

LB/TH/35/2025

TH5933

**DEVELOPMENT OF A RISK MANAGEMENT MODEL
IN TECHNOLOGICAL INNOVATIONS RELATED TO
THE TEXTILE AND APPAREL INDUSTRY**

K.A.U.P. Kumarapeli

188083R

MASTER OF PHILOSOPHY

Department of Textile and Apparel Engineering
Faculty of Engineering

University of Moratuwa
Sri Lanka

APRIL 2025

**DEVELOPMENT OF A RISK MANAGEMENT MODEL
IN TECHNOLOGICAL INNOVATIONS RELATED TO
THE TEXTILE AND APPAREL INDUSTRY**

K.A.U.P. Kumarapeli

188083R

Thesis submitted in partial fulfillment of the requirements for the degree
MASTER OF PHILOSOPHY

Department of Textile and Apparel Engineering
Faculty of Engineering

University of Moratuwa
Sri Lanka

APRIL 2025

DECLARATION

I declare that this is my own work and this thesis/~~dissertation~~ does not incorporate without acknowledgement any material previously submitted for a degree or diploma in any other University or Institute of higher learning and to the best of my knowledge and belief it does not contain any material previously published or written by another person except where the acknowledgement is made in the text. I retain the right to use this content in whole or part in future works (such as articles or books).

Signature:

Date: 17/04/2025

The above candidate has carried out research for the ~~PhD/MPhil/Masters~~ thesis/~~dissertation~~ under my supervision. I confirm that the declaration made above by the student is true and correct.

Name of Supervisor: Mrs. R.M.V.S. Ratnayake

Signature of the Supervisor:

Date: 17/04/2025

Name of the Co-Supervisor: Prof. T.S.S. Jayawardena

Signature of the Supervisor:

Date: 17/04/2025

DEDICATION

To my Amma, whose unwavering warmth, guidance, and care have shaped my
journey,

To my Thaththa, whose strength was my shield,

To my Nangi, who has been my super power,

To my Husband and Son, who have unconditionally believed in me.

ACKNOWLEDGEMENT

First and foremost, I would like to express my sincere gratitude to my supervisory team, Mrs. Vijitha Ratnayake and Prof. Sanath Jayawardena, for their consistent support, compassion, and invaluable guidance throughout my MPhil journey. Their insightful responses and dedication to addressing all my inquiries have been instrumental in shaping this thesis. I am deeply indebted to them for their valuable feedback on my publications and their unwavering commitment to my success. This research would not have been possible without their assistance and active involvement in every step of the process. Our meetings and conversations were crucial in inspiring me to think beyond conventional boundaries, for which I am truly thankful. Besides my supervisors, I would like to express heartfelt gratitude to Dr. Ranga Abeysooriya for his assistance with statistical analysis and the rest of my progressive review committee, Prof. Asela Kulatunga and Prof. Gamini Lanarolle for the advices and motivation provided towards the successful completion of my research.

Furthermore, I am truly blessed to be surrounded by my loving family, whose unwavering support and trust have been the foundation of my journey. Though my parents are not here to witness the fulfilment of the dreams they nurtured for me, they went above and beyond to give me every opportunity to succeed. Their love continues to inspire me. I am deeply grateful to my amazing sister, for being my constant source of strength, and to my brother-in-law for his invaluable support in helping me reach this goal. Finally, I am profoundly thankful to my husband and son, who have stood by me through every high and low, giving me courage and teaching me perseverance. I am incredibly fortunate to have all of you in my life.

I would like to sincerely thank the managers and staff of the textile and apparel manufacturing factories involved in this study and to the experts who participated in the validation survey, their enthusiastic involvement and insightful contributions were crucial to the successful completion of this research. I am also profoundly grateful to the University of Moratuwa for granting me the opportunity to pursue this postgraduate research, and I acknowledge with appreciation the Senate Research Committee grant (SRC/LT/2019/25) that supported my work. Finally, I extend my heartfelt thanks to the Head of the Department of Textile & Apparel Engineering and all the staff for their continuous support during my research.

