकरण मॉडलिंग (PLS-SEM) का उपयोग करके कृषि-खाद्य आपूर्ति श्रृंखला प्रणाली स्थिरता प्राप्त करने पर जोखिम प्रबंधन प्रक्रिया के एकीकरण और महत्वपूर्ण सफलता कारकों के प्रभाव को देखने के लिए एक वैचारिक रूपरेखा सत्यापन किया जाता है। एसएसएम से समाधान आउटपुट के साथ इस विश्लेषण के परिणाम ने हमें विभिन्न जोखिम वाले मुद्दों से निपटने के लिए कृषि-खाद्य आपूर्ति श्रृंखला प्रणाली स्थिरता के लिए महत्वपूर्ण सफलता कारकों की पहचान करने के लिए एक अध्ययन करने के लिए प्रोत्साहित किया। इसलिए, अनुसंधान का अगला खंड कृषि-खाद्य आपूर्ति श्रृंखला प्रणाली स्थिरता के महत्वपूर्ण सफलता कारकों (सीएसएफ) की पहचान करने से संबंधित है। इस उद्देश्य के लिए तीन महत्वपूर्ण सिद्धांतों, "हितधारक सिद्धांत", "सिस्टम स्थिरता" और "महत्वपूर्ण सफलता कारक के सिद्धांत" का उपयोग किया गया है। पहचान के बाद, इन सीएसएफ को क्रोनबैक के गुणांक का उपयोग करके सांख्यिकीय विश्वसनीयता विश्लेषण के अधीन किया गया, इसके बाद कुल

व्याख्यात्मक संरचनात्मक मॉडलिंग (टी आईएसएम) का उपयोग करके उनके अंतर-संबंधों का विश्लेषण किया गया।

इसके अलावा, कृषि-खाद्य आपूर्ति श्रृंखला के विभिन्न हितधारकों से प्रतिक्रिया एकत्र करके एक फजी विश्लेषणात्मक प्रक्रिया और फजी बहुमानदंड समझौता रैंकिंग (विकोर) का उपयोग करके जोखिम मूल्यांकन के माध्यम से पहचाने गए जोखिम चालकों और कारकों का विश्लेषण करने का प्रयास किया गया है। यह जोखिम मूल्यांकन प्रणाली की स्थिरता को प्रभावित करने वाले विभिन्न जोखिम कारकों की श्रेणी प्रदान करता है।

## TABLE OF CONTENTS

	Page
<b>CERTIFICATE .....</b>	<b>i</b>
<b>ACKNOWLEDGEMENTS .....</b>	<b>ii</b>
<b>ABSTRACT .....</b>	<b>iv</b>
<b>TABLE OF CONTENTS .....</b>	<b>x</b>
<b>LIST OF FIGURES .....</b>	<b>xvii</b>
<b>LIST OF TABLES .....</b>	<b>xix</b>
<b>LIST OF ABBREVIATIONS .....</b>	<b>xxi</b>
<b>CHAPTER 1: INTRODUCTION .....</b>	<b>1</b>
1.1. Supply Chain Management .....	1
1.2. Agri-food Supply Chain System .....	2
1.3. Risk Management for Agri-food Supply Chain System .....	3
1.4. Agri-food Supply Chain System Sustainability .....	4
1.5. Indian Agriculture Scenario .....	5
1.6. Major Agriculture Policies in India .....	7
1.6.1. Paramparagat Krishi Vikas Yojana .....	7
1.6.2. Pradhan Mantri Krishi Sinchayee Yojana .....	8
1.6.3. Pradhan Mantri Fasal Bima Yojana (PMFBY) .....	8
1.6.4. National Mission on Micro-Irrigation (NMMI) .....	8
1.6.5. Soil Health Card Scheme (SHCS) .....	8
1.6.6. National Mission on Sustainable Agriculture (NMSA) .....	9
1.7. Motivation for the Research .....	9
1.8. Scope of the Study .....	10
1.9. Research Questions and Research Objectives .....	11

