AN INTEGRATED APPROACH FOR RISK MANAGEMENT IN NEW PRODUCT DEVELOPMENT PROCESS

DOCTOR OF PHILOSOPHY (Ph.D.)
THESIS

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नव उत्पाद विकास प्रक्रिया में जोखिम प्रबंधन के लिए एक एकीकृत दृष्टिकोण

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A THESIS ON

An Integrated Approach for Risk Management in New Product Development Process

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CERTIFICATE

This is to certify that the thesis entitled **"An Integrated Approach for Risk Management in New Product Development Process"** being submitted by **Mr. Avanish Singh Chauhan (2014RME9033)** to the Malaviya National Institute of Technology Jaipur in fulfilment of the requirements for the award of the degree of **Doctor of Philosophy (Ph.D.)** in **Industrial Engineering (Mechanical Engineering)** is a bonafide record of original research work carried out by him under our supervision and guidance. He has fulfilled the requirements for the submission of this thesis, which has reached the requisite standard. The results contained in this thesis have not been submitted anywhere else for award of any other degree or diploma.

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ABSTRACT

New products are major sources of competitive advantage and success for most of the manufacturing enterprises. Research indicates that not all new product development (NPD) initiatives result into a successful product, therefore, a cause for major wasted resource. NPD processes are getting increasingly complex due to today's globalized market and customers' desire for technologically advanced products. This complexity comes along with added risks in the NPD process, in terms of both number and severity, making it more risky and costly. The NPD projects may cause deployment of large amount of an organization's time and capital towards failed initiatives. Since the failure costs could be very high depending upon the nature of a product, organizations cannot continue with NPD projects which are prone to risks; therefore, it becomes a primary area of concern for the firms to minimize the amount of risks inherent in the NPD process. The risk factors occurring in the NPD process need to be pre-emptively recognized at an early stage of NPD process. This should also be coupled with development of a risk management plan to minimize the impact of the risk factors on the overall NPD process.

In this research study, an empirical investigation is conducted to explore various risk factors prevalent in the NPD process, and a comprehensive risk taxonomy is established. Factor analysis techniques are utilised for analysing thirty-five risk factors identified from literature, and these risk factors are classified into seven underlying risk dimensions. The developed taxonomy might act as a reference model for identifying risks prevalent in NPD initiatives in various organizations. The identified risk factors are further modelled into an interpretive structural framework for analysing the inter-dependency between them. It helps in identification of driving risk factors and in understanding the domino effect (influence of one factor on another) in the risk factors. Once the critical risk factors are identified, they are assessed for quantifying the criticality of the risks. A risk evaluation method is developed for quantification of risk factors based on fuzzy approach. The applicability of the prescribed fuzzy risk

evaluation method (FREM) is demonstrated to determine the risk degree for the previously identified critical risk factors in the case of automotive new product development process. The risks are then statistically categorized into four priority groups using k-means clustering technique and normative risk alleviation plan is suggested for dealing with different category of risks. A framework for selecting the appropriate risk mitigation strategy weighing in the selection parameters like cost and effectiveness of the actions in response to risk factors is suggested. This framework presents an approach for choosing favourable mitigation actions for eliminating or reducing the adverse effects of the risks prevalent in NPD process. It provides an empirical model for prioritizing the risk mitigation actions. The suggested framework is illustrated using a case of automotive industry.

Finally, an integrated risk management model for NPD process is presented based on the findings of this study for the implementation of risk management practices in NPD process. The integrated model consolidates the various approaches and techniques used in this work for management of risks prevalent in NPD process. The integrated model developed in this study finds its application in comprehensive analysis of risks occurring in the development process of a product in an organization; and helps in making appropriate decisions to tackle these risks efficiently in a timely manner for ensuring the success of new product development process and project.

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LIST OF ABBREVIATIONS

AGFI	Adjusted Goodness of Fit Index
AHP	Analytical Hierarchical Process
ANP	Analytical Network Process
ANPD	Automotive New Product Development
CFA	Confirmatory Factor Analysis
CFI	Comparative Fit Index
CMIN/DF	Chi-Square / Degree of Freedom
EFA	Exploratory Factor Analysis
FMCG	Fast Moving Consumer Goods
FMEA	Failure Mode and Effects Analysis
FREM	Fuzzy Risk Evaluation Method
GFI	Goodness of Fit Index
ISM	Interpretive Structural Modeling
ISO	International Organization for Standardization
MICMAC	Cross-Impact Matrix Multiplication Applied to Classification
NPD	New Product Development
NPDRM	New Product Development Risk Management
PCA	Principal Components Analysis
PRA	Probabilistic Risk Management
QFD	Quality Function Deployment
R&D	Research and Development
RD	Risk Degree
RMI	Risk Mitigation Index
RMP	Risk Mitigation Potential
RMSEA	Root Mean Square Error of Approximation
RMSR	Root Mean Square Residual
SD	Standard Deviation
SEM	Structural Equation Modeling
SSIM	Structural Self Interaction Matrix

Chapter 1

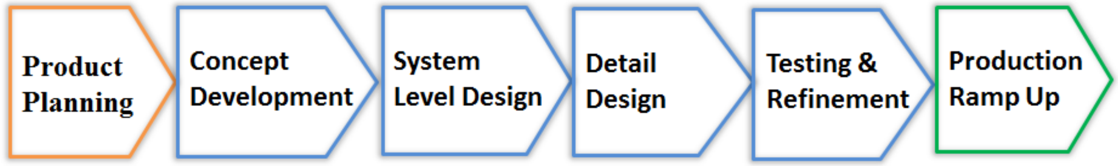
INTRODUCTION

1.1 New Product Development Process

The new product development (NPD) process involves "sequence of steps and activities which an enterprise employs to conceive, design, and commercialize a product" (Ulrich et al., 2009, p. 13). The purpose of NPD is defined as "transformation of a market opportunity and a set of assumptions about product technology into a product available for sale" by Krishnan and Ulrich (2001, p. 1). Many of the NPD steps and activities are organizational and intellectual rather than physical. NPD processes are organized in a way that requires participation by virtually all the major functional departments within the organization such as strategic planning, marketing, product design, manufacturing and financial planning. It also involves interactions with stakeholders such as customers and suppliers that are outside of the organization.

According to Ulrich et al. (2009), a generic product development process can be divided into six phases as shown in Figure 1.1.

Figure 1.1: Generic product development process



Phase 0: Planning activity is often referred to as 'phase zero' as it precedes the project approval and launch of the actual product development process. This phase begins with corporate strategy and includes assessment of technology developments and market objectives. The output of planning phase is the project mission statement, which specifies the target market, business goals, key assumptions, and constraints.

Phase 1: Concept development phase consists of generation and evaluation of alternative product concepts addressing the needs of the target market. A concept is a description of form, function, and features of a product accompanied by a set of specifications, and competitive and financial analysis.

Phase 2: System-level design phase includes the definition of the product architecture and the decomposition of product into sub-systems and components. The final assembly scheme for the production system is usually defined in this phase.

Phase 3: Detail design phase includes the complete specifications of the shape, size, geometry, and tolerances of all the unique parts of the product and the identification of standard parts to be purchased from suppliers. The critical issues of production cost and robust performance are addressed in this phase.

Phase 4: Testing and refinement phase involves the construction and testing of multiple prototypes of the product. The prototypes are tested and refinements are done to make better quality product best suited for consumer needs.

Phase 5: Production ramp-up phase is the final phase of product manufacturing where the actual product is made using the intended production system. The purpose of the ramp-up is to train the workforce and to work out any remaining problems in the production process.

In this study, a four-tier NPD process is considered having four phases namely: concept development, technical design and development, prototyping and testing, and commercialization.

The business processes are getting intensively competitive in this globalised market owing to evolving consumer needs along with rapid advancements in technologies. An organisation needs to develop new promising products catering the evolving needs of customers. The growing consumer expectations are demanding for better products in shorter time, leaving no room for error in an organisation's NPD process. It is widely agreed by researchers that the firms which are capable of delivering new products according to the changing consumer needs are more likely to succeed than those firms, which do not investing time and capital in NPD initiatives (Brown and Eisenhardt, 1995; Poolton and Barclay, 1998; Yadav et al., 2007). Customer demand is rapidly changing in today's turbulent environment, and organisations must be responsive to meet these changes (Singh and Garg, 2015). It is imperative for organisations to strengthen their product development capabilities and develop successful new products catering the evolving needs of consumers. NPD is one of the most crucial processes for business success of organizations, especially for the enterprises competing in markets susceptible to fast product changes (Yadav et al., 2007).

1.2 Motivation for Research:

In today's globalized and highly competitive market, new products are the major source of competitive advantage and success for an organization (Guo, 2008; Yadav et al., 2007; Oehmen et al., 2014). The products and processes in NPD are getting more and more complex and this complexity comes along with added risks in the process, in terms of both number and severity, making the process more risky and costly (Mu et al., 2009; Marmier et al., 2014). The NPD projects may cause wastage of large amount of organization's time and capital towards failed initiatives (Kardes et al., 2013). With the advancements in technologies and consumer needs, the risks and uncertainties in the NPD process also increase.

The motivation of this research comes from the existence of unsuccessful NPD projects in organizations as a result of poor judgment in weighing the risks involved in the development process, and under-utilization of risk management tools for integrated analysis and assessment of risks. Prior research shows that, on a global level, around 80% of the NPD projects fail even before completion; and the developed products from more than half of remaining 20% successful projects fail to return investment (Cooper, 2003; Ahn et al., 2008). More recently, battery failure for its Dreamliner aircraft caused an overage of billions of dollars and delayed the completion by three years for Boeing (Denning, 2013). Similar kind of cases are reported in NPD projects of many products including warfighters

(Kardes et al., 2013), software-based products (Oehmen et al., 2014) and automobiles (Salavati et al., 2016).

1.3 Research Objectives:

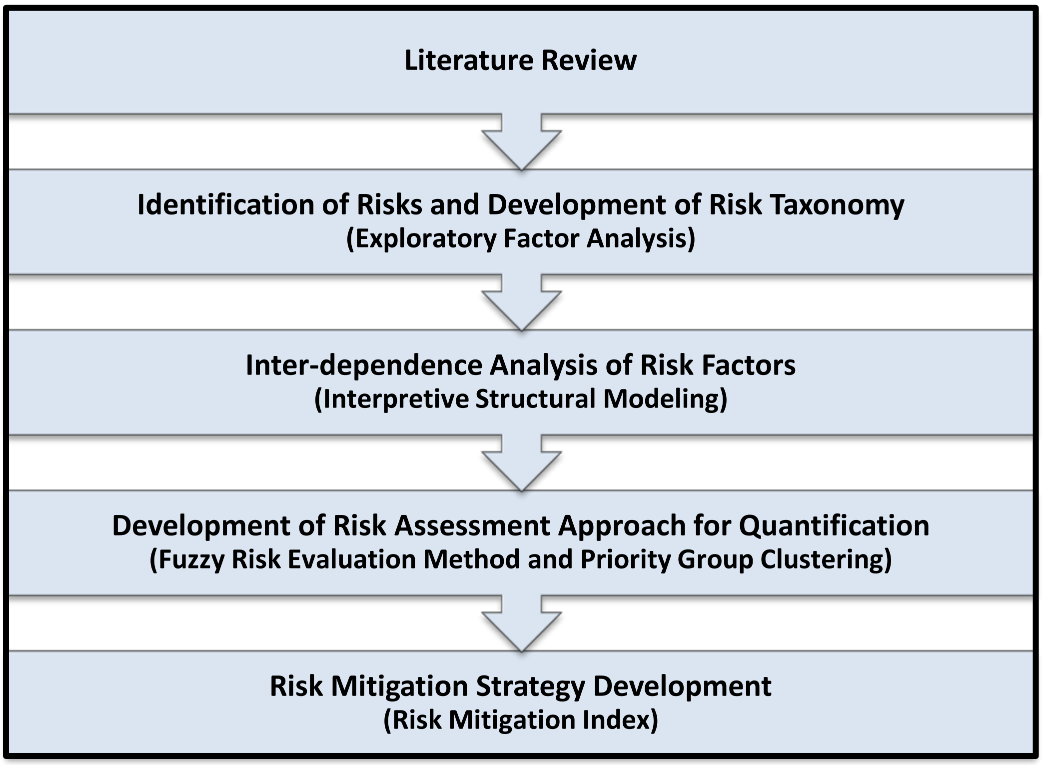
The objectives of this research are formulated as follows:

- ❑ Development of Risk Taxonomy for NPD Process.
- ❑ Inter-dependency Analysis of Risk Factors in NPD Process.
- ❑ Development of Risk Assessment Approach and Risk Mitigation Strategy for NPD Process.
- ❑ Establishment of an Integrated Model for Risk Management in NPD Process.

