A Conceptual Framework for Building Resilience in Supply Chain: A Case of Indian Iron and Steel Manufacturing Sector

Thesis submitted towards the partial fulfillment

for the Award of Degree

Doctor of Philosophy

by

AJEET KUMAR YADAV

DEPARTMENT OF MECHANICAL ENGINEERING
INDIAN INSTITUTE OF TECHNOLOGY
(Banaras Hindu University)
VARANASI – 221 005

Roll No. 17101001 **2022**

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Dr. Cherian Samuel (Supervisor)

Associate Professor

Department of Mechanical Engineering

Indian Institute of Technology (BHU)

VARANSI-221005

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I, ***AJEET KUMAR YADAV,*** certify that the work embodied in this thesis is my own a bona fide work carried out by me, under the supervision of **Dr. CHERIAN SAMUEL** from July 2017 to May 2022, at the Department of Mechanical Engineering, Indian Institute of Technology (BHU) Varanasi. The matter embodied in this thesis has not been submitted elsewhere for the award of any other degree or 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 wilfully 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 own work.

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Dr. Cherian Samuel (Supervisor)

Associate Professor

Department of Mechanical Engineering

Indian Institute of Technology (BHU)

VARANSI-221005

Prof. Santosh Kumar

The Head

Department of Mechanical Engineering

IIT (BHU) Varanasi

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Ajeet Kumar Yadav

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ABBREVIATIONS

FLEX	Flexibility
POST	Postponement
VIS	Visibility
AGI	Agility
COL	Collaboration
CPFR	Collaborative Planning, Forecasting, and Replenishments
IS	Information Sharing
STRG	Strategic Stock
JIT	Just in Time
CDC	Center for Disease Control),
SNS	Strategic National Stockpile
RED	Redundancy
RMC	Risk Management Culture
OEM	Original Equipment Manufacturer
SCRMC	Supply Chain Risk Management Culture
ASSORT	Assortment Planning
SKU	Stock-Keeping Unit
DP	Dynamic Pricing
SPR	Silent Product Rollover
WIM	Warehouse and Inventory Management
ADAPT	Adaptive Capability
SEI	Supply Economic Incentives
IFP	Improving Financial POSTION

SCR	Supply Chain Restructuring
MADM	Multi-Attribute Decision-Making
SSIM	Structural Self-Interaction Matrix
HOQ	House Of Quality
HOR	House Of Resilience
FPI	Fuzzy Performance Index
RFI	Resilience Fuzzy Index
CRS	Crisp Resilience Score
FST	Fuzzy Set Theory
TFN	Triangular Fuzzy Number
NCRS	Normalized Crisp Resilience Score
MICMAC	Matrice d'Impacts Croisés Multiplication Appliquée A Un Classement
ISM	Interpretative Structural Modeling
DEMATEL	Decision-Making Trial and Evaluation Laboratory
PLS	Partial Least Square
VIKOR	Višekriterijumsko Kompromisno Rangiranje
ICT	Information And Communication Technology
ANP	Analytic Network Process
DEA	Data Envelopment Analysis
TISM	Total Interpretative Structural Modeling
TOPSIS	Technique for Order of Preference by Similarity to Ideal Solution
QFD	Quality Function Deployment
AHP	Analytic Hierarchy Proces
SEM	Structural Equation Modeling
NAS	National Academy Of Science

NAT	Normal Accident Theory
RSC	Resilient Supply Chain
SC	Supply Chain
SCM	Supply Chain Management
SCR	Supply Chain Resilience
SCRM	Supply Chain Risk Management
SVDs	Supply Chain Risk, Vulnerability, and Disruptions

LIST OF INDICES AND PARAMETERS

Indices and Parameters for Chapter 2

P_i	i^{th} resilient practice
i, j, k	Resilient practices index
Y	Yes
N	No
1^*	Transitive relationship
D_p	Dependence power
D_r	Driving power

Indices and Parameters for Chapter 3

j, k	Resilient practices index, $j \neq k$
C_i	Resilient capability
A_i	Relative importance weight of resilient capability C_i
a_i	Average rating value corresponds to the capability C_i
P_{Res}	Resilience performance of the case organization with respect to the resilient capabilities
P_{max}	Maximum possible value of the performance rating
p_i	Performance rating of the case organization SC with respect to the capability i
NP_i	Normalized performance rating of the case organization SC with respect to the capability i
g_{jk}	Correlation between resilient practices
g'_{jk}	Normalized value of correlation between the resilient practices
R_{ji}	Relationships between RSC practices and capabilities

D_j	Initial ratings of resilient practices
D_j'	Final ratings of the resilient practices
RD_j	Relative importance rating for the resilient practices
R_{ji}'	Elements of normalized relationship matrix
S_{jk}	Similarity coefficient between every pair of the resilient practices having a non-zero relationship in the roof matrix
d	The number of cells of the relationship matrix, for which either $R_{ji\ or}\ R_{jk} \neq 0$

