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(Supervisor)

Professor A. K. Agrawal
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DECLARATION BY THE CANDIDATE

I, **Harish Babu**, certify that the work embodied in this thesis is my bona fide work and carried out by me under the supervisions of **Prof. Prabhas Bhardwaj** and **Prof. A. K. Agrawal** from December 2013 to December 2020, in the Department of Mechanical Engineering, Indian Institute of Technology (BHU), Varanasi. The matter embodied in this thesis has not been submitted for the award of any other degree/diploma. I declare that I have faithfully acknowledged and given credits to the research workers wherever their works have been cited in my work in this thesis. I further declare that I have not willfully copied any other's work, paragraphs, text, data, results, etc., reported in journals, books, magazines, reports dissertations, theses, etc., or available at websites and have not included them in this thesis and have not cited as my work.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

AHP	Analytic Hierarchy Process
ANP	Analytical Network Process
CI	Consistency Index
CR	Consistency Ratio
DE	Delay Risk
DEA	Data envelopment analysis
DR	Demand Risk
ER	Environmental Risk
FMEA	Failure Mode and Effects Analysis
FMEA	Failure Modes and Effects Analysis
FPII	Fuzzy Performance Importance Index
FRI	Fuzzy Risk Index
GSC	Green Supply Chain
IPA	Importance-performance Analysis
IR	Information Technology Risk
ISM	Interpretive Structural Modelling
MCDM	Multiple Criterion Decision Making
MICMAC	Cross-Impact Matrix-Multiplication Applied to Classification
MOORA	Multi-Objective Optimization by Rational Analysis
MSMED	Micro, Small and Medium Enterprises Development
N-AHP	Neutrosophic Analytical Hierarchy Process
NGT	Nominal Group Technique
PCA	Principle Component Analysis
PR	Process Risk
PROMETHEE	Preference ranking organization method for enrichment evaluation
QFD	Quality Function Deployment
RI	Random Index
RPN	Risk Priority Number
SC	Supply Chain
SCF	Supply Chain Flexibility
SCM	Supply Chain Management
SCOR	Supply Chain Operations Reference Model

SCRES	Supply Chain Resilience
SCRM	Supply Chain Risk Management
SCRMP	Supply Chain Risk Management Process
SEM	Structural Equation Modelling
SMEs	Small and Medium Enterprises
SR	Supply Risk
SSIM	Self-Interaction Matrix
SSIM	Structural Self-Interaction Matrix
TR	Transportation Risk

Abbreviations not listed here are defined as they appear in the text.

ABSTRACT

Market forces such as local and global competition, technological changes, frequent customer changes and environmental changes have forced Supply Chains (SC) of world-wide organisations more complex and exposed to more uncertainty and risks. A disruption in normal operations of a SC such as failure of transportation link, workers' strike, terrorist attacks can make the supply chain more vulnerable and may, sometimes, slowdown or completely shut down the supply chain. The 9/11 terrorist attack, Covid-19 pandemic, Tsunami, earthquake, Uttrakhand disaster and Katerina typhoon had disrupted the supply chain of many organisations. The impact of which could be felt in the entire world. Such disruptions have an impact not only on the organisations of that particular geographical area but also on the upstream and downstream supply partners. The recent incidents in the Indian context, such as the Cyclone 'Fani' in Odisha (2019) and Cyclone 'Amphan' in East India (2020), have severely affected the supply chain of these areas. Maintaining uninterrupted supply chain flow is the primary concern of the supply chain managers. But, due to risks involved in the supply chain, it becomes difficult for supply chain managers to maintain continuous supply chain flow every time. Supply Chain Risk Management (SCRM) help firms to enable proactive management of supply chain risks and maintain the performance of the supply chain. Supply Chain Risk Management (SCRM) has become a popular topic amongst researchers and supply chain managers. It is necessary for decision makers to understand the various Supply Chain Risk (SCR) variables and risk management strategies for effective Supply Chain Risk Management. SCRM enables a firm to respond efficiently and more quickly to disruption in supply chains.

Not only Multi-National Companies (MNCs) and Indian Companies but also Micro, Small and Medium Enterprises (MSMEs) are exposed to such risk and require SCRM. This research is focused on the supply chain risk issues of Indian MSMEs. These supply chain

risk issues are treated as SCR variables. The risk management process starts with the identification of risk variables, so these risk variables are considered critical factors of SCRM and can form the foundation of the SCRM. In this research work, initially literature review on SCRM was carried out to identify the main risk variables and risks attributes. This is followed by an analysis of these variables and attributes and finally finishing the selection of suitable risk management strategies for identified risk variables. This research is specifically conducted with the objective to gain insight into SCRM in the context of Indian MSMEs. To this purpose, a case study of a small-scale manufacturing organisation was carried out.