1.4 Research Methodology:

Various steps of the **research methodology** adopted for achieving the above mentioned objectives are depicted in Figure 1.2 below.

Figure 1.2: Schematic representation of research methodology



1.5 Structure of the Thesis

This thesis is structured into seven chapters as described below:

Chapter 1- Introduction: This research work commences with providing an introduction to the work and discusses the theoretical foundations of the research. The fundamentals of NPD process are discussed along with existence of inherent risks in the process, and the motivation for this research work is provided. This chapter describes the research objectives and the research methodology followed for achieving the objectives.

Chapter 2- Literature Review: In this chapter, the existing knowledge base on risk management in the NPD process is consolidated and classified based on different schemes. It analyses the contemporary NPD risk analysis research on three fronts: risk identification, risk assessment, and risk mitigation. Based on the review, implications for researchers and engineering managers are provided along with research gaps and keys areas for further research.

Chapter 3- Risk Identification and Taxonomy Development: This chapter provides a comprehensive study of different risks existing in new product development process in any organisation. Various risk factors are extracted from literature to conduct empirical investigation in Indian automotive industry, and structured risk taxonomy is established.

Chapter 4- Risk Inter-dependency Analysis: In this chapter, risks influencing the NPD process have been structured into an integrated interpretive structural model (ISM) to analyse the interactions between the risks.

Chapter 5- Risk Assessment Approach: In this chapter, a risk evaluation method is developed for quantification of risk factors based on fuzzy approach. The approach is demonstrated using a case of automotive industry where the identified critical risk factors are quantitatively prioritized and clustered into priority groups.

Chapter 6- Risk Mitigation Strategy: This chapter puts forward a framework for prioritizing the risk mitigation actions weighing in the selection parameters like cost and effectiveness of the actions in response to risk factors. This approach provides an empirical model for prioritizing the risk mitigation actions. The effectiveness of proposed model is demonstrated using a case of automotive industry.

Chapter 7- Discussion and Conclusion: An integrated risk management model for NPD process is established in this chapter based on the findings of this study. This chapter presents the summary of the research work along with limitations of the study and scope for future research.

Chapter 2
LITERATURE REVIEW

In order to formulate an answer to any research question, a literature review is of significant importance for gathering in-depth information on the topic so that a better understanding of the problem can be achieved and more importantly the research question(s) formulated can be justified. Literature review is the basis for any study and contributes to the formulation of answers to the proposed research questions (Cooper and Schindler, 2008). Thus, a systematic literature review has been carried out to examine the state of risk management research in NPD process. While there has been a significant interest in academia about the new product development risks, the existing literature is spread across multiple outlets making it very difficult for any practitioner or researcher to synthesize the current work. This chapter aims to minimize that gap by providing a comprehensive overview of current research activities in the field of risk management in NPD process in one place.

2.1 Introduction

The NPD process is acknowledged by both academia and industrial practitioners as one of the most critical areas of a firm's competence as new products play a pivotal role in success of any business organization (Yadav et al., 2007; Guo, 2008). Rapidly growing technological advancements and rising consumer expectations are demanding for new and improved consumer products, making NPD the nexus of competition. In today's globalized and highly competitive market, firms which can develop new and exciting products are more likely to succeed than their peers. This makes NPD activities the most vital process for survival and renewal of firms, particularly for those which are competing in the markets that are prone to rapid changes.

Engineering managers are faced with enormous challenges in managing large NPD projects due to a lack of historical data and uncertain nature of the globalized marketplace. More specifically, new product development activities are both risky and expensive due to the large amount of research and development budget that can be wasted because of failed new product initiatives (Oehmen et al., 2014). Research shows that, on a global level, around 80% of the NPD projects fail even before completion; and the developed products from more than half of remaining 20% successful projects fail to return investment (Cooper, 2003; Ahn et al., 2008). More recently, battery failure for its Dreamliner aircraft caused an overage of billions of dollars and delayed the completion by three years for the Boeing company (Denning, 2013). Similar kind of cases are reported in NPD projects of many products including warfighters (Kardes et al., 2013), software-based products (Oehmen et al., 2014), and automobiles (Salavati et al., 2016). As per a report by the US government accountability office, "due to the extensive amount of testing of aircraft concepts and alteration of manufacturing processes for F-35 jet, an additional $289 million dollars were allocated for the project which require another couple of years to complete its first production" (Akram and Pilbeam, 2015, pp. 1).

As mentioned earlier, developing new products is much more challenging than introducing simple product line extensions, therefore, calls for the need to better manage the risks involved in the NPD process. Connell et al. (2001), based on their study of various successful and failed NPD initiatives, advised to assess technical and market risks, and then design appropriate mitigation strategies for ensuring a successful NPD project. Salavati et al. (2016) suggested that if organizations can improve their knowledge base regarding risks and major factors which can jeopardize the success of NPD process, they could work more efficiently and also increase their ability to predict future glitches that may affect NPD process performance. Since the failure costs could be very high depending upon the nature of a product, organizations cannot continue with NPD projects which are prone to risks; therefore, it becomes a primary area of concern for the firms to minimize the amount of risks inherent in the NPD process. Hence, risk management plays a major role in enabling the success of the product development process in an organization (Mu et al., 2009; Bharathy and McShane, 2014; Oehmen et al., 2014). In other words, risk factors occurring during the NPD process need to be pre-emptively recognized at early stage of NPD process. This should also be coupled with development of a risk management plan to minimize the impact of the risk factors on the overall NPD process (Ahn et al., 2008; Marmier et al., 2014). It is rightly stated by Bahill and Smith (2009, p.1) that "good risk management will not prevent bad things from happening, but when bad things happen, good risk management will have anticipated them and will reduce their negative effects".

Interestingly, although it is widely agreed (Mu et al., 2009; Oehmen et al., 2014; Salavati et al. 2016) in the existing NPD literature that understanding and managing risks in NPD process is an important contributing factor towards success of an organization and its products, there have been very few attempts in consolidating the prior works in one place in a timely manner (Oehmen et al., 2006; Ahmed et al., 2007; Segismundo and Miguel, 2008a; Oehmen et al., 2010). Providing a timely and comprehensive analysis of prior works can not only help disseminate the existing domain knowledge but also facilitate the future research in this growing field, especially due to the advancement of the technologies coupled with globalized competition. Therefore, the main objective of this chapter is to perform a comprehensive review of scholarly articles on new product development risk management (NPDRM) to identify the current trends/gaps and future research directions. The unique contributions of this chapter are as follows: a) Mapping of existing literature on risk management in the new product development process to identify current trends; b) examination of contemporary risk management tools applied to the NPD process on three fronts: risk identification, risk assessment, and risk mitigation; c) identification of any notable gaps, and potential avenues for future research; and d) development of an integrated conceptual framework for risk management in NPD process.

The remainder of the chapter is organized as follows. The next section on 'research design' illustrates the methodology undertaken to fulfil the review task. The following section 'mapping the existing body of knowledge' deals with reviewing the existing literature on NPDRM and classifying the work based on multiple schemes. The key findings of the review along with implications for future research are discussed in the next section. In the subsequent section, a ‘conceptual framework for risk management in NPD process’ is presented. Implications of this research for engineering managers and practitioners are provided in the penultimate section after the conceptual framework. Finally, the last section concludes the chapter by providing the final thoughts.

2.2 Research Design for Review

The central objective of this chapter is to contribute to the body of knowledge on managing risks in the NPD process, by means of review and classification of existing risk analysis and management methods in NPD process. The research methodology for conducting the literature review is based on mapping of the published literature relevant to NPDRM, thereby identifying current trends and directions for future research. Furthermore, research design also consists of both research-based classification and content-based classification of existing literature.

2.2.1 Data Collection

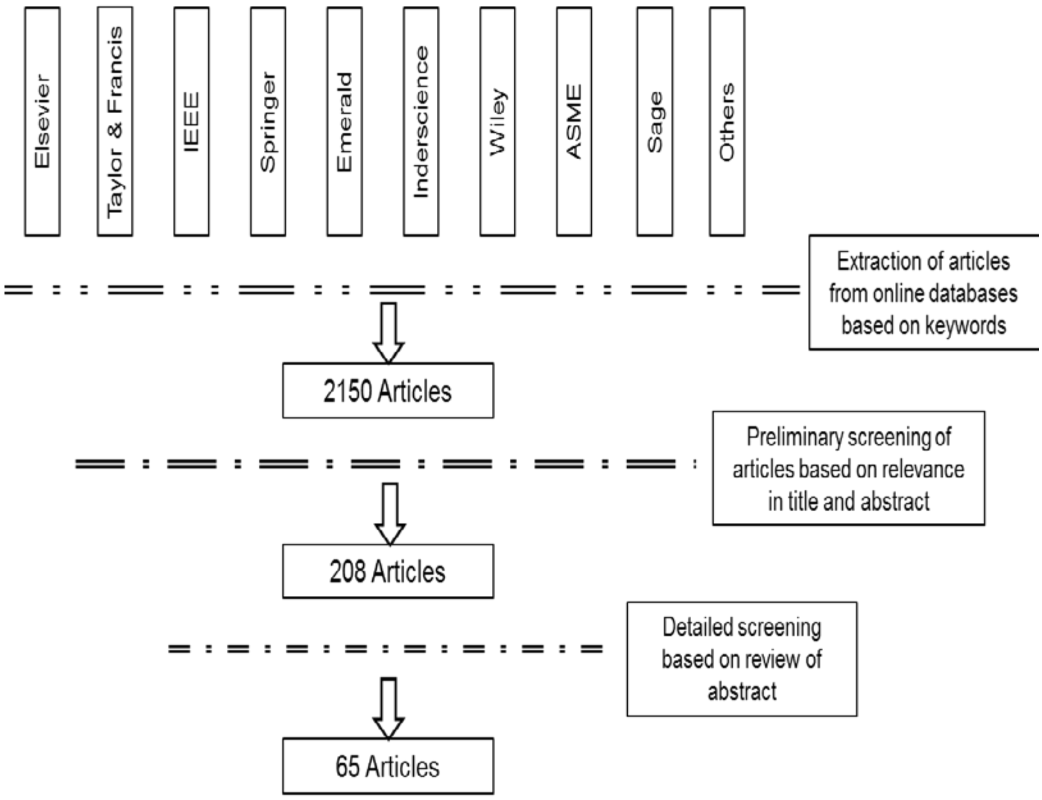
The electronic databases of major peer-reviewed engineering and management publishers (Elsevier, Taylor and Francis, IEEE, Springer, Emerald, Inderscience, Wiley, ASME, Sage) are searched for articles related to the research area. The relevant articles are extracted using the keywords (as shown in Table 2.1) representing the main constructs ‘New Product Development’, ‘Risk’, and ‘Management’. The search strings are created using these constructs such that the results would be broad enough to cover a wide range of prior research works and yet allows minimizing the selection of unnecessary or irrelevant materials (Duff, 1996; Sarka and Ipsen, 2017).

