

**A STUDY OF RISKS ASSOCIATED WITH
SUSTAINABLE FREIGHT TRANSPORTATION
SYSTEMS**

DIVYA CHOUDHARY



**DEPARTMENT OF MANAGEMENT STUDIES
INDIAN INSTITUTE OF TECHNOLOGY DELHI**

JULY, 2019

**A STUDY OF RISKS ASSOCIATED WITH
SUSTAINABLE FREIGHT TRANSPORTATION
SYSTEMS**

by

DIVYA CHOUDHARY

Department Of Management Studies

**Submitted
in fulfillment of requirement of the degree of Doctor of
Philosophy**

to



Indian Institute of Technology Delhi

JULY, 2019

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CERTIFICATE

The Thesis entitled “**A Study of Risks Associated with Sustainable Freight Transportation Systems**”, being submitted by **Ms Divya Choudhary** to the Indian Institute of Technology Delhi, for the award of the degree of Doctor of Philosophy (Ph.D.) is a record bona fide 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 standard required for a 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

Department of Management Studies

Indian Institute of Technology Delhi

Hauz Khas, New Delhi-110016

India.

ACKNOWLEDGEMENTS

It is my privilege to have worked with Professor Ravi Shankar (Sir). My profound gratitude and indebtedness goes to sir for having devoted his incredible time and relentless effort in supervising and guiding me in bringing this work to its present state of completion. I am also thankful to Dr Poonam Shankar (Mam) for her support and encouragement.

I would like to thank the members of my Student Research Committee (SRC) comprising Dr. Seema Sharma (Chairman); Dr. S. P. Singh (Internal Expert) and Abhijit Majumdar (External Expert) for giving useful comments and valuable suggestions at various stages of this study. They have devoted their valuable time and took personal care in motivating me whenever I was disheartened.

I am also deeply grateful to the entire faculty and staff of Department of Management Studies, IIT Delhi, for contributing in one way or the other in the successful completion of my research. My thanks are due to fellow research scholars especially, Devendra, Vijayata, Deendayal, Mahamaya, Rachita and Ashish for their support during the course of my research.

Words fail me while expressing my love and respect for my mother Mrs Sushma Chaudhary and my husband Mr. Suprit Wakde. They have been my true pillars of strength and support and remained a continuous source of inspiration for me.

(Divya Choudhary)

ABSTRACT

Freight Transportation (FT) sector is one of the largest contributors to the ever-rising threats of environmental degradation, resource depletion, global climate change, accidents, congestions, over-flowing waste disposal sites, health problems etc. faced by our society nowadays. Accordingly, there is an urgent need to adopt sustainable practices in freight operations to overcome the associated negative externalities. Organizations are under substantial pressure to develop sustainable freight transportation systems (SFTSs) owing to the increasing societal pressure, market awareness and government regulations. Development of SFTSs faces a major challenge due to the various inherent sustainability risks. Sustainability risks can be defined as probable threats that adversely impact the integration of triple-bottom-line framework and act as impediments in the path of sustainable systems. The domain of sustainability risks is relatively new and has recently attracted both academic and practitioner attention. Recent review papers in the area of sustainability and risk management have also acknowledged the need to investigate risk aspects in the context of sustainability. The studies focusing on sustainability risks are very limited and research papers investigating sustainability risks in the FT context are virtually non-existent. This research is quite crucial in addressing these gaps in the literature. A number of analytical models have been developed to index, quantify, profile and manage sustainability risks in freight transportation systems (FTSs) using different methodologies such as evidential reasoning algorithm (ERA), expected utility theory (EUT), neighborhood rough set theory (NRST), D-Number theory, interval two tuple linguistic representation model (ITL), intuitionistic fuzzy sets etc. This research is very significant in the current scenario as it can improve the performance of sustainable systems, which is the key requirement in many sectors.

The research proposes a sustainability risk management framework to facilitate the development of SFTSs. The entire research focusses on investigating sustainability risks in the context of FT and is basically divided into four steps namely risk identification, risk indexing, risk analysis and risk treatment. Each step contributes towards the accomplishment of underlying research objective(s) and assist in achieving the desired outcomes. In the first step, a total of 36 sustainability risks present in FT are identified and categorized under seven dimensions namely, fleet management (FM) risks, financial (FI) risks, informational (IN) risks, ecological & social (E&S) risks, market (MR) risks, operational (OP) risks and organizational & governmental (O&G) risks. Then, in the second step, a sustainability risk index (SRI) is developed to measure the risk exposure of FTs using an integrated approach combining interval two tuple linguistic representation model (ITL) and digraph matrix approach (DMA).