The first phase of this research started with an exhaustive literature review on SCRM and the identification of challenges faced by Indian MSMEs during the implementation of SCRM. Based on the literature review and expert opinion, seven main risk variables were identified as (i) Environmental Risk (ER), (ii) Information Technology Risk (IR), (iii) Supply Risk (SR), (iv) Process Risk (PR), (v) Transportation Risk (TR), (vi) Delay Risk (DE) and (vii) Demand Risk (DR). Interpretive Structural Modelling (ISM) methodology is applied to analyse the risk variables and to establish the interrelationship among these seven risk variables. This technique provides a hierarchical interrelationship structure of supply chain risk variables. Such interrelationships help the supply chain managers to understand how these risk variables affect each other to make the supply chain robust. The interrelationship structure also helps in identifying the significant and insignificant risk variables of the model. After that, MICMAC analysis is used to understand and calculate the driving power and dependence power of each risk variable, based on which, supply chain risk variables are classified into four categories: (i) autonomous, (ii) dependent, (iii) linkage and (iv) independent risk variables. Supply risk, demand risk, transportation risk are classified as the linkage variables; information

technology risk and environmental risk as the driver variables while process risk and delay risk are dependent variables. No autonomous variables out of these seven SC variables meaning by all the considered risk variables are significant to SCRM.

Indian MSMEs face several risks associated with their supply chain, but cannot give equal attention to all the risks due to limited resources, such as money, manpower, time etc.. Thereby, it creates a strong and justifiable reason for the assessment and for prioritization of risk variables in the context of Indian MSMEs. The relative weights of the variables cannot be obtained from ISM methodology. So, Analytic Hierarchy Process (AHP) methodology, a Multiple Criterion Decision Making (MCDM), is used for the assessment of risk variables and to obtain their relative weights. With the help of literature review and expert opinion, five criteria were used to evaluate these risk variables: (i) probability of occurrence, (ii) severity of risk, (iii) detectability of risk, (iv) risk management cost and (v) risk controllability. Prioritization of risk variables and ranking has been done with the help of relative weights of risk variables. Environmental Risk 'ER' and Information Technology Risk 'IR' are assigned higher priorities, while Demand Risk 'DR', Transportation Risk 'TR', Supply Risk 'SR' and Process Risk 'PR' are assigned lower priorities. So, it is also learnt that the hierarchy established through ISM & classification obtained by MICMAC seems to be aligned with the priority results of AHP. For example, the SCR variables such as Environmental Risk 'ER' and Information Technology Risk 'IR' are assigned with high driving power through MICMAC while more weight/high priority through AHP.

Indian MSMEs face different types of risks associated with their supply chain network. The unpredictable nature of risks, improper evaluation of the impact of the risks and selection of imperfect strategy, in turn, lead to an adverse effect on the performance of the supply chain. Therefore, Indian MSMEs have to adopt SCRM practices to achieve

better performance resulting in uninterrupted supplies to ultimate consumer. From here, the problems of SC managers start, i.e., “What exact risks the supply chain are exposed to?” and “How can the risk level be measured?”. SC managers need to evaluate the risk level of their supply chain. The outcomes of ISM and AHP have been used as the input in the Fuzzy logic approach for developing the integrated Fuzzy-ANP SCRM model. Risk-variables are the main foundation of the SCRM. Before the implementation of SCRM, evaluation of the risk variables, risk attributes and risk-level of the supply chain becomes an essential activity. This leads to the evaluation of risk level by using fuzzy logic approach of Lin *et al.* (2006). A conceptual framework is structured with two levels; seven risk variables are placed at the first level and the forty-two risk attributes are placed at the second level. The fuzzy logic approach provides the fuzzy risk index of the case organisation indicating the risk level of the case organisation to be “HIGH”. Fuzzy risk index (FRI) is calculated based on risk variables and risk attributes. From Fuzzy risk index, it is observed that there are few risk variables/attributes that significantly affect the risk level of the supply chain. Accordingly, fuzzy performance importance index (FPII) of each risk variable and risk attribute is calculated to identify the main obstacles of the SCRM. Out of the forty-two risk attributes, twenty risk attributes were identified as the main obstacles to SCRM. Identifying the main obstacles/risks of SCRM, the selection of a suitable risk management strategy to anticipate these risks, are identified. Analytical Network Process (ANP) methodology is used to evaluate and select the most feasible risk management strategy for each SCR variable. Findings of ANP approach shows that mitigation strategy, a generic strategy, is the most preferential strategy for SCRM followed by sharing strategy, retention strategy and avoidance strategy. SC managers can make the supply chain more robust and can improve its performance by proactive management of these SCR variables/attributes.

Through this research, an attempt has been made to present a comprehensive understanding of supply chain risks and risk management strategies for the risks in the context of Indian MSMEs. Modelling of SCR variables, assessment and prioritization of SCR variables, determination of risk level and selection of suitable risk management strategies are the main studies conducted in this research.

This study will also help the academicians and researchers to understand the concept of various supply chain risks and risk management strategies in the context of Indian MSMEs. This study shall also help them to understand the relative importance of SCR variables, SCR attributes and risk management strategies.