Table 2.1: Keywords used for searching articles

S. No.	Constructs	Keywords
1	Risk	Risk; Threat; Challenge; Barrier; Issue
2	Management	Management; Identification; Prioritization; Monitoring; Assessment; Evaluation; Quantification; Planning; Control; Mitigation; Treatment
3	New Product Development	(New) Product Development; (New) Product Design; (New) Product Launch; (New) Product Introduction; Innovation

As expected, the initial search based on keywords resulted in a large number of articles (over two thousands). In the next stage, these initial articles are then carefully reviewed based on their title and abstract to determine the actual relevance of an article to NPD risk management domain. It should be noted that the focus of this study is to examine the NPD process risks (related to execution of the NPD process), not the product risks (related to functional requirements of the product) in the fields like medical, health, energy, environment, etc. Therefore, the papers focusing on non-process risks are excluded from the detailed review. Likewise, the articles discussing risks in projects like construction (not related to the new product development process) are also excluded from this study. In other words, only those articles that are explicitly discussing risks in the new product development process were selected for detailed study. Figure 2.1 provides a graphical illustration of the scrutiny procedure followed for selection of relevant articles for review.

Figure 2.1: Scrutiny process for selection of articles



2.2.2 Data Analysis

The contents of each of the finally selected articles are explored and recorded in a spread sheet by organizing under various categories. The categorization of articles is done based on different classes, such as research type, industrial sector, geographical location, type of publication, and year of publication to identify the existing trends of research in the area of NPDRM. Also, articles are classified based on the risk management aspect (risk identification, risk assessment, and risk mitigation) and the tools/techniques used in the articles for managing risks in the NPD process. Various methods are employed by different researchers and practitioners for identification, assessment, and mitigation of the risks and are discussed in the later section of this chapter. The above described content analysis is categorised into two classification schemes (adapted from Badhotiya et al., 2016):

Research-based Classification: The articles are classified according to the research approach employed in the articles based on six constructs – year, publishing outlet, publication type, research method, industrial sector, and country.

Content-based Classification: The articles are categorised as per the risk management issue (identification, assessment, and mitigation) addressed in the article.

2.3 Mapping the Existing Body of Knowledge

After the second phase of screening (as shown in Figure 2.1), a total of sixty-five articles are selected for the comprehensive review. These articles are explored in order to determine various trends in the research on NPDRM.

One of the earliest review articles published in the extant literature on NPD risk management by Oehmen et al. (2006) organized the prior works on risks in lean product development by industry type. Authors provided a general risk management process model for NPD process and product risks. Savci and Kayis (2006) reviewed the methods for knowledge elicitation to identify risks encompassing concurrent engineering new product development process. The paper discusses several techniques related to extraction and compilation of the knowledge, such as brainstorming, expert interviews, Delphi technique, benchmarking, lessons learnt, reasoning, analogy process, and decision trees.

Ahmed et al. (2007) consolidated various risk management techniques in concurrent engineering product development projects. They provided an overview of the techniques for context establishment, identification, assessment, and treatment of risks. Segismundo and Miguel (2008a) mapped the erstwhile articles related to NPDRM to classify them according to focus and approach along with application area. Their study tabulated the findings to discuss distribution of the articles and concluded that most of the research in the area is generalised and not focussing on particular application areas. Oehmen et al. (2010) reviewed literature on risk management in product design. The authors explored the ISO 31000 risk management standard and guidelines; and identified various techniques used by past researchers for managing risks in product development.

In this review, the selected sixty-five articles are explored to discover the trends in the research area of NPDRM. Two classification schemes, research-based classification and content-based classification, are employed to organise the articles into different categories and inferences are drawn.

2.3.1 Research-based Classification

This section of the chapter discusses the research-based classification scheme for the selected articles and provides detailed insight into the history and research trends of NPDRM subject area. The classification of articles is done according to the classes described below.

Year of Publication: The yearly distribution of articles shows an increasing trend in the quantity of published articles in the fields of NPD risk analysis and management over the past several years. It helps in understanding the importance and evolution of NPDRM as a research agenda over the past years. Figure 2.2 illustrates the classification of articles on the basis of year of publication.

Figure 2.2(a): Distribution of articles over the years (N=65)

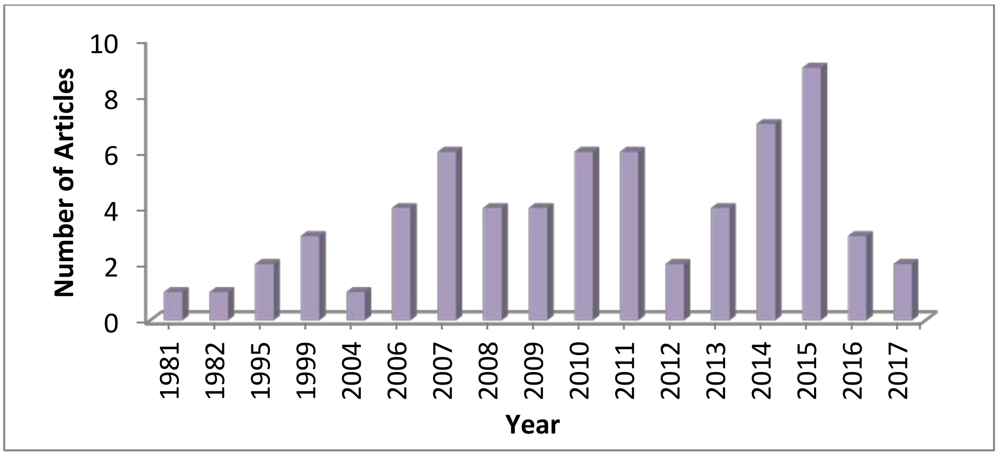
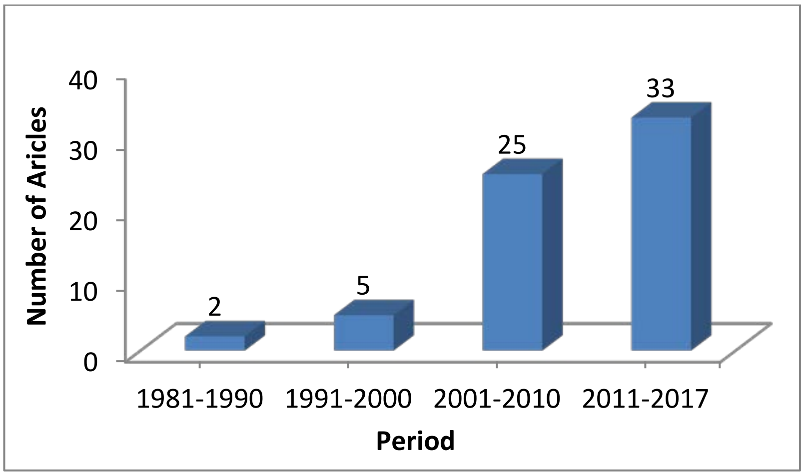


Figure 2.2(b): Growth of articles over last four decades (N=65)



The first research article dealing with the risks in the NPD process dates back to 1981. Since then, an increasing trend is seen over the past four decades with more than 50% of the articles being published after 2010. The reviews by Segismundo and Miguel (2008a) and Oehmen et al. (2010) showed the concerns that the risk management scenario in NPD process is not well developed and there is a dearth of studies on ‘risks in NPD’. Mu et al. (2009) highlighted the importance of risk management in NPD and the improvement in odds of NPD success by implementing risk management strategies. These studies published in late 2000s might have paved the way for increasing scholarly work in this field in the current decade.

Publishing Outlets and Type of Publication: Figure 2.3 provides the distribution of articles on NPDRM according to different scientific publishers. It can be observed that the publisher with the most articles in this field is *Elsevier* followed by *Taylor and Francis*. The distribution of research articles based on the type of publication is shown in Figure 2.4.

Figure 2.3: Distribution of articles across publishers (N=65)

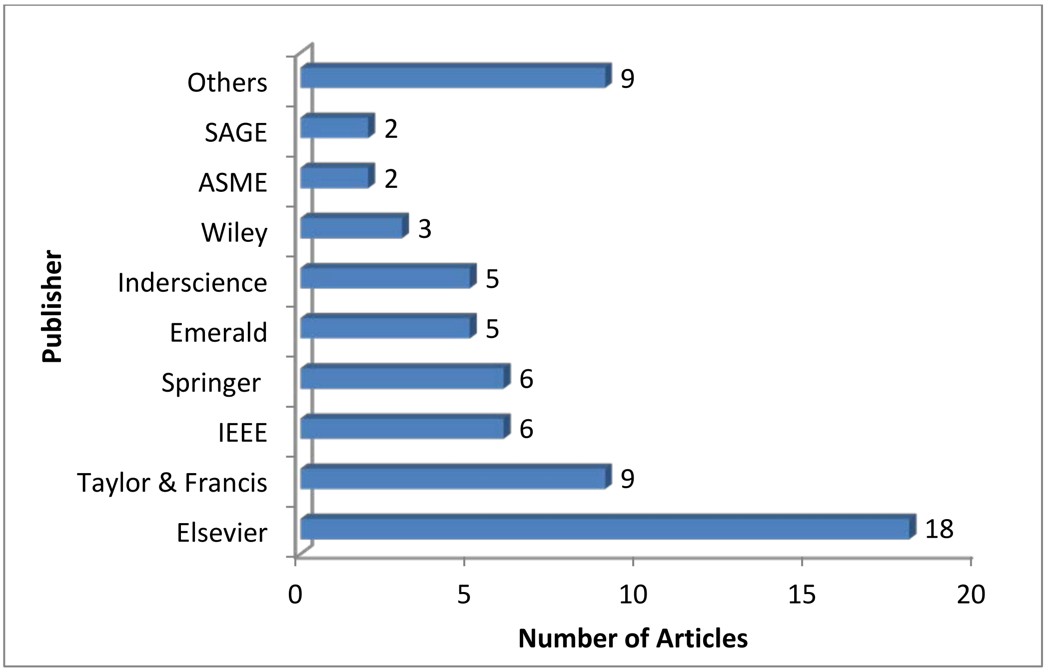
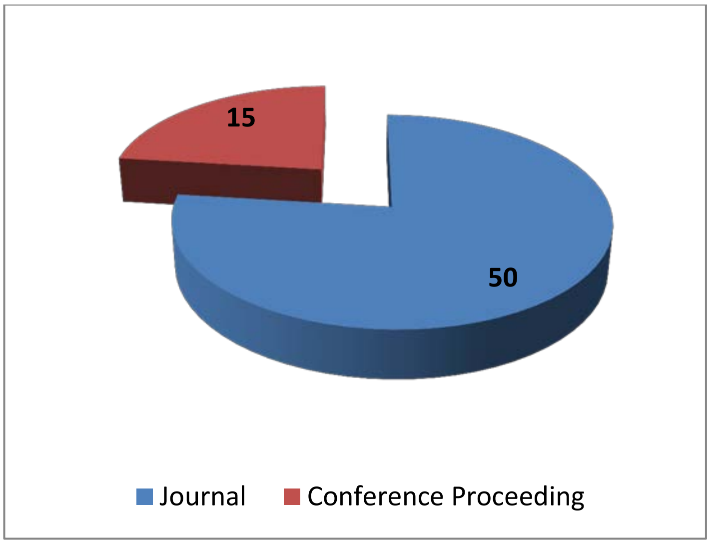


Figure 2.4: Division of articles based on type of publication (N=65)