In the risk analysis step, three models are developed to evaluate, prioritize and profile the sustainability risks associated with FT in detail. In the first model, each identified sustainability risk is quantified to obtain the risk priority score (RPS) and accordingly categorized into very low, low, medium, high and very high priority groups for three ubiquitous risk preferences namely, risk-averse, risk-neutral and risk-taking. This model is based on fuzzy evidential reasoning algorithm (FERA) and expected utility theory. It is found in the results that lack of awareness & logistics skills is the highest priority risk all three cases. The second model analyzes sustainability risks considering both the membership and non-membership degrees to compute the D+ and D- risk scores respectively with the help of D-number theory and intuitionistic fuzzy numbers (IFNs). Sustainability risks with D+ score > D- score are classified as the high priority risks and the risks with D- score > D+ score are classified as the low priority risks. Based on the outcomes of the two

above mentioned models, 17 high priority sustainability risks are determined that require primary attention and treatment. These 17 high priority sustainability risks are further evaluated and profiled from four perspectives i.e. economic, social, environmental and overall sustainability perspective considering both long-term and short-term time frames respectively in the next model using D-number theory and IFNs. Finally, in the last step i.e. risk treatment, 22 risk treatment strategies are identified and a decision support system (DSS) is developed based on D-number theory, neighborhood rough set theory (NRST) and grey relational projection analysis (GRPA). The redundant attributes are determined by computing the significance of each sustainability risk and core attribute set is obtained. The DSS assists in the determination of the preferable set of strategies and the most suitable strategy for different scenarios considering cost, time and effectiveness as the decision attributes.

This study addresses the research gaps in the literature regarding the understanding and management of sustainability risks especially in the context of FTs. The research offers several insights that can assist the organizations in the adoption of sustainable practices in FT. It is one of the few initial researches that investigates and quantitatively models sustainability risks in the context of FTs. This research facilitates in the development of SFTs by alerting the freight managers about the high priority sustainability risks that require primary attention and assisting in the pro-active strategy formulation to minimize disruptions in SFTs. The findings indicate that unlike conventional perception, organizations need to emphasize more on the social dimension primarily on improving the behavioral and skill aspects while developing SFTs.

सार

फ्रेट ट्रांसपोर्टेशन (एफटी) क्षेत्र हमारे समाज द्वारा सामना किए जा रहे पर्यावरणीय गिरावट, संसाधन की कमी, वैश्विक जलवायु परिवर्तन, दुर्घटनाओं, भीड़भाड़, अति-अपशिष्ट, अपशिष्ट निपटान स्थलों, स्वास्थ्य समस्याओं आदि के बढ़ते खतरों के लिए सबसे बड़ा योगदानकर्ताओं में से एक है। तदनुसार, संबंधित नकारात्मक बाहरीताओं को दूर करने के लिए माल ढुलाई कार्यों में स्थायी प्रथाओं को अपनाने की तत्काल आवश्यकता है। बढ़ते सामाजिक दबाव, बाजार जागरूकता और सरकारी नियमों के कारण सतत परिवहन प्रणालियों (एसएफटीएस) को विकसित करने के लिए संगठन काफी दबाव में हैं। एसएफटीएस का विकास विभिन्न अंतर्निहित स्थिरता जोखिमों के कारण एक बड़ी चुनौती का सामना करता है। स्थिरता के जोखिमों को संभावित खतरों के रूप में परिभाषित किया जा सकता है जो ट्रिपल-बॉटम-लाइन फ्रेमवर्क के एकीकरण पर प्रतिकूल प्रभाव डालते हैं और स्थायी प्रणालियों के मार्ग में बाधा के रूप में कार्य करते हैं। स्थिरता जोखिमों का क्षेत्र अपेक्षाकृत नया है और हाल ही में इसने अकादमिक और व्यवसायी दोनों का ध्यान आकर्षित किया है। स्थिरता और जोखिम प्रबंधन के क्षेत्र में हालिया समीक्षा पत्रों ने भी स्थिरता के संदर्भ में जोखिम पहलुओं की जांच करने की आवश्यकता को स्वीकार किया है। स्थिरता जोखिमों पर ध्यान केंद्रित करने वाले अध्ययन बहुत सीमित हैं और एफटी संदर्भ में स्थिरता जोखिमों की जांच करने वाले शोध पत्र वस्तुतः गैर-मौजूद हैं। साहित्य में इन अंतरालों को संबोधित करने में यह शोध काफी महत्वपूर्ण है। कई प्रकार के विश्लेषणात्मक मॉडल विकसित किए गए हैं, जो सतत परिवहन प्रणालियों (एफटीएस) में प्रत्यक्ष विचार एल्गोरिदम (ईआरए), अपेक्षित उपयोगिता सिद्धांत (ईयूटी), पड़ोस अपरिष्कृत समूह थ्योरी (एनआरएसटी) का उपयोग करके सूचकांक, मात्रा, प्रोफाइल और स्थिरता जोखिमों को प्रबंधित करते हैं।), डी-संख्या सिद्धांत, अंतराल टूटपल भाषाई प्रतिनिधित्व मॉडल, अंतर्ज्ञानवादी फजी समूह आदि। यह शोध वर्तमान परिदृश्य में बहुत महत्वपूर्ण है क्योंकि यह टिकाऊ प्रणालियों के प्रदर्शन में सुधार कर सकता है, जो कई क्षेत्रों में महत्वपूर्ण आवश्यकता है।