1.9.1. Research Questions .....	11
1.9.2. Research Objectives .....	11
1.10. Outline of the Study and Methodological Overview .....	11
1.11. Organization of the Thesis .....	12
1.12. Chapter Summary .....	15
<b>CHAPTER 2: LITERATURE REVIEW .....</b>	<b>16</b>
2.1 Risk Management for Agri-Food Supply Chain .....	18
2.2 Agri-food Supply Chain System Sustainability .....	23
2.3 Critical Success Factors for Agri-food Supply Chain System Sustainability ....	26
2.4 Review of Methodologies Adopted in the Research Study/ Underlying Theoretical Support .....	30
2.5 Research Gaps .....	35
2.6 Chapter Summary .....	36
<b>CHAPTER 3: IDENTIFICATION AND MAPPING OF RISK DRIVERS FOR AGRI-FOOD SUPPLY CHAIN USING SOFT SYSTEM METHODOLOGY AND GREY RELATIONAL ANALYSIS .....</b>	<b>37</b>
3.1. Introduction .....	37
3.2. Identification and Mapping AFSC Risk Drivers and Risk Factors .....	39
3.3. Soft System Methodology (SSM) .....	40
3.3.2. Risk Drivers at Different Nodes of the Supply Chain .....	42
3.3.2.1. Agriculture Input Risk (AR) .....	42
3.3.2.2. Production Risk (PR) .....	42
3.3.2.3. Logistics Risk (LR) .....	43
3.3.2.4. Storage and Processing Risk (SPR) .....	44
3.3.2.5. Market Risk (MR) .....	44
3.3.2.6. Government Regulations and Policies Risk (GR) .....	45
3.3.2.7. Food Quality Risk (FQR) .....	45
3.3.2.8. ICT Infrastructure Risk (IR) .....	45

3.4.2. Application of SSM .....	47
3.4.2.1. Developing Symptoms Map .....	47
3.4.2.2. Developing Rich Picture .....	48
3.4.2.3. Developing Root Definition .....	50
3.4.2.4. CATWOE Formulation .....	52
3.4.2.5. Development of Conceptual Model .....	54
3.4.2.6. Development of Final Implementation Model .....	55
3.4. Grey Relational Analysis Application .....	56
3.5. Grey Relational Analysis of AFSC Risk Drivers .....	58
3.6. Discussion and Managerial Implications .....	63
3.7. Chapter Summary .....	64
<b>CHAPTER 4: DEVELOPMENT OF CONCEPTUAL FRAMEWORK MODEL FOR AGRI-FOOD SUPPLY CHAIN SYSTEM SUSTAINABILITY AND VALIDATION USING PLS- SEM MODELLING .....</b>	<b>65</b>
4.1. Introduction .....	65
4.2. Conceptual Framework Model for Agri-food Supply Chain System Sustainability- Theoretical Foundation .....	66
4.3. Hypothesis Development for Conceptual Model .....	68
4.4. Data Collection .....	73
4.5. Partial-Least Square -Structural Equation Modeling (PLS-SEM) – Data Analysis Technique .....	75
4.5.1. Validity and Reliability Test – Measurement Model Assessment .....	76
4.5.2. Structural Model Assessment .....	76
4.6. Model Analysis Result .....	76
4.6.1. Measurement Model – Convergent and Discriminant Validity .....	76
4.6.2. Structural Model .....	79
4.7. Discussion .....	81
4.8. Chapter Summary .....	82

**CHAPTER 5: MODELING OF THE HIERARCHICAL  
RELATIONSHIP BETWEEN THE IDENTIFIED CRITICAL  
SUCCESS FACTORS FOR AFSC SYSTEM SUSTAINABILITY ..... 83**

5.1. Introduction .....	83
5.2. Underlying Theory Concept used in Study .....	85
5.2.2. Stakeholder Theory .....	85
5.2.3. System Sustainability Theory .....	85
5.2.4. Critical Success Factors Theory .....	86
5.3. Critical Success Factors for Sustainable AFSC .....	86
5.3.2. Integration of National Agriculture Market .....	86
5.3.3. Coordination and Collaboration in AFSC .....	86
5.3.4. Risk Management .....	87
5.3.5. Trust among Partners .....	87
5.3.6. Storage and Processing Facilities .....	87
5.3.7. Logistics Network and Capabilities .....	87
5.3.8. Government Regulations and Policies .....	88
5.3.9. ICT Infrastructure .....	88
5.3.10. Food Quality .....	88
5.3.11. Visibility and Traceability .....	89
5.3.12. Customer Awareness and Satisfaction .....	89
5.4. Method Used .....	89
5.4.2. Reliability test using Cronbach’s coefficient and Pearson’s correlation test using SPSS .....	89
5.4.3. TISM Methodology .....	90
5.4.4. The MICMAC Principle .....	92
5.5. Result Analysis .....	92
5.5.2. Interpreting TISM Digraph .....	93
5.5.3. Interpretation of MICMAC Analysis .....	95
5.5.4. Stakeholder Influence on System Sustainability .....	96