ABSTRACT

The Textile and Apparel industry, including Sri Lanka's, has grown significantly, offering substantial employment and economic benefits globally. Over the past four decades, Sri Lanka's apparel sector has experienced exceptional growth, becoming the nation's primary foreign exchange earner and employing thousands. Despite this success, Sri Lankan apparel faces higher costs and lead times compared to competitors, alongside a limited product range, which hampers its competitiveness. To stand out, it is crucial to leverage technological innovation for faster production, improved delivery times, precise research and development processes, and modern manufacturing techniques to reduce costs. However, technological innovation is fraught with uncertainty and a broad spectrum of risks, underlining the need for a robust risk management strategy. Due to varying organizational resources and product requirements, a generic risk management model is ineffective across different products and organizations. This situation necessitates a customized risk management approach, a need that current literature often overlooks. Furthermore, organizations are often hesitant to share confidential information with third parties, adding another layer of complexity. To address these issues, a risk management model was designed as a game, to solve the root causes of risk factors in technological innovations and effectively manage the associated risks. It integrates key elements from cooperative game theory, behavioral game theory, teamwork dynamics, psychological aspects of decision-making, visual problem-solving, and the board gaming concept. This model enhances resilience and agility while preserving the confidentiality of organizational strategies. 13 leading apparel manufacturers and 10 textile manufacturers were selected covering 145 factories. Data collection was conducted via questionnaires and structured/semi-structured interviews. The results present a flexible, customized risk management model that adapts to emerging risks while maintaining the strategic confidentiality of manufacturing organizations, addressing a significant gap in existing literature.

Keywords: Textile and Apparel Industry, Technological Innovations, Risk Management Model, Risk Factors and Root Causes, Game Theory

TABLE OF CONTENTS

| | |
|---|------|
| Declaration of the candidate and the supervisor | i |
| Dedication | ii |
| Acknowledgement | iii |
| Abstract | iv |
| Table of Contents | v |
| List of Figures | ix |
| List of Tables | xii |
| List of Abbreviations | xiii |
| List of Appendices | xv |
| 1. Introduction | 1 |
| 1.1 Sri Lankan textile and apparel industry | 1 |
| 1.1.1 Innovations in the Sri Lankan textile and apparel industry | 2 |
| 1.2 Research gap | 3 |
| 1.3 Research problem | 4 |
| 1.3.1 Aim of the research | 4 |
| 1.3.2 Research objectives | 4 |
| 1.3.3 Scope of the research | 4 |
| 1.3.4 Research design | 5 |
| 1.4 Outline of the thesis | 5 |
| 2. Literature Review | 6 |
| 2.1 Introduction | 6 |
| 2.2 Challenges in the textile and apparel industry | 6 |
| 2.3 An overview of different innovation concepts | 9 |
| 2.4 Different approaches to the innovation process | 12 |
| 2.4.1 Different innovator types in textile and apparel industry | 14 |
| 2.5 Role of technological innovations in textile and apparel industry | 15 |
| 2.6 Risk in innovation process | 15 |
| 2.7 Risk management in the technological innovation process | 16 |
| 2.7.1 Risk factors related to the technological innovation process | 16 |
| 2.7.2 Root causes related to risk factors of technological innovation | 17 |

| | | |
|---------|---|----|
| 2.8 | Interconnections between different factors | 20 |
| 2.9 | Classification techniques | 21 |
| 2.9.1 | Artificial neural networks for data classification | 22 |
| 2.10 | Consistency of the data classification | 23 |
| 2.11 | Dealing with large data sets | 23 |
| 2.12 | Root cause analysis methods | 24 |
| 2.13 | Prioritization techniques of root causes | 25 |
| 2.14 | Methods used in risk management models | 25 |
| 2.14.1 | Visual representation in problem-solving | 26 |
| 2.14.2 | Validation | 26 |
| 3. | Research Methodology | 28 |
| 3.1 | Introduction | 28 |
| 3.2 | Interconnections of innovation concepts | 28 |
| 3.2.1 | Detailed analysis of the interpretation of innovation concept | 29 |
| 3.2.1.1 | Visualization of inter-connections of innovation concepts | 31 |
| 3.3 | Classification of innovation concepts | 32 |
| 3.3.1 | Classification of innovation concepts using Grounded | 32 |
| 3.3.2 | Validation of the consistency of the classification | 33 |
| 3.3.2.1 | Statistically proving the consistency of the classification | 34 |
| 3.4 | Core innovation concepts | 35 |
| 3.4.1 | Deriving core innovation concepts from three main phases using Grounded Theory | 36 |
| 3.5 | Base for the risk management model | 38 |
| 3.6 | Risk factors associated with technological innovations | 39 |
| 3.6.1 | Refined list of risk factors associated with technological innovations | 42 |
| 3.7 | Classification of risk factors into main phases of innovation process | 46 |
| 3.7.1 | Intra-organizational innovation phase (P1) | 47 |
| 3.7.2 | Peripheral innovation phase (P2) | 47 |
| 3.7.3 | Sustainable innovation phase (P3) | 47 |
| 3.8 | Validation of the consistency of risk factor classification | 48 |
| 3.9 | Root causes associated with technological innovations | 48 |
| 3.10 | Different innovator types | 54 |