अनुसंधान एसएफटीएस के विकास को सुविधाजनक बनाने के लिए एक स्थिरता जोखिम प्रबंधन ढांचे का प्रस्ताव करता है। संपूर्ण शोध एफटी के संदर्भ में स्थिरता जोखिमों की जांच पर केंद्रित है और मूल रूप से जोखिम की पहचान, जोखिम अनुक्रमण, जोखिम विश्लेषण और जोखिम उपचार के चार चरणों में विभाजित है। प्रत्येक चरण अंतर्निहित अनुसंधान उद्देश्यों की उपलब्धि में योगदान देता है और वांछित परिणामों को प्राप्त करने में सहायता करता है। पहले चरण में, एफटी में मौजूद कुल 36 स्थिरता जोखिमों की पहचान की जाती है और उन्हें सात आयामों के अंतर्गत वर्गीकृत किया जाता है, जैसे कि बेड़े प्रबंधन जोखिम, वित्तीय जोखिम, सूचनात्मक जोखिम, पारिस्थितिक और सामाजिक जोखिम, बाजार जोखिम, परिचालन जोखिम

और संगठनात्मक और सरकारी जोखिम। फिर, दूसरे चरण में, एक निरंतरता जोखिम सूचकांक (एसआरआई) को एफटीएस के जोखिम जोखिम को मापने के लिए विकसित किया गया है जो एक एकीकृत दृष्टिकोण का उपयोग करके अंतराल दो ट्यूपल भाषाई प्रतिनिधित्व मॉडल (आईटीएल) और डिग्राफ आव्यूह दृष्टिकोण (डीएमए) का संयोजन करता है।