5.5.5. Managerial Implication .....	96
5.6. Contribution, limitation and Future Scope .....	97
5.7. Conclusion .....	97
5.8. Chapter Summary .....	98
<b>CHAPTER 6: RISK EVALUATION FOR AGRI-FOOD SUPPLY CHAIN SYSTEM USING FUZZY AHP AND FUZZY VIKOR .....</b>	<b>99</b>
6.1. Introduction .....	99
6.2. Risk Drivers and Factors consider for the Study .....	101
6.2.1. Pre-harvest Risk .....	101
6.2.2. Post-harvest Risk .....	102
6.2.3. Political Policy Risk .....	103
6.2.4. Logistics and Technology Risk .....	104
6.2.5. Market Risk .....	104
6.2.6. Social and Economic Risk .....	105
6.2.7. Hybrid Risk .....	105
6.3. Material and Method Used .....	106
6.3.1. Data Collection .....	106
6.3.2. Evaluation Methods .....	108
6.3.2.1. Fuzzy AHP- Calculating Risk Drivers and Factors Weight Criteria .....	108
6.3.2.2. The Calculation for Degree of Possibility .....	110
6.3.2.3. Risk Factors Evaluation using FVIKOR .....	113
6.4. Discussion .....	116
6.5. Sensitivity Analysis .....	120
6.6. Contribution, Limitation and Scope of Future Work .....	121
6.7. Chapter Summary .....	122
<b>CHAPTER 7: AGRI-FOOD SUPPLY CHAIN PRODUCTION RISKS AND MITIGATIONS: A CASE STUDY OF WHEAT AND SOYABEAN IN MADHYA PRADESH .....</b>	<b>123</b>

7.1. Introduction .....	123
7.1.1. Production Risk due to Postharvest losses in AFSC .....	124
7.1.2. The Objective of the Case Study .....	125
7.1.3. Agriculture Scenario in Madhya Pradesh State: An Overview .....	126
7.1.4. Factor Affecting the Postharvest Production Losses.....	128
7.1.5. Proposed Research Framework .....	128
7.2. Material and Methods .....	128
7.2.1. Problem Face Index (PFI) of Farmers of Narbadapuram District .....	130
7.2.2. Multiple Linear Regression analysis Factors Affecting Post-harvest Losses at Farm Level: Analytical Technique .....	131
7.3. Result and Discussion .....	132
7.3.1. Socio-Economic Characteristics of Farmers .....	132
7.3.2. Extent and Quantification of Crop Production Losses .....	134
7.3.3. Interpretation of Multiple Linear Regression Analysis .....	135
7.3.4. Determinants of Postharvest Losses for Soybean Production .....	136
7.3.5. Determinants of Postharvest Losses for Wheat Production .....	137
7.3.6. Problem faced Index (PFI) by Narbadapuram Farmers .....	139
7.4. Decision Support System for Risk Mitigation Activity .....	140
7.5. Risk Mitigation and Sustainable Solution to Reduces Postharvest Losses along the AFSC .....	141
7.6. Conclusion .....	143
7.7. Chapter Summary .....	143
<b>CHAPTER 8: SYNTHESIS AND CONCLUSIONS.....</b>	<b>145</b>
8.1. Introduction .....	145
8.2. Significant Research Findings and Contributions .....	149
8.2.1. Theoretical Contributions .....	150
8.2.2. Practical Contributions .....	151
8.3. Limitation of Research .....	151
8.4. Scope for Future Work .....	152