Indices and Parameters for Chapter 4

i	Resilient practice index
j	Resilient practice attribute index
A_{ij}	j^{th} attribute of the i^{th} practices
E	Excellent
VG	Very good
G	Good
F	Fair
P	Poor
VP	Very poor
W	Worst
VH	Very high
H	High
FH	Fairly high
M	Medium
FL	Fairly low

L	Low
VL	Very low
t	Experts indices
E_t	t^{th} experts, $t = 1, 2 \dots, 7$
R_{ijt}	Performance rating given by t^{th} expert for j^{th} attribute of i^{th} practices
W_{ijt}	Weight allotted by t^{th} Expert for j^{th} attribute of i^{th} Practices
W_i	Aggregated importance weight of the i^{th} Practices
W_{ij}	Importance weight of the j^{th} attribute of i^{th} Practices
R_{ij}	Performance rating corresponds to the j^{th} attribute of i^{th} Practices
RP_i	Resilience score of i^{th} practice
$U_{RFI}(x)$	Membership function for RFI
a	Lower number of triangular fuzzy numbers (a, b, c)
b	Middle number of triangular fuzzy numbers (a, b, c)
c	Upper number of triangular fuzzy numbers (a, b, c)
RL_i	Linguistic resilient labels

Indices and Parameters for Chapter 5

i, j	Barriers index
B_i	i^{th} barrier
k	Experts indices
NO	No influencing relation
VL	Very low influencing relation
LI	Low influencing relation
HI	High influencing relation
VH	Very high influencing relation

A_{ij}^{k}	Linguistic score provided by the expert k ($k = 1,2, \dots, d$) regarding the effect/influence of factor i over factor j
l	Lower number of triangular fuzzy numbers (l, m, r) regarding the effect/influence of factor i over factor j
m	Middle number of triangular fuzzy numbers (l, m, r) regarding the effect/influence of factor i over factor j
r	Upper number of triangular fuzzy numbers (l, m, r) regarding the effect/influence of factor i over factor j
xl	Normalized lower number of triangular fuzzy numbers regarding the effect/influence of factor i over factor j
xm	Normalized middle number of triangular fuzzy numbers regarding the effect/influence of factor i over factor j
xr	Normalized upper number of triangular fuzzy numbers regarding the effect/influence of factor i over factor j
ls	Left normalized value of triangular fuzzy numbers
rs	Right normalized value of triangular fuzzy numbers
x_{ij}^{k}	Total normalized crisp value of expert response regarding the effect/influence of factor i over factor j
a_{ij}^{k}	Final crisp values of expert response regarding the effect/influence of factor i over factor j
a_{ij}	Aggregated final crisp values of expert response regarding the effect/influence of factor i over factor j
Y	Normalized direct-relation matrix
T	Total relational matrix
d_i	Influencing ability of barrier i

r_i Influence of other factors over the barrier i

w_i Priority weights of the barriers i

W_i Relative priority weights of the barriers i

PREFACE

The 21st-century global business has been very competitive and derived from the complex set of connected and inter-dependent organizations called SC. These SCs are intended to enhance customer value, minimize cost, and optimize the organization's financial benefits. However, the success of the SCs is subjective to the success of each of its entities which is subjected to risks, uncertainties, and disruptive events. The impacts of the SC failure are very pronounced, and if not addressed rightly, it may lead to the complete loss of the business. Therefore, for the survival and growth of the business in the propensity of the adversities, the SC needs to be incorporated with the capabilities that enable them to counter and capitalize on the events that could potentially harm and questions its survival. Hence the resilient concept of the SC gains its importance, which not only enables the SC entities to prepare for the expected challenges and respond effectively to the adversities but also enables quick and efficient recovery post disruptions.

This study reviewed the extant literature on the RSC's functions, characteristics, and capabilities and clustered them based on their similarity into the four resilient capabilities of the SC, i.e., readiness, robustness, rapidity, and recovery and growth. Further, the literature suggests that much research is available explaining the importance of resilient practices for enabling the resilient characteristics of the SCs; however, very few attempts to identify and define their interdependence relationships. And evaluating the resilience score of a SC while considering the resilient practices and their corresponding attributes is even rare. Further, very little research has been carried out to explore and analyze the factors inhibiting the successful implementation of the resilient practices of the SC, which ultimately hinders the attainment of the 'definitely

resilient' position of the SC. The literature also suggests that research study focusing on enabling the resilient behavior of Indian manufacturing SC is rare. However, there is the complete absence of comprehensive research done with respect to Indian iron and steel manufacturing SC.

This research provides a wider perspective of the RSC and is carried into the four objectives considering the case of an Indian iron and steel manufacturing SC as listed below:

1. To identify the resilient practices of the SC and interpret their causal dependence relationships.
2. To estimate the utility of the resilient practices for enabling the resilient capabilities to the SC.
3. To evaluate the resilience level of the case organization SC.
4. To identify the hindrances to the successful implementation of the resilient practices to the SC and also prioritize them based on their causal dependence relationships.