जोखिम विश्लेषण चरण में, एफटी के साथ जुड़े स्थिरता जोखिमों का मूल्यांकन, प्राथमिकता और बाह्य रूपरेखा करने के लिए तीन मॉडल विकसित किए गए हैं। पहले मॉडल में, प्रत्येक पहचाने गए स्थिरता जोखिम को जोखिम प्राथमिकता स्कोर (आरपीएस) प्राप्त करने के लिए निर्धारित किया गया है और तदनुसार तीन सर्वव्यापी जोखिम वरीयताओं के लिए बहुत ही कम, निम्न, मध्यम, उच्च और बहुत उच्च प्राथमिकता वाले समूहों में वर्गीकृत किया गया है, जोखिम-विपरीत, जोखिम-तटस्थ और जोखिम लेने वाला। यह मॉडल फ़ज़ी प्रत्यक्ष विचार अल्गोरिथम और अपेक्षित उपयोगिता सिद्धांत पर आधारित है। परिणामों में यह पाया गया है कि जागरूकता और रसद कौशल की कमी तीनों मामलों में सर्वोच्च प्राथमिकता वाला जोखिम है। दूसरा मॉडल D- संख्या सिद्धांत और अंतर्ज्ञानवादी फ़ज़ी संख्या की मदद से क्रमशः D + और D- जोखिम स्कोर की गणना करने के लिए सदस्यता और गैर-सदस्यता दोनों डिग्री पर विचार करते हुए स्थिरता जोखिमों का विश्लेषण करता है। D + स्कोर के साथ स्थिरता जोखिम > D- स्कोर को उच्च प्राथमिकता वाले जोखिमों के रूप में वर्गीकृत किया गया है और D- स्कोर > D + स्कोर के साथ जोखिमों को निम्न प्राथमिकता वाले जोखिमों के रूप में वर्गीकृत किया गया है। दो उपर्युक्त मॉडल के परिणामों के आधार पर, 17 उच्च प्राथमिकता स्थिरता जोखिम निर्धारित किए जाते हैं जिन्हें प्राथमिक ध्यान और समाधान की आवश्यकता होती है। इन 17 उच्च प्राथमिकता स्थिरता जोखिमों का मूल्यांकन और विश्लेषण चार दृष्टिकोणों से किया गया है, यानी कि आर्थिक, सामाजिक, पर्यावरण और समग्र स्थिरता के परिप्रेक्ष्य में डी-नंबर सिद्धांत और आईएफएफएस का उपयोग करके अगले मॉडल में क्रमशः दीर्घकालिक और अल्पकालिक दोनों समय के फ्रेम पर विचार किया गया है। अंत में, अंतिम चरण यानी जोखिम उपचार में, 22 जोखिम उपचार रणनीतियों की पहचान की जाती है और एक निर्णय समर्थन प्रणाली (डीएसएस) को डी-संख्या सिद्धांत, पड़ोस अपरिष्कृत समूह सिद्धांत (एनआरएसटी) और ग्रे संबंधित प्रक्षेप विश्लेषण (जीआरपीए) के आधार पर विकसित किया जाता है। निरर्थक विशेषताओं को प्रत्येक स्थिरता जोखिम के महत्व की गणना करके निर्धारित किया जाता है और कोर विशेषता समूह प्राप्त किया जाता है। डीएसएस रणनीतियों के बेहतर समूह और निर्णय लेने की विशेषताओं के अनुसार लागत, समय और प्रभावशीलता पर विचार करने वाले विभिन्न परिदृश्यों के लिए सबसे उपयुक्त रणनीति के निर्धारण में सहायता करता है।

यह अध्ययन विशेष रूप से एफटीएस के संदर्भ में स्थिरता जोखिमों की समझ और प्रबंधन के बारे में साहित्य में शोध अंतराल को संबोधित करता है। अनुसंधान कई अंतर्दृष्टि प्रदान करता है जो एफटी में टिकाऊ प्रथाओं को अपनाने में संगठनों की सहायता कर सकते हैं। यह कुछ प्रारंभिक शोधों में से एक है जो एफटीएस के संदर्भ में जांच और मात्रात्मक रूप से स्थिरता के जोखिमों को दर्शाता है। यह शोध उच्च प्राथमिकता स्थिरता जोखिमों के बारे में माल प्रबंधकों को सचेत करके एसएफटीएस के विकास में सुविधा प्रदान करता है, जिन्हें एसएफटीएस में व्यवधानों को कम करने के लिए प्राथमिक सक्रियता और समर्थक सक्रिय रणनीति तैयार करने में सहायता की आवश्यकता होती है। निष्कर्ष बताते हैं कि पारंपरिक धारणा के विपरीत, संगठनों को मुख्य रूप से एसएफटीएस विकसित करते समय व्यवहार और कौशल पहलुओं में सुधार पर सामाजिक आयाम पर अधिक जोर देने की आवश्यकता है।