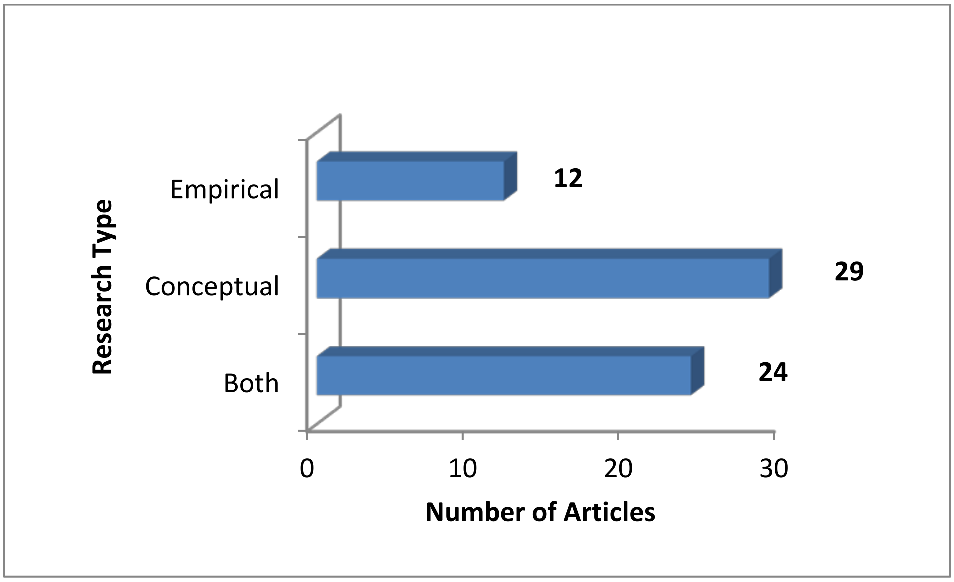
Journal publications form the major part (more than 75%) of articles database on NPDRM; but the contribution of conference proceedings (about 25%) in generating research articles in the field of NPDRM cannot be ignored. Given the importance of the research area, there appears a need for more conferences focussing on risk management in the NPD process to motivate researchers towards this field. The leading conference proceedings consisting two or more articles on this area are: *Procedia CIRP (Elsevier)*, *International Conference on Industrial Engineering and Systems Management (IEEE)*, and *International Design Engineering Technical Conferences (ASME)*. The fifty identified journal articles on NPDRM are spread over thirty-nine different journals, comprising of twenty engineering-related and nineteen management-related journals, which shows that this research area is equally appreciated in both engineering as well as management fields. Table 2.2 lists the leading journals that have published two or more articles belonging to this research domain.

Table 2.2: Leading journals in NPDRM research domain

S. No.	Journal	Publisher	Frequency
1	Expert Systems with Applications	Elsevier	4
2	Engineering Management Journal	Taylor and Francis	2
3	International Journal of Production Research	Taylor and Francis	2
4	Research-Technology Management	Taylor and Francis	2
5	International Journal of Management Science and Engineering Management	Taylor and Francis	2
6	Technovation	Elsevier	2
7	CIRP Annals-Manufacturing Technology	Elsevier	2
8	Computers and Industrial Engineering	Elsevier	2
9	Concurrent Engineering	Sage	2
10	International Journal of Business Continuity and Risk Management	Inderscience	2

Research Method: Researchers used different research methodologies, which can be classified broadly into conceptual and empirical studies. Conceptual methods are primarily desk-based research consisting of reviews, structural models, mathematical models; whereas empirical methods consists of surveys, case studies, interviews, action research. The distribution of articles based on the research method employed is shown in Figure 2.5.

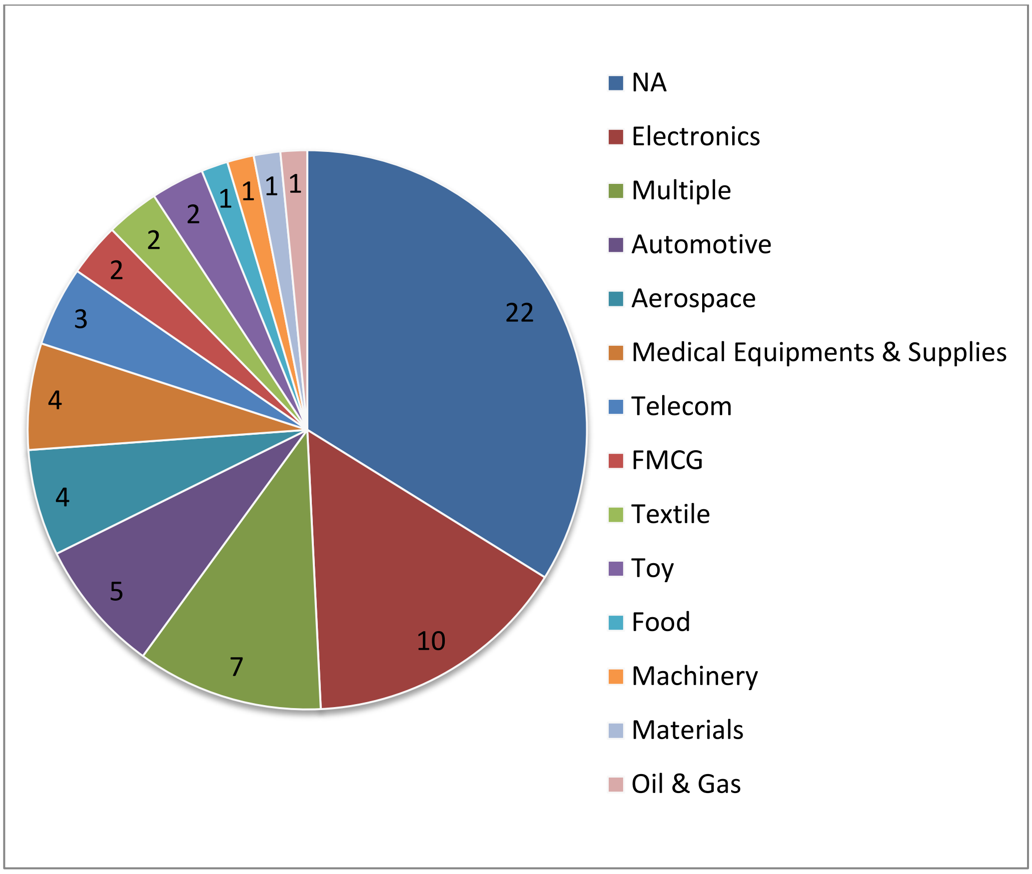
Figure 2.5: Distribution of articles based on research method (N=65)



It can be observed from Figure 2.5 that conceptual research studies form the base of most of the articles, either standalone (45%) or in conjunction with empirical methods (37%). The reason for most of the prior work being conceptual can be attributed to the ease of study; since collecting large data (surveys/interviews) for complex industrial processes is an arduous and time-taking task requiring more amounts of resources. There is a need for more studies supported by empirical findings as NPD has more of a practical outlook rather than desk based study. Empirical research based on the findings in an industrial scenario would yield in more realistic results and allow for an improved understanding of the research area.

Industrial Sector: Research in the field of NPDRM is not confined to any specific industry and applications can be found across wide range of industries. This criterion of classification identifies the sectors receiving more importance from the researchers as well as pointing out the industry segments receiving low attention from researchers and practitioners in the area of NPDRM. Figure 2.6 shows the distribution of articles according to industrial sectors.

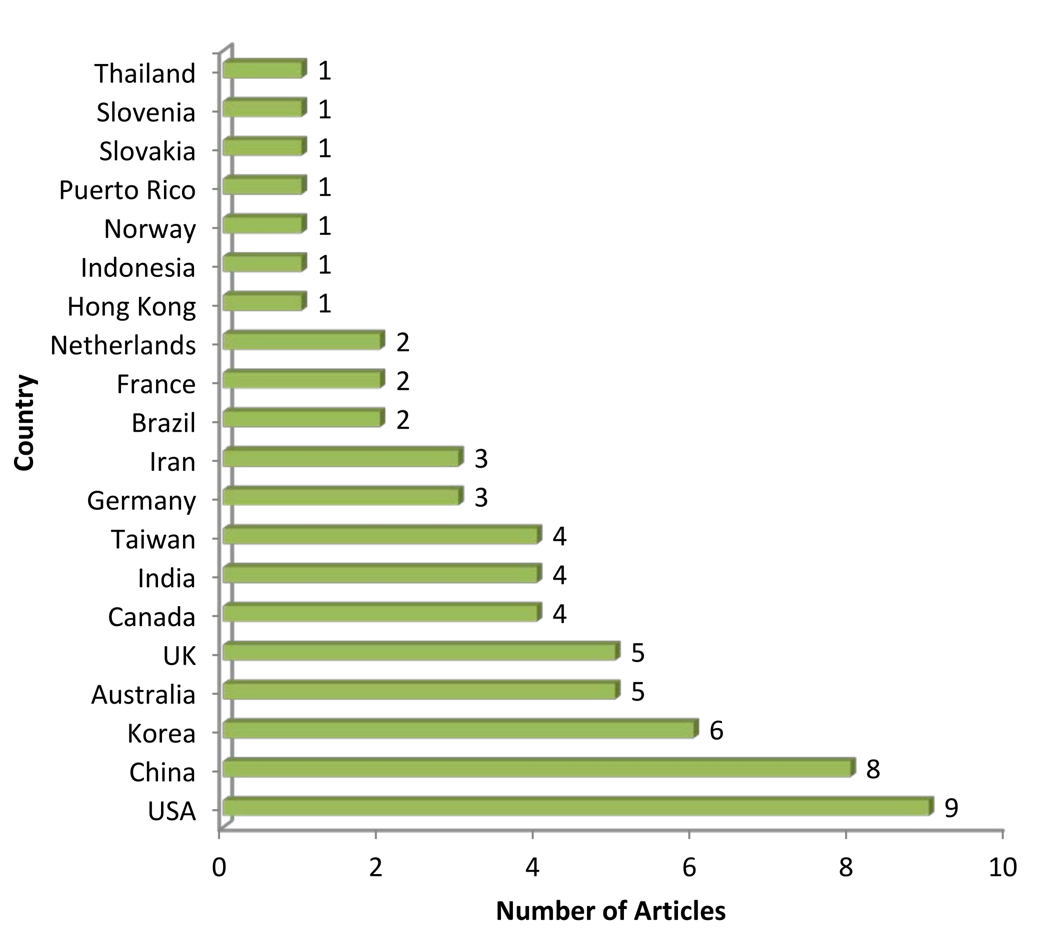
Figure 2.6: Distribution of articles based on industrial sector (N=65)



The majority of papers (34%) were focussed on conceptual or mathematical models, and did not associate with a particular industry; such articles are labelled under 'not available' (NA) category. This was acknowledged by Segismundo and Miguel (2008a) as well, that half of the studies in their review did not touch upon a specific area of application. The lack of implementation of research in various industries motivates towards carrying out more empirical studies in such industries. On the other hand, there are some papers (11%) having a multi-industry study; they were categorised under the 'multiple' category. The highest share of research is found to be applied in 'electronics' industry (15%) followed by 'automotive' (8%). Both 'aerospace' and 'medical equipment and supplies' industry have 6% each share of articles. It can be inferred that most of the focus is in electronics, aerospace, automotive, and medical equipment industry because: a) they are complex products, and b) they have distributed supply chains spanning across the globes that makes their NPD processes increasingly complex and risky.

Geographical Distribution: The researchers contributing in the field of NPDRM are not confined to only a few countries and are spread across the globe. Figure 2.7 shows the distribution of articles based on the originating location of the articles. Major contributions are given by researchers based in United States of America (14%) followed by China (12%) and Korea (9%). Additionally, it was observed that eleven articles (17%) are co-authored by researchers belonging to organizations and institutes located in different countries showing a growing trend of collaborative research.