| | | |
|----------|--|-----|
| 3.10.1 | Innovator type of the organization | 54 |
| 3.10.1.1 | Structuring the Neural Network | 55 |
| 3.10.1.2 | Hidden layers and the nodes | 56 |
| 3.10.1.3 | Output of the Neural Network | 56 |
| 3.11 | Priorities of root causes and risk factors | 57 |
| 3.11.1 | Priorities of risk factors related to different innovator types | 58 |
| 3.11.2 | Priorities of root causes on risk factors | 59 |
| 3.12 | Limitations in developing a customized risk management model | 62 |
| 3.13 | The rationale for the risk management model | 62 |
| 3.13.1 | Methodology for forming the game | 64 |
| 3.14 | The risk management model | 70 |
| 3.14.1 | Pitch Making Phase | 72 |
| 3.14.2 | Kick Start Phase | 72 |
| 3.14.3 | Unsolved risk factors | 73 |
| 3.15 | Validation of the risk management model | 78 |
| 4. | Results and Discussion | 80 |
| 4.1 | Interconnections of different innovation concepts | 80 |
| 4.1.1 | Visualization of interconnections of innovation concepts | 82 |
| 4.2 | Classification of innovation concepts | 82 |
| 4.2.1 | Validation of consistency of classification | 83 |
| 4.2.2 | Statistical validation of consistency of classification | 84 |
| 4.3 | Deriving core innovation concepts | 87 |
| 4.4 | Classification of risk factors into main phases of innovation process | 87 |
| 4.5 | Classification of innovation concepts | 88 |
| 4.5.1 | Validation of consistency of risk factor classification | 89 |
| 4.6 | Root causes associated with technological innovation risk factors | 89 |
| 4.7 | Innovator type of the organization | 93 |
| 4.8 | Assesing priorities of risk factors related to different innovator types | 96 |
| 4.9 | Assesing priorities of root causes related to each risk factor | 100 |
| 4.10 | Risk management model for technological innovations in Textile and Apparel industry | 104 |
| 4.11 | Validation of the risk management model | 104 |
| 4.11.1 | Feedback of the industry validation process | 104 |

| | |
|--|-----|
| 4.11.2 Validation of the risk management model with System Usability Scale | 105 |
| 4.12 Discussion | 107 |
| 5. Conclusion and future research | 112 |
| 5.1 Conclusion | 112 |
| 5.2 Limitations and future research | 114 |
| Reference List | 115 |
| Appendix A: Questionnaire (QE1) to validate the consistency of the Classification | 144 |
| Appendix B: Summary of Normality tests on feedback of QE1 | |
| Summary of Hypothesis test on feedback of QE1 | 148 |
| Appendix C: Questionnaire (QE2) assesses the industry's willingness to share information on core innovation concepts | 158 |
| Appendix D: Questionnaire (QE3) – To validate the consistency of risk factor classification | 160 |
| Appendix E: Questionnaire (QE4) – To gather reasons behind the occurrence of risk factors of technological innovations | 162 |
| Appendix F: Questionnaire (QE5) – To obtain input data to the FFNN in assessing the innovator type of the organization | 164 |
| Appendix G: Data Visualization | 181 |
| Appendix H: Neural network architectures | 194 |
| Appendix I: Risk factor interdependencies | 199 |
| Appendix J: Abbreviations of Figure 3.10 Questionnaire (QE6), to obtain for pairwise comparisons | 200 |
| Appendix K: User Guide | 203 |
| Appendix L: System Usability Scale | 240 |