TABLE OF CONTENTS

CERTIFICATE	I
ACKNOWLEDGEMENTS	II
ABSTRACT	III
TABLE OF CONTENTS	X
LIST OF FIGURES	XV
LIST OF TABLES	XVII
LIST OF ABBREVIATIONS	XX
CHAPTER 1. INTRODUCTION	
1.1 BACKGROUND	1
1.2 FRIEGHT TRANSPORTATION SYSTEMS	2
1.3 SUSTAINABLE FREIGHT TRANSPORTATION SYSTEMS	3
1.4 SUSTAINABILITY RISKS	5
1.5 RISK PERSPECTIVES	7
1.6 FREIGHT TRANSPORTATION SECTOR IN INDIA	9
1.7 NEED AND SCOPE OF RESEARCH	11
1.8 RESEARCH QUESTIONS & RESEARCH OBJECTIVES	12
1.9 RESEARCH OUTLINE	13
1.10 ORGANIZATION OF THESIS	17
1.11 CHAPTER SUMMARY	20
CHAPTER 2. LITERARTURE REVIEW	
2.1 INTRODUCTION	21
2.2 REVIEW OF LITERATURE RELATED TO SUSTAINABLE FREIGHT TRANSPORTATION	22

2.2.1 SUSTAINABLE URBAN FREIGHT TRANSPORTATION	23
2.2.2 PRACTICES TOWARDS SFT	26
2.2.3 NEGATIVE EXTERNALITIES	29
2.2.4 MULTI-MODAL FREIGHT TRANSPORTATION	32
2.2.5 LITERATURE REVIEW STUDIES	34
2.3 REVIEW OF LITERATURE RELATED TO SUSTAINABILITY RISKS	36
2.4 RESEARCH GAPS IN LITERATURE	40
2.5 SUSTAINABILITY RISKS IN FREIGHT TRANSPORTATION SYSTEMS	42
2.6 CHAPTER SUMMARY	45

**CHAPTER 3. RISK EXPOSURE OF SUSTAINABLE FREIGHT TRANSPORTATION:
A TWO-PHASE SOLUTION APPROACH**

3.1 INTRODUCTION	47
3.2 PROBLEM STATEMENT AND BACKGROUND	48
3.3 A TWO-PHASE INTERVAL 2-TUPLE (ITL) AND DIGRAPH MATRIX APPROACH (DMA) BASED MODEL	50
3.3.1 INTERVAL 2-TUPLE LINGUISTIC REPRESENTATION MODEL (ITL)	50
3.3.2 DIGRAPH MATRIX APPROACH (DMA)	54
3.3.3 A TWO-PHASE ITL-DMA APPROACH FOR EVALUATE THE SRI	55
3.4 APPLICATION OF PROPOSED TWO-PHASE MODEL IN A CASE STUDY FREIGHT TRANSPORTATION	60
3.5 RESULTS AND DISCUSSION	67
3.6 SENSITIVITY ANALYSIS	71
3.7 IMPLICATIONS OF THE RESEARCH	73
3.7.1 METHODOLOGICAL IMPLICATIONS	73
3.7.2 MANAGERIAL IMPLICATIONS	73
3.8 CHAPTER SUMMARY	74

CHAPTER 4. QUANTIFICATION AND CATEGORIZATION OF SUSTAINABILITY RISKS IN FREIGHT TRANSPORTATION SYSTEMS FOR DIFFERENT RISK PREFERENCES

4.1	INTRODUCTION	76
4.2	PROBLEM STATEMENT AND BACKGROUND	77
	4.2.1 RISK PREFERENCES	78
4.3	AN INTEGRATED METHOD USING FERA& EXPECTED UTILITY THEORY (EUT)	80
	4.3.1 LINGUISTIC ASSESSMENT OF SUSTAINABILITY RISKS	82
	4.3.2 APPLICATION OF FST FOR RISK EVALUATION	82
	4.3.3 TRANSFORMATION OF TFN(PI) _s INTO BELIEF DEGREE STRUCTURES	85
	4.3.4 APPLICATION OF ERA FOR ASSESSMENT AGGREGATION	87
	4.3.5 DETERMINATION OF EQUIVALENT RISK PRIORITY SCORE VIA EXPECTED UTILITY THEORY (EUT)	89
4.4	APPLICATION OF THE PROPOSED APPROACH FOR ANALYZING SUSTAINABILITY RISKS	91
	4.4.1 DATA COLLECTION	91
	4.4.2 DETERMINATION OF RISK PRIORITY SCORES (RPS _s)	93
4.5	RESULTS AND MANAGERIAL IMPLICATIONS	100
4.6	SENSITIVITY ANALYSIS	105
4.7	CHAPTER SUMMARY	108