Figure 2.7: Geographical distribution of articles (N=65)



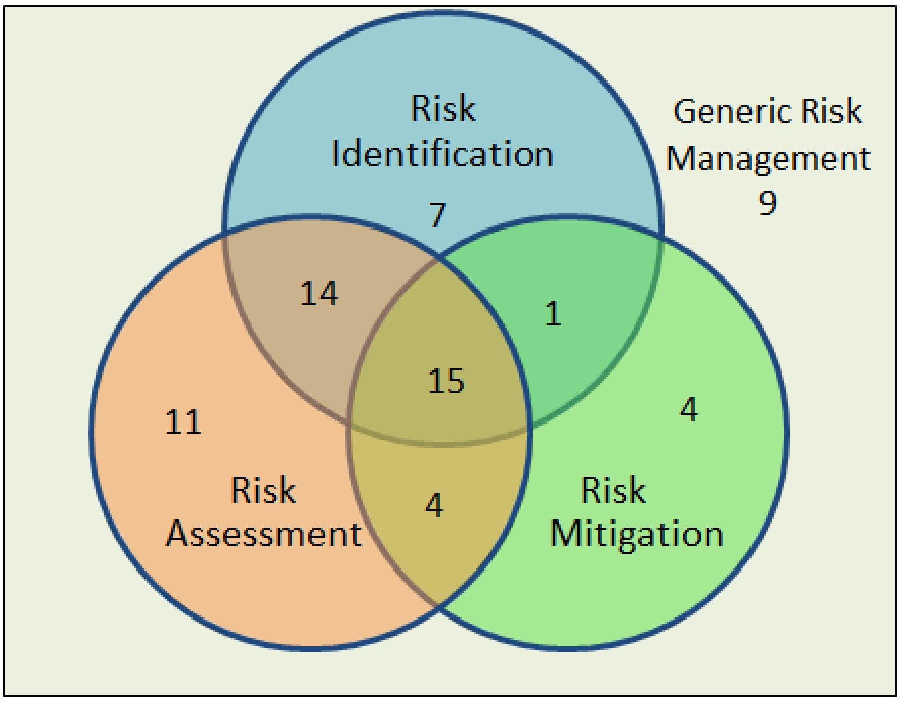
2.3.2 Content-based Classification

The risk management system for NPD process in an enterprise can be differentiated into three aspects, namely identification, assessment, and mitigation (Kimbrough and Componation, 2009; Prakash et al., 2017). The risk identification step involves generating the list of various risks encompassing the development process, which have a potentially harmful effect on the objectives of the NPD project. During the risk assessment phase, previously identified risks are evaluated and prioritised according to their criticality. Various qualitative and quantitative methods are available for assessment of the risk factors. It helps in identifying the major risk factors, which needs action from the product development managers. The risk mitigation stage consists of the activities required to select and execute the mitigation measures for the risks assessed at the previous stage. It deals with development of a strategy to eliminate or minimise the adverse effects of the prevalent risks in the process.

The articles selected for review are classified according to the risk management aspects in the NPD process. The research articles on NPDRM deal with all the aspects of risk management applied to the NPD process. Some of the articles have focussed on only identification, or only assessment, or only mitigation step of risk management; whereas the other researchers have worked on different combinations of the above-mentioned three aspects of risk management and applied risk management principles for analysing risks in the NPD process.

Figure 2.8 depicts the distribution of the sixty-five research articles based on the risk management aspect being discussed in the article. It can be observed that risk assessment (with thirty-four articles) is the most discussed aspect among the three. Further, it can be seen that only nine articles (14%) talk about generic risk management in NPD process; and fifteen articles (23%) consider all three aspects of risk management process. However, a majority of these articles focus on either a particular phase of the NPD process or a particular type of risk thereby failing to deliver a holistic risk management solution for NPD process.

Figure 2.8: Contextual classification of NPDRM research (N=65)



Note: The numbers in the figure depict actual number of articles on a particular aspect.

Various methods and techniques are employed for identification, assessment, and mitigation by researchers and practitioners while managing risks in the NPD process during the various stages of risk management. An overview of these techniques is provided in the following sub-sections.

Risk Identification Methods: Broadly speaking, there are mainly three approaches used in the existing literature to identify the risk in an NPD process. This includes the following: a) analysis of literature and knowledge base; b) survey and expert interviews; and c) diagnostic models. *Literature analysis* is the most basic method to identify the risk factors that occur in any process. In this method, factors reported in published articles and different knowledge bases are taken as per the established context of the NPD project. *Expert interviews* are a reliable source of identifying the risks in the NPD process as the industry practitioners working daily on these projects can provide a good insight. Many researchers rely on literature analysis validated by interview or survey of industry experts for identification of risk factors. *Diagnostic models* like analysis of failure modes, root causes, cause and effect, fault tree, event tree, etc. are also used by some researchers for identifying risk sources in the NPD process by examining the processes for signs of potential risks. Event tree and fault tree analyses are visual/graphical techniques to break down the system into components and analyse the failure consequences using gates and events. Event tree analysis works on small zones of influence of potential risk events. Table 2.3 provides a summary of risk identification methods used by researchers.

Table 2.3: Risk identification methods

S. No.	Identification Method	Literature Sources
1	Literature and knowledge base	Ahn et al., 2008; Ayala-Cruz, 2016; Caillaud et al., 1999; Chaudhuri et al., 2013; Cheng et al., 2011; Choi and Choi, 2012; Dewi et al., 2015; Elstner and Krause, 2014; Gosnik, 2011; Kayis et al., 2006; Kayis et al., 2007a; Kayis et al., 2007b; Kirkire et al., 2015; Mehrjerdi and Dehghanbaghi, 2013; More, 1982; Oehmen et al., 2010; Porananond and Thawesaengskulthai, 2014; Rane and Kirkire, 2017; Song et al., 2013; Steen, 2015; Sundaram et al., 2007; Szwejczewski et al., 2008; Wu et al., 2010; Zhang et al., 2015; Zhao and Cao, 2015; Zhao et al., 2014; Wang et al., 2010.
2	Survey and interview	Ayala-Cruz, 2016; Carbone and Tippett, 2004; Cheng et al., 2011; Cooper, 1981; Coppendale, 1995; Dewi et al., 2015; Kayis et al., 2007b; Keizer and Halman, 2007; Keizer and Halman, 2009; Kirkire et al., 2015; Littler et al., 1995; More, 1982; Rane and Kirkire, 2017; Skelton and Thamhain, 2006; Szwejczewski et al., 2008; Thamhain and Skelton, 2007; Zhang et al., 2013; Zhang et al., 2015; Zhao and Cao, 2015.
3	Diagnostic models	Chang, 2014; Li et al., 2015; Mousaei and Hatefi, 2014; Susterova et al., 2012; Zhang and Chu, 2011; Elstner and Krause, 2014.

Risk Assessment Methods: Various techniques for assessment and evaluation of risks in the NPD process are listed in Table 2.4. *Failure mode and effects analysis* (FMEA) is the most commonly used tool to calculate the risk priority number (RPN) of each identified risk mode by multiplying its severity, occurrence, and detection scores. *Statistical methods for rating and ranking* the risks are also widely used for prioritising the risk factors. Multi-criteria decision making techniques like *analytical hierarchy process* (AHP) and Fuzzy AHP can be applied to compare the impact of risk factors and to evaluate project options based on risk rating. Researchers have also used *Bayesian networks* for analysing the risk factors and assessing the impact of those risks on the process using *a priori* and conditional probabilities of occurrence of risk events based on Bayesian belief rules. *Probabilistic risk assessment* (PRA) is one of the most basic techniques to evaluate the level of risk of a NPD process. It is based on probabilistic rating of the likelihood of occurrence of a risk event and the severity of consequences of the risks.

Table 2.4: Risk assessment methods

S. No.	Assessment Method	Literature Sources
1	Failure mode and effects analysis	Carbone and Tippett, 2004; Chang, 2014; Chaudhuri et al., 2013; Dewi et al., 2015; Kirkire et al., 2015; Mehrjerdi and Dehghanbaghi, 2013; Segismundo and Miguel, 2008a; Wu et al., 2010; Zhang and Chu, 2011.
2	Statistical rating and ranking	Ahn et al., 2008; Chaudhuri et al., 2013; Cheng et al., 2011; Mehrjerdi and Dehghanbaghi, 2013; Mousaei and Hatefi, 2014; Pickshaus et al., 2016; Rane and Kirkire, 2017; Steen, 2015; Wu et al., 2010; Zhang and Chu, 2011; Zhang et al., 2015.
3	Bayesian Network	Chiang and Che, 2010; Chin et al., 2009; Goswami and Tiwari, 2014; Kayis et al., 2006; Kayis et al., 2007b; Qazi et al., 2015; Tang et al., 2011; Zhang et al., 2013.
4	Probabilistic Risk Assessment	Ayala-Cruz, 2016; Coppendale, 1995; Elstner and Krause, 2014; Li et al., 2015; Susterova et al., 2012; Zhang et al., 2013.
5	Analytical Hierarchy Process	Akomode, 1999; Chiang and Che, 2010; Choi and Choi, 2012; Choi et al., 2009; Kayis et al., 2007b; Park et al., 2011; Song et al., 2013.
6	Markov Process	Choi and Ahn, 2010; Choi and Choi, 2012; Choi et al., 2010; Park et al., 2011.

It was observed that some researchers reduced subjectivity and vagueness in the risk evaluation process of above mentioned approaches by incorporating *fuzzy theory* (Chiang and Che, 2010; Choi and Ahn, 2010; Zhang and Chu, 2011; Chang, 2014; Kirkire et al., 2015; Ahn et al., 2008; Choi et al., 2010; Choi and Choi, 2012; Chaudhuri et al., 2013; Park et al., 2011; Choi et al., 2009) and *rough set theory* (Song et al., 2013; Zhang et al., 2015). These approaches use fuzzy scoring for capturing the subjectivity in rating the risk factors and soft sets are sometimes used for evaluation purpose.

Risk Mitigation Methods: The literature review reveals that prior researchers have used reactive (feedback) approach as well as a proactive (preventive) approach for mitigating the risks occurring during the NPD process. Table 2.5 summarizes the risk mitigation methods applied to NPD process.

Table 2.5: Risk mitigation methods

S. No.	Mitigation Method	Literature Sources
1	Action/Response plan	Carbone and Tippett, 2004; Chaudhuri et al., 2013; Choi et al., 2010; Coppendale, 1995; Dewi et al., 2015; Kayis et al., 2007b; Kirkire et al., 2015; Marmier et al., 2014; Mehrjerdi and Dehghanbaghi, 2013; Neumann, Sporbeck, Sadek, and Bender, 2015; Segismundo and Miguel, 2008a; Skelton and Thamhain, 2006; Steen, 2015; Wang et al., 2010.
2	Knowledge management	Cheng et al., 2011; Kayis et al., 2006; Park et al., 2011; Yang, Zhang, and Yao, 2012.
3	Cost based approach	Kayis et al., 2007a.
4	QFD	Ahn et al., 2008; Zhao et al., 2014.
5	Monitoring and review	Marmier et al., 2014; Oehmen et al., 2006; Rane and Kirkire, 2017.
6	Heuristics	Choi and Choi, 2012; Dewi et al., 2015; Kayis et al., 2007a.

Generally, *action plans* or *response plans* are used to attack the risks occurring in NPD projects. The identified critical risk factors are assessed and a response plan is suggested for removal of risks or minimization of the effects of risks. *Knowledge management* is mentioned as a way to treat risks occurring in the NPD process by only a few researchers. *Cost-based approaches* for mitigation of risks, such as least cost first, minimum cost-risk ratio first can be applied according to the project's specific needs. *Quality function deployment* (QFD) based risk mitigation approach can be used to reduce risks at an early stage, where the potential risks are addressed at the design phase. *Monitoring and review* of the process for risk mitigation is suggested for tracking and controlling the risks in NPD process. *Heuristic* approaches suggested for developing mitigation strategy by Kayis et al., (2007a), Choi and Choi (2012), and Dewi et al. (2015) are the only studies identified in the literature that showed the comparison of alternative strategies for risk mitigation and selection of optimal mitigation plan.