8.5. Chapter Summary .....	153
<b>REFERENCES</b> .....	<b>154</b>
<b>APPENDIX</b> .....	<b>177</b>
<b>Appendix A.</b> Cover letter to Participants about the Research Study .....	177
<b>Appendix B.</b> Experts Profile and GRA analysis .....	178
<b>Appendix C.</b> Descriptive statistics of the respondent .....	179
<b>Appendix D.</b> Questionnaire Base Survey .....	181
<b>Appendix E.</b> Respondent Profile and FAHP and FVIKOR analysis .....	184
<b>Appendix F.</b> Case study survey, Wheat, and Soybean Data .....	185

## LIST OF FIGURES

<b>Figure</b>	<b>Title</b>	<b>Page</b>
Figure 1.1	Chapter Structure .....	1
Figure 1.2	Agri-food Supply Chain .....	2
Figure 1.3	Impact of Risk on AFSC Sustainability .....	10
Figure 1.4	Framework of Research Flow .....	14
Figure 2.1	Chapter Structure .....	16
Figure 2.2	Literature Review Major Topic and Flow .....	17
Figure 2.3	Main Research Gaps of the Study .....	35
Figure 3.1	Chapter Structure .....	38
Figure 3.2	Major Risk Drivers .....	43
Figure 3.3	Symptoms Map .....	48
Figure 3.4	Rich Picture .....	49
Figure 3.5	Formulation of Alternative Root Definition .....	53
Figure 3.6	Conceptual Model .....	54
Figure 3.7	Final Implementable Model .....	55
Figure 3.8	Risk Driver Mapping .....	62
Figure 4.1	Chapter Structure .....	66
Figure 4.2	A Conceptual Framework for Agri-food Supply Chain Sustainability .....	68
Figure 4.3	The Hypothesis Related to the Conceptual Framework Model .....	72
Figure 4.4	Conceptual Framework Path Model in PLS-SEM .....	81
Figure 5.1	Chapter Structure .....	84
Figure 5.2	TISM based system model for critical success factors of Sustainable AFSC .....	94
Figure 5.3	MICMAC Analysis .....	95
Figure 6.1	Chapter Structure .....	100
Figure 6.2	Proposed Research Flow Diagram for Risk Evolution using Hybrid FAHP and FVIKOR Methods .....	107

Figure 6.3	Sensitivity Analysis of Risk Factors .....	121
Figure 7.1	Chapter Structure .....	124
Figure 7.2	Proposed Research Framework .....	129
Figure 7.3	Area of Study for Postharvest Losses (Madhya Pradesh State and Narbadapuram District) .....	130
Figure 7.4	DIKW Hierarchy Framework for Risk Mitigation Activity .....	142

## LIST OF TABLES

<b>Table</b>	<b>Title</b>	<b>Page</b>
Table 1.1	Major Crops Area, Production and Yield .....	5
Table 2.1	Research Related to Risk Management for Agri-food Supply Chain .....	21
Table 2.2	Research Related to Agri-food Supply Chain Sustainability .....	25
Table 2.3	Research related to CSFs for Agri-food Supply Chain System Sustainability .....	29
Table 3.1	The Root Cause of Risk Issue for Sustainable AFSC .....	50
Table 3.2	CATWOE Analysis for Risk Management for Sustainable AFSC .....	52
Table 3.3	Scale on the basis of the expert's judgement.....	58
Table 3.4	Decision Matrix for Risk Drivers .....	58
Table 3.5	Normalisation Decision Matrix for Risk Drivers .....	59
Table 3.6	Reference Sequence Matrix for Risk Drivers .....	59
Table 3.7	Difference Matrix for Risk Drivers .....	60
Table 3.8	Grey Relational Coefficient and Grey Relational Grade and Rank of Risk Drivers .....	61
Table 4.1	Dimension of Sustainability Effected by Risk Factors .....	69
Table 4.2	Latent Variable and Construct .....	73
Table 4.3	Construct Reliability and Validity .....	77
Table 4.4	Fornell–Larcker Criterion Test .....	77
Table 4.5	Cross-Loading .....	78
Table 4.6	Model Value for $R^2$ and Adjusted $R^2$ .....	79
Table 4.7	Path Coefficient and t-statistics Values .....	80
Table 5.2	Correlation Coefficient of CSFs .....	90
Table 5.3	Initial Reachability Matrix .....	91
Table 5.4	Final Reachability Matrix .....	91
Table 5.5	Iterations for Level Partitioning .....	92
Table 5.6	Driving Power and Dependence using Final Reachability Matrix.....	92
Table 5.8	MICMAC Analysis Cluster .....	93
Table 5.9	MICMAC Ranking of CSFs .....	95