CHAPTER 5. AN INTEGRATED RISK ASSESSMENT MODEL: A CASE OF SUSTAINABLE FREIGHT TRANSPORTATION SYSTEMS

5.1	INTRODUCTION	109
5.2	PROBLEM STATEMENT AND BACKGROUND	110
5.3	AN INTEGRATED APPROACH BASED ON INTUITIONISTIC FUZZY SET (IFS) AND D-NUMBER THEORY	112
	5.3.1 PRELIMINARIES	112

5.3.2 AN IFNS-D-NUMBER THEORY BASED MODEL	116
5.4 APPLICATION OF THE PROPOSED IFNS-D-NUMBER THEORY BASED MODEL FOR EVALUATING SUSTAINABILITY RISKS IN FTSS	120
5.5 RESULTS AND DISCUSSIONS	127
5.6 IMPLICATIONS OF THE RESEARCH	133
5.6.1 METHODOLOGICAL IMPLICATIONS	133
5.6.2 IMPLICATIONS FOR PRACTICE	134
5.7 CHAPTER SUMMARY	135

CHAPTER 6. ANALYSIS AND PROFILING OF SUSTAINABILITY RISKS FOR LONG-TERM & SHORT-TERM SCENARIOS CONSIDERING DIFFERENT PERSPECTIVES

6.1 INTRODUCTION	137
6.2 PROBLEM STATEMENT AND BACKGROUND	138
6.3 AN INTEGRATED IFNS-D-NUMBER THEORY BASED RISK PROFILING MODEL	140
6.3.1 APPLICATION OF THE PROPOSED MODEL FOR ANALYZING SUSTAINABILITY RISKS	144
6.4 RESULTS AND SUSTAINABILITY RISK PROFILING	152
6.5 CHAPTER SUMMARY	165

CHAPTER 7. A DECISION SUPPORT SYSTEM FOR THE TREATMENT OF SUSTAINABILITY RISKS IN FREIGHT TRANSPORTATION SYSTEMS

7.1 INTRODUCTION	166
7.2 RISK TREATMENT STRATEGIES	167
7.3 A THREE-PHASE D-NUMBER THEORY, NEIGHBORHOOD ROUGH SET THEORY (NRST) AND GREY THEORY BASED DECISION SUPPORT SYSTEM	171
7.3.1 PRELIMINARIES	171
7.3.2 A THREE-PHASE DECISION SUPPORT SYSTEM (DSS) FOR THE EVALUATION OF RISK TREATMENT STRATEGIES	176
7.4 APPLICATION OF THE PROPOSED THREE-PHASE DECISION SUPPORT SYSTEM (DSS) FOR THE EVALUATION OF RISK TREATMENT STRATEGIES	181

7.5 RESULTS AND DISCUSSIONS	192
7.6 CHAPTER SUMMARY	196
CHAPTER 8. SUMMARY OF RESEARCH FINDINGS AND CONCLUSIONS	
8.1 INTRODUCTION	197
8.2 SUMMARY OF RESEARCH FINDINGS & CONTRIBUTIONS	198
8.3 IMPLICATIONS & CONTRIBUTIONS FOR ACADEMIA & INDUSTRY PRACTITIONERS	203
8.4 IMPLICATIONS FOR POLICY MAKERS	205
8.5 LIMITATIONS OF THE STUDY	205
8.6 SCOPE OF FUTURE WORK	206
8.7 CHAPTER SUMMARY	207
REFERENCES	208
ANNEXURE I	225
LIST OF PAPERS EMANATING FROM THIS RESEARCH	227
ABOUT THE AUTHOR	228