2.4 Discussions and Research Gaps

The mapping of literature has provided various insights into the research trends in the area of NPDRM. It is observed that the research in this field is showing an upward trend with an increasing number of articles being published in recent years. Also, this review's findings show that there is a lack of empirical research and application of the research findings in industries. The researchers and engineering practitioners shall focus on engaging in empirical studies concerning risk management in NPD process and explore their characteristics in different industrial contexts. It is observed that sectors like automotive, telecom, and textiles received less attention despite the high significance of these industries in economic development. There is therefore clearly a need for research to be directed towards exploring such industries for analyzing the risks prevalent in these industries and applying risk management principles to drive towards a successful product development process.

Many risk assessment and prioritisation methods are reported in the literature; a combination of the available methods could be used to develop an integrated approach to generate better results overcoming the limitations and gaps of previous methods. Further studies could be undertaken to identify the optimal risk evaluation technique. It is observed from the literature that there is limited emphasis on quantification of risks and most of the methods rely on prioritisation based on pairwise comparisons and rankings. The prioritisation methods could be used in integration with quantitative techniques to analyse the risks in the NPD process. The mitigation approaches reported in the literature are mostly case based action plans. A framework for selecting prioritized actions to mitigate risks would be a useful tool for controlling the adverse effects of risk factors in the NPD process. Finally, the need for an integrated approach to thoroughly manage the risks in the entire NPD process still exists, as most of the studies focused on either a particular risk category or a particular phase of NPD process. An integrated approach for identifying, assessing, and mitigating the inherent risks in NPD process would be beneficial for the industry practitioners and engineering managers.

The current review helps in identifying potential areas for future research, which received limited attention from the researchers in the past and need further exploration by engineering management scholars. The key research areas identified for future research based on the research gaps discussed above are summarised below:

- Firstly, while multiple risk analysis approaches are presented in the extant literature, it is hard to generalize their application because of a lack of empirical evidence. In other words, there is clearly a need for more empirical studies on the application of risk analysis methodologies in the NPD process. More specifically, given the complexity and cost of products, more research is needed on the economically significant sectors like automotive, telecommunications, textiles, etc.

- Secondly, studies are needed for developing risk evaluation technique applicable to the NPD process. Research task can be undertaken for development of integrated approach for prioritization and quantification of risks in NPD process for aiding product development managers in taking more informed decisions. Risk analysis methods can be further developed, which consider domino effect (chain reaction) that one factor will influence another factor due to the inter-relationships among the risk factors, thereby affecting cumulative risk in the NPD process.

- Thirdly, while FMEA types of methodologies have been used extensively for risk identification and prioritization, there is currently a lack of methodologies for prioritization of risk mitigation actions based on the available resources and organizational priorities.

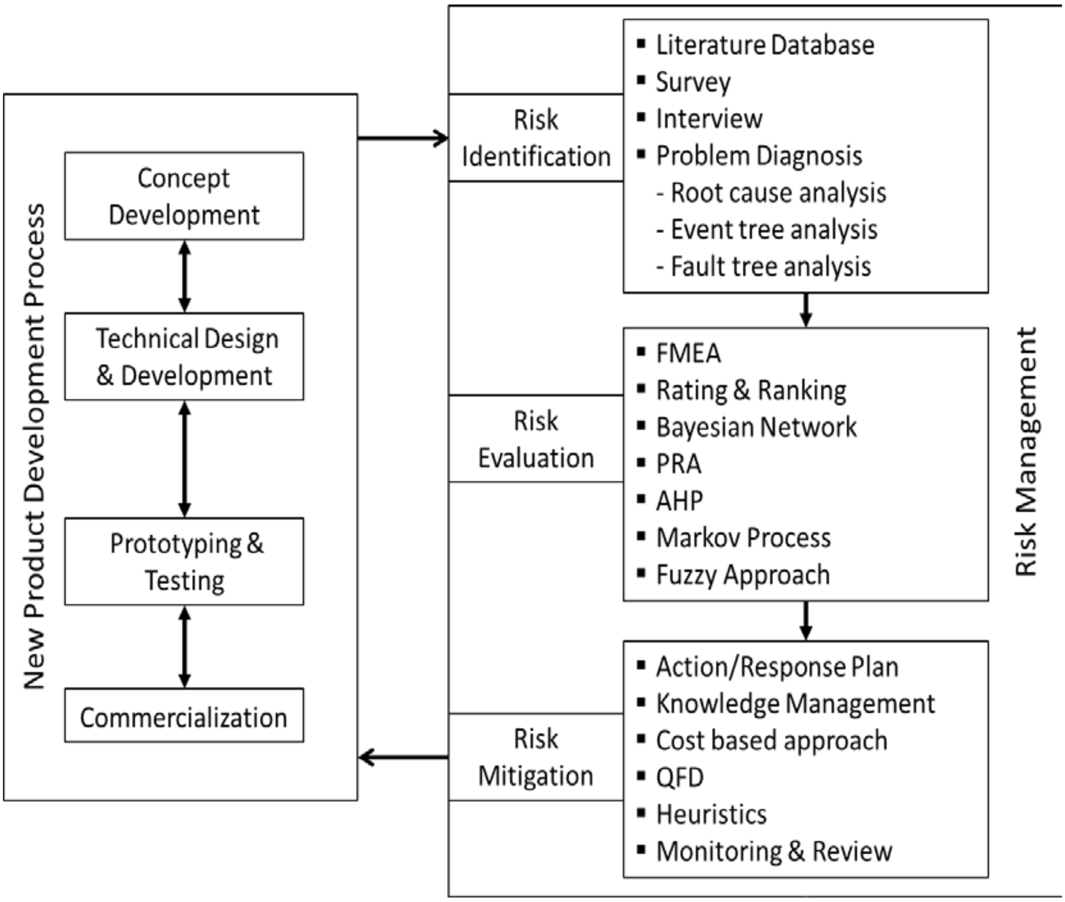
- Lastly, an integrated approach for comprehensive risk management (from elicitation of risks to implementation of mitigation measures) for the entire NPD process considering various risks prevalent in the process is clearly in demand from the engineering manager's perspective. Although there are methodologies developed to analyze the risks at various phases of product development, an integrated approach to manage the overall risks at the system level can help minimize the delays and failures.

2.5 Conceptual Framework of Risk Management in NPD Process

A conceptual framework of contemporary activities for managing risks in the NPD process has been established based on the mapping of literature on NPDRM. The conceptual framework, depicted in Figure 2.9, presents a holistic framework to help manage the risks in the NPD process, along with mapping the contemporary methods available for managing risks in NPD process.

The conceptual framework illustrates the implementation of risk management in the new product development process. The first stage of risk management process deals with exploring the risk identification methods for extracting the risk factors existing in each stage of the NPD process. Identification of the risk factors leads to the evaluation step where quantitative techniques to numerically assess and prioritize the risk factors obtained in first step of risk management process are explored. Evaluation of the risk factors provides a basis for recognition of the critical risk factors hindering the success of NPD project. These identified high ranked critical risk factors need to be mitigated for ensuring the success of the NPD process; which is the purpose of the third step of risk management process. The risk mitigation measures finalised in the last stage of the risk management process needs to be applied to the appropriate phases of the NPD process to address the risk issues; and eliminate or minimize the adverse effects of the identified risks.

Figure 2.9: Conceptual framework of risk management in NPD process



2.6 Implications for Engineering Managers and Practitioners

As mentioned earlier, this review reveals that the existing knowledge on NPD risk analysis and management is scattered across multiple publication sources. This review study can help engineering managers and practitioners by bringing the scattered knowledge and information on NPD risk management methodologies in one place so they have a better understanding of existing best practices. In other words, the consolidated knowledge base provided by this review would provide a jump start to the practicing engineering managers working in the field of NPD. Likewise, the potential areas for future research presented above might assist engineering management scholars to direct their attention towards these emerging issues in the NPDRM domain. Practicing engineering managers can utilize the findings of this review to make more informed decisions in formulating appropriate risk mitigation strategies for their NPD projects.

The conceptual framework presented in the chapter provides various approaches selected by prior researchers and practitioners for addressing the risks faced in NPD processes. This contemporary framework of existing methods can be used by engineering managers and practitioners for selecting the appropriate approach according to their needs, by adapting a given method or combining techniques for better management of risks. Thus, the conceptual framework provides a path for an integrated risk management solution to address the risks prevalent in the new product development process.

2.7 Conclusion

In this chapter, the existing knowledge base on risk management in the NPD process is consolidated and classified based on different schemes. In any research, mapping of existing knowledge is an important step; and in this sense, the present study makes a contribution in understanding the contemporary scenario of risk management approaches for the new product development process. It becomes clear that risk management is a crucial part of any NPD project so as to develop a successful product in given time period and budget by reducing the risks at appropriate stage. The risk management methods mentioned in this chapter can help decision makers in choosing suitable approach for managing risk in their NPD project by using a given method or combining two or more methods to form an integrated approach.

This review serves as a stepping stone to obtain insights into the risk management practices in the new product development process and pave a way towards improved management of risks prevalent in any organization. The conceptual framework presented in this review can be used for development of integrated risk management tools for engineering and product development projects. Future work is focussed on development of a comprehensive risk management approach in line with the research gaps and future research areas discussed in the chapter.

Chapter 3

RISK IDENTIFICATION AND TAXONOMY DEVELOPMENT

This chapter provides a comprehensive study of the prevalent risk factors in the NPD process and proposes a risk taxonomy based on the empirical research carried out for Indian automotive industry. Factor analysis techniques are utilized for analysing various risks identified from literature, and the risk factors are classified into seven risk dimensions. The study reveals major risks prevalent in the NPD process and categorizes them for the aid of managers dealing with development of new products. The results of this study would help researchers and practitioners in developing a better understanding of the risk factors existing in their NPD projects and serve as a risk reference framework.

3.1 Introduction

Although, NPD is considered as one of the major sources of competitive advantage (Guo, 2008; Yadav et al., 2007), it involves great amount of risk due to rising complexities in design and production processes (Marmier et al., 2014; Oehmen et al., 2014). Prior research studies indicate that the rate of success for NPD projects is very low (Cooper, 2003; Ahn et al., 2008; Salavati et al., 2016). To address and control potential process and/or product failures, identification and proper management of risks is a critical issue in the product management literature (Akram and Pilbeam, 2015; Mu et al., 2009). *Risk identification* is considered as the first and most crucial step for risk management activities as only the identification of risks will trigger any further risk management activity (Prakash et al., 2017). Hence this chapter attempts to provide a comprehensive study on identification of prevalent risk factors in the NPD process. The contribution of this study to the field of product development and management lies in providing a risk taxonomy which is expected to act as a reference model for practicing engineering managers in the field of new product development.

This chapter is structured into six sections with the current section providing introduction to the work. Literature background regarding the study is discussed in the next section. Research methodology followed in this study is described in the third section. Fourth section provides the literature analysis for identification of risk factors in NPD process. Fifth section discusses the analysis of the identified risk factors for the development of risk taxonomy. Lastly, the chapter concludes with summary and further research direction of the study.

3.2 Background

It has been reported in literature that around 80% of the NPD projects fail before completion (Cooper, 2003; Ahn et. al., 2008). Coppendale (1995) introduced a formal RM process to reduce risk issues in NPD projects. Brockhoff (2003) highlighted the problems in integration of customer in NPD process from customers' viewpoint. Application of risk management philosophy to NPD process in a pharmaceutical company was reported by Katsanis and Pitta (2006). They advised to introduce risk management activities in early phases of NPD. Mu et al. (2009) reported that risk management approach targeting specific risk elements contribute towards improving the performance of NPD. Wang et al. (2010) proposed a framework integrating balanced scorecard and QFD for managing risks in NPD projects. The risk factors of customer integration in product innovation have been explored by Song et al. (2013). Porananond and Thawesaengskulthai (2014) tabulated common risk factors for NPD in food industry and developed a model for risk management. Zhao and Cao (2015) explored the risk causes and analysed the power asymmetry between supplier and manufacturer in joint product development project. Salavati et al. (2016) revealed that if organizations improve their knowledge base regarding risks, they could increase their ability to predict future issues that may affect performance of NPD process.