Table 6.1	Pre-harvest Risk Factors .....	102
Table 6.2	Post-harvest Risk Factors .....	103
Table 6.3	Political Policy Risk Factors .....	103
Table 6.4	Logistics and Technology Risk Factors .....	104
Table 6.5	Market Risk Factors .....	105
Table 6.6	Social and Economic Risk Factors .....	105
Table 6.7	Hybrid Risk Factors .....	106
Table 6.8	Triangle fuzzy Scale for FAHP Pairwise Comparison .....	109
Table 6.9	Extent Analysis Value for Each Risk Drivers .....	109
Table 6.10	Fuzzy Synthetic Extent Value (S <sub>i</sub> ) .....	109
Table 6.11	Degree of Possibility .....	110
Table 6.12	Defuzzified Matrix .....	111
Table 6.13	Consistency Index, R.I. of Random Matrices .....	111
Table 6.14	Risk Drivers Weight Criteria and according to Rank .....	112
Table 6.15	Risk Factors Weight Criteria .....	112
Table 6.16	Crip Value, Fuzzy Best Value and Fuzzy Worst Value .....	114
Table 6.17	Value of S, R and Q for Risk Factors and Rank .....	115
Table 7.1	Madhya Pradesh Crop Production Share in Indian Union 2018-19 .....	127
Table 7.2	Socio-Economic Characteristics of Respondent Farmers .....	132
Table 7.3	Share of Soybean and Wheat in Cultivated Area .....	133
Table 7.4	Losses in Crop Production in MP 2018-19 .....	134
Table 7.5	Factors Influencing Postharvest Losses in Soybean .....	137
Table 7.6	Factors Influencing Postharvest Losses in Wheat .....	138
Table 7.7	The Rank order of problems faced by Narbadaprum farmers using PFI .....	140
Table 8.1	Research Objectives and Methodology Adopted .....	146

## LIST OF ABBREVIATION

AFSC	Agri-food Supply Chain
AFSC-RM	Agri-food Supply Chain Risk Management
AFSCSS	Agri-food Supply Chain System Sustainability
ANP	Analytical Network Process
CSFs	Critical Success Factors
DEA	Data Envelopment Analysis
DIKW	Data, Information, Knowledge, and Wisdom
DM	Decision Making
FAHP	Fuzzy Analytical Hierarchy Process
FAO	Food and Agriculture Organisation
FST	Fuzzy Set Theory
FVIKOR	Vle Kriterijumsko KOMPromisno Rangiranje or Multi-criteria Optimization and Compromise Solution
GHGs	Greenhouse Gases
GRA	Grey Relational Analysis
ICAR	The Indian Council of Agricultural Research
ICRIER	Indian Council for Research on International Economic Relations
ICT	Information, communication, and technology
IFAD	International Fund for Agricultural Development
MADM	Multiple Attribute decision making
MCDM	Multi-criteria Decision Making
MICMAC	Matrice d'impacts croisés multiplication appliquée á un classement
MLRA	Multiple Linear Regression Analysis
MP	Madhya Pradesh
NITI	National Institution for Transforming India
OECD	Organisation for Economic Co-operation and Development
PFI	Problem Faced Index
PHLs	Postharvest losses
PLS-SEM	Partial Least Square- Structural Equation modelling
PPP	Public Private Partnership
R&D	Research and Development
RA	Risk Analysis

RDs	Risk Drivers
RFID	Radio Frequency Identification
RFs	Risk Factors
RI	Risk Identification
RM	Risk Management
RMP	Risk Management Process
SCM	Supply Chain Management
SCs	Supply Chains
SDGs	Sustainable Development Goals
SSM	Soft System Methodology
TFNs	Triangular Fuzzy Numbers
TISM	Total Interpretive Structural Modelling
TOPSIS	Technique for Order Preference by Similarity to Ideal Solution
WFP	World Food Programme