LIST OF FIGURES

Figure 1.1	Different Perspectives To Understand Risks	8
Figure 1.2	Contribution Of Transportation Sector To GDP	9
Figure 1.3	Logistics Cost (% Of GDP)	10
Figure 1.4	Modal Split (In Percentage)	11
Figure 1.5	Sustainability Risk Management Framework For FTSs	14
Figure 1.6	Research Framework	16
Figure 2.1	Classification Framework	21
Figure 3.1	Framework For Computing The SRI Of FTSs	56
Figure 3.2	Digraphs For Sub-Risks Within Each Sustainability Risk Category I.E. A) FM, B) FI, C) IN, D) E&S, E) MR, F) OP, G) O&G.	62
Figure 3.3	Digraph For Sustainability Risk Categories	61
Figure 3.4	Disruption Scores (DSs) Of Sustainability Risks	68
Figure 3.5	Sensitivity Analysis Of Sustainability Risk Index (SRI)	72
Figure 4.1	Sustainability Risk Assessment Framework For FTSs	77
Figure 4.2	Research Framework	80
Figure 4.3	Fuzzy Triangular Membership Function	83
Figure 4.4	Example Of Transformation Of TFN(PI) Into 5 Non- Normalized Grades	86
Figure 4.5	Utility Functions Of Decision Makers	90
Figure 4.6	Risk Priority Order Of Sustainable Risks In FTSs	100
Figure 4.7	Risk Priority Order Of Sustainability Risks For Risk-Taking Attitude	104
Figure 4.8	Risk Priority Order Of Sustainability Risks For Risk-Averse Attitude	104
Figure 4.9	Sensitivity Of RPSs To Variation In Input	107
Figure 5.1	Research Framework For Sustainability Risk Assessment In FTSs	117
Figure 5.2	High Priority Sustainability Risks Present In FTSs	132
Figure 6.1	Scores Of Sustainability Risks From Economic Perspective In Short-Term	152
Figure 6.2	Scores Of Sustainability Risks From Economic Perspective In Long-Term	153
Figure 6.3	Scores Of Sustainability Risks From Environmental Perspective In Short-Term	153

Figure 6.4	Scores Of Sustainability Risks From Environmental Perspective In Long-Term	154
Figure 6.5	Scores Of Sustainability Risks From Social Perspective In Short-Term	154
Figure 6.6	Scores Of Sustainability Risks From Social Perspective In Long-Term	155
Figure 6.7	Scores Of Sustainability Risks From Overall Sustainability Perspective In Short-Term	155
Figure 6.8	Scores Of Sustainability Risks From Overall Sustainability Perspective In Long-Term	156
Figure 6.9	Classification Of Sustainability Risks Based On Economic Perspective	157
Figure 6.10	Classification Of Sustainability Risks Based On Environmental Perspective	159
Figure 6.11	Classification Of Sustainability Risks Based On Social Perspective	160
Figure 6.12	Classification Of Sustainability Risks Based On Overall Sustainability Perspective	160
Figure 7.1	Priority Ranking Of Treatment Strategies	192

LIST OF TABLES

Table 1.1	Definitions Related To Sustainable Freight Transportation Systems	4
Table 1.2	Research Objectives & Methodologies	17
Table 2.1	Summary Of Papers Related To Sustainable Urban Freight Transportation	24
Table 2.2	Summary Of Papers Related To Practices Towards SFT	27
Table 2.3	Summary Of Papers Related To Negative Externalities	30
Table 2.4	Summary Of Papers Related To Multi-Modal Transportation	33
Table 2.5	Summary Of Literature Review Studies	34
Table 2.6	Summary Of Papers Related To Sustainability Risks	37
Table 2.7	Recent Review Papers In The Area Of Sustainability & Risk Management	40
Table 2.8	Sustainability Risks In Freight Transportation Systems	42
Table 3.1	Relational Matrix	63
Table 3.2	Results For The Sustainability Risk Categories	65
Table 3.3	Influencing Power Of Sub-Risks	68
Table 3.4	SRI Values For Ideal And Worst Case Scenarios	72
Table 4.1	Transformation Of Linguistic Variables To Fuzzy Triangular Membership Functions	83
Table 4.2	Description Of Qualitative Scale Used For Risk Analysis Based On TFN_s	84
Table 4.3	Example Of Transformation Of $TFN_{(PI)}$ Into Belief Structure R	86
Table 4.4	Fuzzy Probability And Fuzzy Impact Of Sustainability Risk Issues	94
Table 4.5	Risk Priority Level In The Form Of $(TFN)_{PI}$ & Normalized Intersection Results Of Risks	95
Table 4.6	Crisp Values On Application Of Expected Utility Theory	98
Table 4.7	Categorization Of Sustainability Risks Based On RPSs	97
Table 4.8	Comparison Of Risk-Neutral, Risk-Averse And Risk-Taking Perceptions	99
Table 4.9	Reducing The Input Associated With The Most Preferred Linguistic Term And Simultaneously Increasing The Input Associated With The Least Preferred Linguistic Term	106
Table 5.1	Comparative Analysis Of Different Methodologies	112
Table 5.2	Transformation Of Linguistic Variables Into IFNs	118