Prior research indicates that researchers have used variety of methods for identification of risks in NPD process. Literature analysis is the most basic method used by researchers to identify the risks that exist in any process (Ahn et al., 2008; Chaudhuri et al., 2013; Elstner and Krause, 2014). Expert interviews are reliable source of identifying the risks in NPD process as the industry practitioners working daily on these projects can provide a good insight (Carbone and Tippett, 2004; Keizer and Halman, 2009; Thamhain and Skelton, 2007). Many researchers rely on literature analysis validated by interview or survey of industry experts for identification of risk factors (More, 1982; Cheng et al. 2011; Dewi et al., 2015). In this research, literature analysis along with expert consultation is used for exploration of various risks in NPD process. While, many researchers have worked on identification of risks focusing on either a particular phase of the NPD process or a particular type of risk, there have been very few attempts for consolidating various risk factors in the NPD process to provide a holistic risk reference model. Hence, this study tries to address this gap and provide comprehensive taxonomy of risks in NPD process.

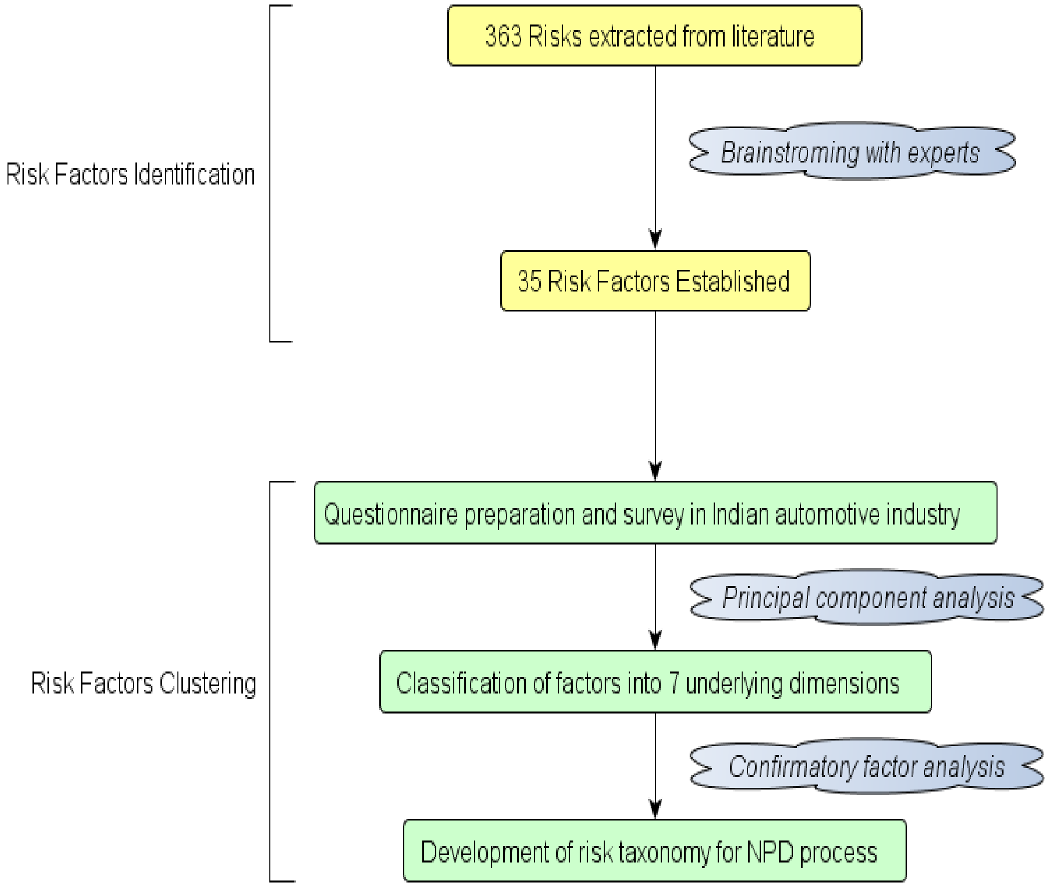
3.3 Research Method

Various steps of the methodology adopted in this research to develop risk taxonomy for NPD process is explained in the following sub-sections. A schematic representation of the research methodology is presented in Figure 3.1. The methodology can be broadly divided into two phases: identification of risk factors, and classification of risk factors.

3.3.1 Identification of risk factors

The risk identification phase involves extraction of various risks reported in literature and brainstorming on these risks to establish a list of prevailing risk factors in the NPD process. In this study, a total of 363 risks are identified by scrutinizing the available literature in the field of NPD risk management. These risks are then subjected to further screening to eliminate duplicate and redundant elements. The approach used for extracting the factors from literature is based on Delphi method which utilises the expertise of industry practitioners and subject matter experts for gathering information on a defined issue (Mehta et al., 2014). The risk factors extracted from literature were discussed with subject matter experts from industry and a comprehensive list has been prepared for development of risk taxonomy.

Figure 3.1: Schematic diagram of methodology to develop risk taxonomy



3.3.2 Survey instrument and data collection

After the identification of various risk factors prevalent in the NPD process, a survey was conducted to validate these factors with industry professionals working in the area of NPD. This research is based on empirical investigations in Indian automotive industry, and for this purpose an online survey was administered to collect responses from engineering managers working on NPD activities in Indian automotive organisations. The survey questionnaire was divided into two parts: first part was designed to collect basic demographic details of the respondents and their general perception regarding risk management in NPD process; and the second part consisted of the thirty-five identified risk factors to be given rating on a seven-point Likert scale on the basis of their relevance in NPD process. The survey was administered through electronic means for wide distribution and ease of data collection. The online survey form was sent to practicing engineers and managers working in automotive organisations in India. The target respondents were those professionals, who were associated with new product development activities of their organisation.

3.3.3 Data analysis methods

The collected responses are statistically tested for reliability measures to confirm the eligibility of data for further analysis. The reliability of a factor is measured using Cronbach's alpha (Hair et al. 2006), which is “an index of the internal consistency of the items” and also “a useful estimate of reliability” (Gregory 2000, p. 85). Descriptive statistics are calculated for initial analysis of the risk factors. Further exploratory factor analysis (EFA) is performed using principal components analysis (PCA) with varimax rotation to extract the underlying components (or ‘dimensions’) of the identified factors (Hair et al., 2006). Varimax rotation produces uncorrelated factors and is commonly used because it reduces the small loadings and decreases the number of variables which load highly on each factor. While performing EFA, when no prior theory or model exists, PCA is generally used to explore the nature and number of variables, and propose a theory (Hair et al., 2006). Here, PCA is utilised to classify the diverse thirty-five risk factors into clusters of smaller number of risk factors, called risk dimensions.

The taxonomical structure derived from PCA is further validated using confirmatory factor analysis (CFA). Jain and Raj (2013) reports that there is not one clear measurement index for testing the model fit of the developed structure, thus a combination of different measures should be considered to determine the goodness of structure. Six model fit indices, viz. ratio of chi-square to degree of freedom (CMIN/DF), root mean square residual (RMSR), goodness-of-fit index (GFI), adjusted goodness-of-fit (AGFI), root mean square error of approximation (RMSEA), and comparative fit index (CFI) are calculated to establish the goodness of the developed structure. Thirupathi and Vinodh (2016) utilised similar approach to verify the constructs for variables modelled using interpretive structural modeling for sustainable manufacturing in Indian automotive component sector. A similar analysis was performed by Soni and Kodali (2016a) for measuring supply chain constructs in Indian manufacturing industry. Mu et al. (2007) used identical procedure for exploring success factors of new product development in Chinese enterprises. Vazquez-Bustelo et al. (2007) also employed PCA and CFA for empirically testing agile manufacturing factors. Owing to its ability to allow the researchers to focus on the structural level, exploratory factor analysis technique is considered more flexible than other statistical methods (Vinodh and Joy, 2012). Thus, widely used PCA and CFA tools are adopted for the analysis of survey responses in this study.

3.4 Identification of Risk Factors in NPD Process

Cooper (1981) discussed the components of risk in NPD, while More (1982) explored risk factors in various successful and failed new product endeavours. Some of the researchers concentrated on risks in a particular aspect of NPD process like collaborative product development (Littler et al., 1995), ramp-up phase (Elstner and Krause, 2014), customer integration (Song et al., 2013), supply chain (Chaudhuri et al., 2013), etc. Many researchers focussed on exploring the risks in particular industry segment, e.g. fast moving consumer goods (FMCG) industry (Keizer and Halman, 2009), food industry (Porananond and Thawesaengskulthai, 2014), fashion industry (Dewi et al., 2015), etc. Thamhain and Skelton (2007) identified factors enhancing effectiveness of risk management in new product development projects. Cheng et al. (2011) identified various risks encountered while developing assistive devices for elderly people. Keizer and Halman (2007) conducted eight case studies to diagnose risks in radical innovation NPD projects, which resulted in identification of 12 categories of risks and provided normative advice for R&D managers. Wu et al. (2010) provided a risk analysis model for concurrent engineering product development project for identification and analysis of risk factors in a case of a motor company in China. Analysis of ten risk sources in medical device development process was conducted by Rane and Kirkire (2017).

Each study used somewhat distinct method and generated different factors related to their area of research application, deriving results that are not necessarily consistent with findings of other studies. Identification of appropriate risk factors from the vast literature needs brainstorming and logical thinking. In this study, a brainstorming session with academicians and industrial experts is conducted as discussed in the research methodology section above. Thirty-five risk factors are finally identified, which affects the success of NPD process. The identified risks are summarised in Table 3.1 along with their notations and literature sources.

Table 3.1: Summary of identified risk factors

S. No.	Notation	Risk Factor	Source
R01	*leak_sec*	Leakage of technical trade secrets about new product before product commercialization	Song et al., 2013; Littler et al., 1995
R02	*ipr_pat*	Intellectual property rights (IPR) and patent issues pertaining to the new product	Skelton and Thamhain, 2006; Akram and Pilbeam, 2015; Keizer and Halman, 2007
R03	*team_cap*	Lack of capability of product development team to create the new product as per requirements	Cheng et al., 2011; Akram and Pilbeam, 2015; Dewi et al., 2015
R04	*team_corm*	Lack of coordination and communication within the product development team	Rane and Kirkire, 2017; Dewi et al., 2015; Song et al., 2013
R05	*reg_chg*	Changes in regulatory requirements for the product during development phase	Cheng et al., 2011; Thamhain and Skelton, 2007
R06	*sch_unst*	Unsuitable or unrealistic schedule of the product development process	Cheng et al., 2011; Kayis et al., 2007
R07	*org_prio*	Changing organizational priorities and commitment by senior management regarding the planned new product	Wu et al., 2010; Thamhain and Skelton, 2007; Dewi et al., 2015
R08	*tech_cap*	Lack of technological R&D capability of the organization and development team for the planned new product	Song et al., 2013; Akram and Pilbeam, 2015; Cheng et al., 2011; Wu et al., 2010