LIST OF FIGURES

| Figure | Description | Page |
|-------------|---|------|
| Figure 3.1 | Consent to share information on risk factors of core innovation concepts in questionnaire (QE2) | 39 |
| Figure 3.2 | Causes for product not being accepted due to over Value-addition | 43 |
| Figure 3.3 | Fewer orders and order quantities | 44 |
| Figure 3.4 | Higher lead times | 44 |
| Figure 3.5 | Difficulty in convincing operators on changes | 45 |
| Figure 3.6 | Not achieving the expected profit | 45 |
| Figure 3.7 | Finding out the customer market share | 46 |
| Figure 3.8 | Structure of the FFNN used in classification | 56 |
| Figure 3.9 | Risk breakdown structure to evaluate priorities | 58 |
| Figure 3.10 | Breakdown structure of the technological innovation risk factors and root causes | 61 |
| Figure 3.11 | Main phases of the risk management model | 64 |
| Figure 3.12 | The game board | 65 |
| Figure 3.13 | Symbols of the key mechanisms | 66 |
| Figure 3.14 | Unit cell of the Game board | 67 |
| Figure 3.15 | Game pieces | 68 |
| Figure 3.16 | Checklist of the pitch-making meeting | 70 |
| Figure 3.17 | Breakdown of main processes related to each phase of the risk management model | 71 |
| Figure 3.18 | Assessing risk level with risk matrix | 74 |
| Figure 3.19 | Four risk levels and their boundaries | 75 |
| Figure 3.20 | Risk matrix with different risk levels | 75 |
| Figure 3.21 | Risk Prioritization matrix | 76 |
| Figure 3.22 | Risk prioritization and management | 76 |

| | | |
|-------------|---|-----|
| Figure 3.23 | How to define risk levels | 78 |
| Figure 4.1 | Inter-connections of innovation concepts | 82 |
| Figure 4.2 | Classification of innovation concepts using the Grounded theory | 83 |
| Figure 4.3 | Summary of responses for the classification on P1-Structuring the organization for a sustainable innovation | 83 |
| Figure 4.4 | Summary of responses for the classification on P2 - information, outside the organization for a sustainable innovation | 84 |
| Figure 4.5 | Summary of responses for the classification on P3 - implementing a sustainable innovation | 84 |
| Figure 4.6 | Summary of hypotheses regarding boxplot ranges in business model innovation | 85 |
| Figure 4.7 | Classification of risk factors into main phases of the innovation process | 89 |
| Figure 4.8 | Validation loss over 5 epochs | 96 |
| Figure 4.9 | Priorities of 14 technological innovation risk factors related to 6 innovator types | 99 |
| Figure 4.10 | Priorities of main phases of innovation process related to 6 innovator types | 99 |
| Figure 4.11 | Priorities of root causes related to C1 | 100 |
| Figure 4.12 | Priorities of root causes related to C2 | 100 |
| Figure 4.13 | Priorities of root causes related to C3 | 101 |
| Figure 4.14 | Priorities of root causes related to C4 | 101 |
| Figure 4.15 | Priorities of root causes related to C6 | 101 |
| Figure 4.16 | Priorities of root causes related to C7 | 101 |
| Figure 4.17 | Priorities of root causes related to C8 | 102 |
| Figure 4.18 | Priorities of root causes related to C8 | 102 |
| Figure 4.19 | Priorities of root causes related to C9 | 102 |

| | | |
|-------------|--|-----|
| Figure 4.20 | Priorities of root causes related to C10 | 102 |
| Figure 4.21 | Priorities of root causes related to C11 | 103 |
| Figure 4.22 | Priorities of root causes related to C12 | 103 |
| Figure 4.23 | Priorities of root causes related to C13 | 103 |
| Figure 4.24 | Priorities of root causes related to C14 | 103 |
| Figure 4.25 | Risk management model | 106 |