Table 5.3	Linguistic Assessment Of Sustainability Risks	122
Table 5.4	Intuitionistic Fuzzy Assessment Of Sustainability Risks	123
Table 5.5	Decision Matrix For R1	124
Table 5.6	D-Number Representation Of R1 From Positive & Negative Side	124
Table 5.7	Result Of $D_{R1}^{EP1} \oplus D_{R1}^{EP2} \oplus D_{R1}^{EP3}$	125
Table 5.8	D^+ And D^- Risk Scores Of Sustainability Risks	125
Table 6.1	High Priority Sustainability Risks In FTSs	137
Table 6.2	Transformation Of Linguistic Variables Into IFNs	142
Table 6.3	Assessment Of Sustainability Risks For The Short-Term Scenario	146
Table 6.4	Assessment Of Sustainability Risks For The Long-Term Scenario	147
Table 6.5	Severity Of Sustainability Risks From Different Perspectives In The Short-Term Scenario	148
Table 6.6	Severity Of Sustainability Risks From Different Perspectives In The Long-Term Scenario	149
Table 6.7	D^+ And D^- Risk Scores Of Sustainability Risks From Economic Perspective	150
Table 6.8	D^+ And D^- Risk Scores Of Sustainability Risks From Environmental Perspective	150
Table 6.9	D^+ And D^- Risk Scores Of Sustainability Risks From Social Perspective	151
Table 6.10	D^+ And D^- Risk Scores Of Sustainability Risks From Overall Perspective	151
Table 6.11	Sustainability Risk Profiling From Economic Perspective	158
Table 6.12	Sustainability Risk Profiling From Environmental Perspective	158
Table 6.13	Sustainability Risk Profiling From Social Perspective	159
Table 6.14	Sustainability Risk Profiling From Overall Sustainability Perspective	161
Table 6.15	Analyzing The Variations In Risk Priorities w.r.t. Different Perspectives And Time-Frames.	162
Table 7.1	Risk Treatment Strategies	168
Table 7.2	Aggregated Assessment Of Risk Treatment Strategies	183
Table 7.3	Aggregated Assessment Of Risk Treatment Strategies On Decision Attributes	184
Table 7.4	Neighborhood Relational Matrix For Sustainability Risk Attributes Between Strategies	187
Table 7.5	Significance Values Of Sustainability Risk Attributes	186

Table 7.6	Positive Grey Relational Matrix (γ^+)	189
Table 7.7	Negative Grey Relational Matrix (γ^-)	190
Table 7.8	Projection Values Of Risk Treatment Strategies	191
Table 7.9	Compiled Evaluation Results For Risk Treatment Strategies	195
Table 8.1	Summary Of Research Objectives & Corresponding Findings	201

LIST OF ABBREVIATIONS

AHP	Analytical Hierarchy Process
DMA	Digraph Matrix Approach
DSS	Decision Support System
ECI	Economic Impact
ECP	Economic Perspective
ENI	Environmental Impact
ENP	Environmental Perspective
ERA	Evidential Reasoning Approach
EUT	Evidential Reasoning Approach
FERA	Fuzzy Evidential Reasoning Approach
FMEA	Failure Mode Effect Analysis
FT	Freight Transportation
GHG	Greenhouse Gas
GRPA	Grey Relational Projection Analysis
FTSs	Freight Transportation Systems
ICT	Information & Communication Technology
IFS	Intuitionistic Fuzzy Set
IFN	Intuitionistic Fuzzy Number
ITL	Interval Two-Tuple Linguistic Representation Model
NRST	Neighborhood Rough Set Theory
OSP	Overall Sustainability Perspective
RPS	Risk Priority Score

SFT	Sustainable Freight Transportation
SFTSs	Sustainable Freight Transportation Systems
SI	Social Impact
SP	Social Perspective
TBL	Triple-Bottom Line Framework
TFN	Triangular Fuzzy Number
US	United States
UK	United Kingdom
CO ₂	Carbon dioxide