LIST OF TABLES

| Table | Description | Page |
|------------|---|------|
| Table 2.1 | Summarized interpretations of innovation concepts | 9 |
| Table 2.2 | Summarized characteristics of different innovator types | 13 |
| Table 3.1 | Percentage distribution of feedback on questionnaire (QE1) | 34 |
| Table 3.2 | Technological innovation risk factors in the literature | 39 |
| Table 3.3 | Technological innovation risk factors identified from the industry | 41 |
| Table 3.4 | Risk factors and corresponding root causes of technological innovations | 49 |
| Table 4.1 | Inter-connections of innovation concepts | 81 |
| Table 4.2 | Hypothesis test summary related to business model innovation concept | 85 |
| Table 4.3 | Hypothesis test summary of Kruskal-Wallis test results | 86 |
| Table 4.4 | Core innovation concepts related to main phases of innovation process | 87 |
| Table 4.5 | Refined list of risk factors related to technological innovations | 87 |
| Table 4.6 | Risk factors and corresponding root causes of technological innovations | 89 |
| Table 4.7 | Summary of the neural network configurations used to determine innovator type of the organization | 94 |
| Table 4.8 | Summary of the network parameters | 95 |
| Table 4.9 | Priorities of risk factors related to different innovator types using ANP | 97 |
| Table 4.10 | Alternative suggestions to form teams for the Pitch-making meeting | 105 |

LIST OF ABBREVIATIONS

| Abbreviation | Description |
|--------------|--|
| A | Alternatives |
| AHP | Analytic Hierarchy Process |
| AI | Artificial Intelligence |
| ANP | Analytic Network Process |
| ANN | Artificial Neural Network |
| ASQ | After Scenario Questionnaire |
| BGT | Behavioural Game Theory |
| C | Clusters |
| CATPCA | Categorical Principle Component Analysis |
| CGT | Co-operative Game Theory |
| CI | Consistency Index |
| CR | Consistency Ratio |
| ELM | Extreme Learning Machine |
| FFNN | Feed Forward Neural Network |
| FMEA | Failure Mode and Effect Analysis |
| HR | Human Resources |
| HCI | Human-Computer Interaction |
| HRM | Human Resource Management |
| IP | Intellectual Property |
| IS | Information Systems |
| KNN | K- Nearest Neighbour |
| MCDM | Multi-Criteria Decision Making |
| N | Nodes |
| NDA | Non-Disclosure Agreement |
| NCGT | Non-Corporative Game Theory |
| NLPCA | Non Linear Principle Component Analysis |

| | |
|-------|---|
| PCA | Principle Component Analysis |
| PSSUQ | Post-Study System Usability Questionnaire |
| RBM | Random Boltzmann Machine |
| RBN | Radial Basis Network |
| RCA | Root Cause Analysis |
| RCASE | Root Cause Analysis Solver Engine |
| R&D | Research and Development |
| RCI | Random Consistency Index |
| SDS | Super Decision Software |
| SVM | Support Vector Machine |
| SUS | System Usability Scale |
| TAM | Technology Acceptance Model |
| UMUX | Usability Metric for User experience |
| Wrt | With respect to |

LIST OF APPENDICES

| Appendix | Description | Page |
|--------------|--|------|
| Appendix - A | Questionnaire (QE1) to validate the consistency of the classification | 144 |
| Appendix - B | Summary of Normality tests on feedback of QE1 Summary of Hypothesis test on feedback of QE1 | 148 |
| Appendix - C | Questionnaire (QE2) assesses the industry's willingness to share information on core innovation concepts | 158 |
| Appendix - D | Questionnaire (QE3) – To validate the consistency of risk factor classification | 160 |
| Appendix - E | Questionnaire (QE4) – To gather reasons behind the occurrence of risk factors of technological innovations | 162 |
| Appendix - F | Questionnaire (QE5) – To obtain input data to the FFNN in assessing the innovator type of the organization | 164 |
| Appendix - G | Data Visualization | 181 |
| Appendix - H | Neural network architectures Risk factor interdependencies | 194 |
| Appendix - I | | 199 |
| Appendix - J | Abbreviations of Figure 3.10 Questionnaire (QE6), To obtain feedback for pairwise comparisons | 200 |
| Appendix - K | User Guide | 203 |
| Appendix - L | System Usability Scale | 240 |