S. No.	Notation	Risk Factor	Source
R09	*tech_chg*	Changes in the technology for new product development	Skelton and Thamhain, 2006; Thamhain and Skelton, 2007
R10	*soc_chg*	Changes in social and economic conditions of consumers affecting their buying behavior	Skelton and Thamhain, 2006; Thamhain and Skelton, 2007
R11	*sup_cap*	Lack of capability of supplier to deliver good quality components within stipulated time frame	Dewi et al., 2015; Akram and Pilbeam, 2015; Chaudhuri et al., 2013
R12	*scm_cplx*	Complexity of logistic network for distribution of new product	Elstner and Krause, 2014; Song et al., 2013
R13	*res_aval*	Non-availability and inappropriate allocation of required resources for new product	Song et al., 2013; Cheng et al., 2011
R14	*sup_rel*	Instability in the supplier relations affecting new product development	Cheng et al., 2011; Skelton and Thamhain, 2006
R15	*bdgt_cons*	Product development budget constraint	Cheng et al., 2011; Akram and Pilbeam, 2015; Dewi et al., 2015
R16	*cost_err*	Error in estimation of project cost	Cheng et al., 2011; Kayis et al., 2007
R17	*tech_cplx*	Technical complexity of product design for manufacturing	Chiang and Che, 2010; Elstner and Krause, 2014
R18	*envr_iss*	Environment risk posed by the new product technology and the development process	Skelton and Thamhain, 2006; Thamhain and Skelton, 2007
R19	*comp_act*	Actions of competitors and potential price wars	Cheng et al., 2011; Akram and Pilbeam, 2015; Keizer and Halman, 2007
R20	*mrkt_lim*	Limited market segment for the planned new product	Song et al., 2013; Littler et al., 1995
R21	*prod_via*	Low commercial viability of the planned new product	Keizer and Halman, 2007; Wu et al., 2010
R22	*brnd_img*	Effect of brand image of the organization on acceptance of new	Song et al., 2013; Keizer and Halman, 2009

S. No.	Notation	Risk Factor	Source
		product by consumers	
R23	*ssrv_unf*	Unfamiliar sales and service tasks requirements for the new product	More, 1982
R24	*mfg_cap*	Lack of manufacturing capability of the organization with respect to planned initiative	Akram and Pilbeam, 2015; Chaudhuri et al., 2013; Keizer and Halman, 2009
R25	*dsgn_chg*	Incorporation of late design changes in product development process	Elstner and Krause, 2014; Kayis et al., 2007
R26	*spec_fail*	Inability to attain specifications and intended functions in final product	Cheng et al., 2011; Keizer and Halman, 2009; Rane and Kirkire, 2017
R27	*cust_int*	Customer integration in development process	Song et al., 2013
R28	*prmg_cplx*	Complexities in project management for the planned new product	Skelton and Thamhain, 2006; Thamhain and Skelton, 2007
R29	*qa_fail*	Lack of quality assurance by the developers for the new product	Song et al., 2013; Cheng et al., 2011; Rane and Kirkire, 2017; Song et al., 2013;
R30	*plc_shrt*	Short life cycle of the new product due to changes in trends and needs of customer	More, 1982; Dewi et al., 2015; Skelton and Thamhain, 2006
R31	*demp_fail*	Inability to predict demand for the new product	More, 1982; Dewi et al., 2015
R32	*user_trng*	Lack of training to end users for the new product	Rane and Kirkire, 2017; Keizer and Halman, 2009
R33	*prod_nov*	Lack of novelty in new product	Elstner and Krause, 2014; Dewi et al., 2015
R34	*prod_cplx*	Complexity of production process for the new product	Elstner and Krause, 2014; Chaudhuri et al., 2013
R35	*prod_var*	Developing many variants of the new product at once	Dewi et al., 2015

3.5 Analysis and Discussions

3.5.1 Demographic details and descriptive statistics

A total of 375 responses were received out of which 366 response forms were complete in all respects, which were considered for further analysis. Out of these 366 responses, around 95% of respondents agreed with giving ‘reasonable’ to ‘very much’ emphasis on NPD in their organisation for business survival; and about 5% of the respondents said that the emphasis on NPD is ‘very little’ or ‘insignificant’. These 5% responses are removed from the data set and further analysis is conducted on remaining 348 responses, which represented the respondents having adequate exposure to NPD activities in their organisations. In total, a useable sample size of 348 responses for 35 factors suggests that the study has an acceptable value of observations-to-variables ratio (Hair et al., 2006). These 348 respondents are spread across 26 automotive organisations having pan-India presence. Table 3.2 presents the summary of profile of the respondents, showing their level of position and work experience.

Table 3.2: Profile of respondents

Experience	Frequency	Percentage	Management Level	Frequency	Percentage
1 to 5 years	108	31.03			
6 to 10 years	167	47.99	Lower Management	148	42.53
11 to 20 years	56	16.09	Middle Management	181	52.01
> 20 years	17	4.89	Upper Management	19	5.46
Total	*348*	*100*	*Total*	*348*	*100*

The first part of the questionnaire enquired about general perception of industry professionals regarding risk management and NPD process in their organisation. Figure 3.2 depicts the perception of industry professionals regarding effect of risk management on NPD, and Figure 3.3 shows formal implementation of risk management practices in their organisations. It is interesting to observe that almost 99% of the respondents believe that risk management has a positive impact on NPD success; yet 14% of the respondents do not have formal risk management system for their NPD projects. This indicates towards a need for more studies on exploration of risks in NPD process in Indian manufacturing industries, and motivating industry practitioners towards adopting risk management practices.

Figure 3.2: Perception regarding effect of risk management on NPD

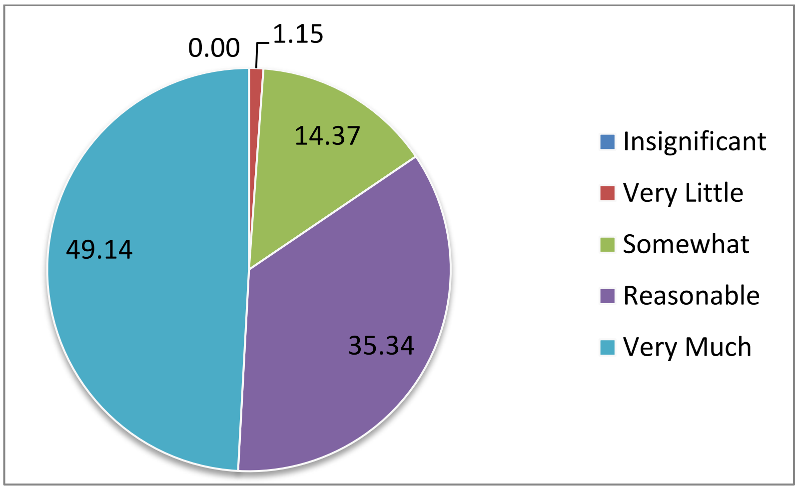
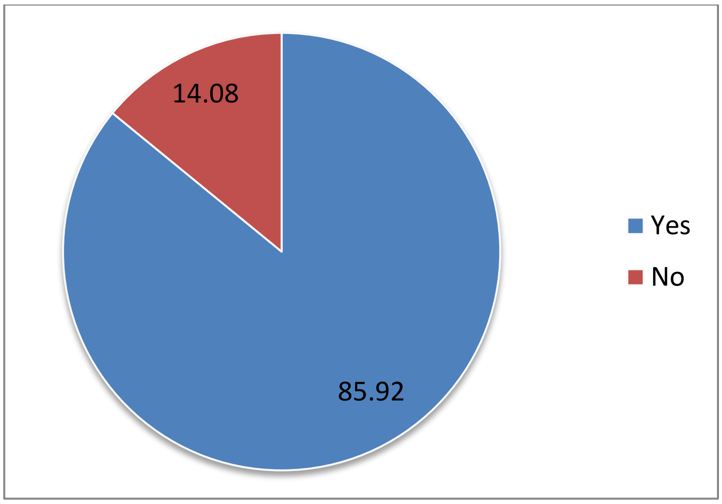


Figure 3.3: Implementation of formal risk management practices



The descriptive statistics of the collected responses are given in Table 3.3. It can be observed from Table 3.3 that all the risk factors are given an average importance rating of more than 4 on a scale of 1 to 7, which shows that all the identified risk factors have a substantial impact on the NPD process and requires attention from engineering managers for ensuring success of NPD project. The set of reliability measurements associated with the risk factors showed that the Cronbach's alpha reliability coefficient (value of α) is 0.96. A value of 0.7 or higher for alpha coefficient (α) indicates an acceptable level of internal consistency (Cortina, 1993; Hair et al., 2006). Thus, it can be inferred that the collected response data is having excellent internal consistency and reliable to perform subsequent analysis.

Table 3.3: Descriptive statistics of risk factors

S. No.	Risk Factor	Mean	Std. Dev.	S. No.	Risk Factor	Mean	Std. Dev.
R01	*leak_sec*	5.3	1.04	R19	*comp_act*	4.3	1.17
R02	*ipr_pat*	4.5	1.20	R20	*mrkt_lim*	4.6	1.19
R03	*team_cap*	4.7	1.06	R21	*prod_via*	4.5	1.04
R04	*team_corm*	4.5	1.45	R22	*brnd_img*	4.7	1.10
R05	*reg_chg*	4.9	0.89	R23	*ssrv_unf*	4.9	1.12
R06	*sch_unst*	4.9	1.27	R24	*mfg_cap*	4.8	1.21
R07	*org_prio*	4.8	0.98	R25	*dsgn_chg*	5.5	0.91
R08	*tech_cap*	5.2	1.15	R26	*spec_fail*	4.7	1.06
R09	*tech_chg*	4.7	1.08	R27	*cust_int*	4.0	1.17
R10	*soc_chg*	4.5	1.05	R28	*prmg_cplx*	4.8	1.05
R11	*sup_cap*	5.1	1.36	R29	*qa_fail*	5.0	1.44
R12	*scm_cplx*	4.5	1.07	R30	*plc_shrt*	4.6	0.78
R13	*res_aval*	4.3	0.91	R31	*demp_fail*	4.7	1.38
R14	*sup_rel*	4.2	1.24	R32	*user_trng*	4.6	1.20
R15	*bdgt_cons*	4.5	1.21	R33	*prod_nov*	4.3	1.21
R16	*cost_err*	4.8	1.12	R34	*prod_cplx*	4.4	1.13
R17	*tech_cplx*	4.9	1.94	R35	*prod_var*	5.0	1.20
R18	*envr_iss*	4.4	0.88				

3.5.2 Classification of risk factors into risk dimensions

Exploratory factor analysis using PCA is used for classifying the identified risk factors into underlying dimensions. As shown in Table 3.4, seven components (risk dimensions) are extracted from the data where all factor loadings that permit assignment of a risk factor to a specific dimension component exceeds 0.475. It is suggested to consider loadings greater than 0.32 to be poor, 0.45 to be fair, 0.55 to be good, 0.63 to be very good, and 0.71 to be excellent (Tabachnick and Fidell, 2007). Gerbing and Anderson (1988) suggest that loadings exceeding 0.40 are acceptable and represent a good loading. Reliability of the extracted dimensions is estimated using the Cronbach's alpha, having a satisfactory value of greater than 0.7 (Hair et al., 2006). Also, Table 3.4 reports that the value of co-efficient alpha for each risk dimension exceeds the recommended acceptable value.

Table 3.4: Summary of PCA results

Risk Dimension			Risk Factors		Factor Loading	Cronbach's alpha
D1	*MKT*	Market	R19	*comp_act*	0.663	0.874
			R20	*mrkt_lim*	0.698	
			R21	*prod_via*	0.796	
			R22	*brnd_img*	0.646	
			R23	*ssrv_unf*	0.601	
			R30	*plc_shrt*	0.632	
			R31	*demp_fail*	0.496	
			R32	*user_trng*	0.652	
			R35	*prod_var*	0.639	
D2	*SUP*	Supply Chain	R06	*sch_unst*	0.610	0.799
			R11	*sup_cap*	0.701	
			R12	*scm_cplx*	0.716	
			R13	*res_aval*	0.764	
			R14	*sup_rel*	0.647	
D3	*MFG*	Manufacturing	R24	*mfg_cap*	0.751	0.878
			R25	*dsgn_chg*	0.703	
			R26	*spec_fail*	0.698	
			R27	*cust_int*	0.618	
			R29	*qa_fail*	0.565	
			R33	*prod_nov*	0.519	
			R34	*prod_cplx*	0.475	
D4	*TEC*	Technological	R08	*tech_cap*	0.867	0.713
			R09	*tech_chg*	0.782	
			R17	*tech_cplx*	0.536	
D5	*REG*	Regulatory	R01	*leak_sec*	0.566	0.869
			R02	*ipr_pat*	0.486	
			R05	*reg_chg*	0.651	
			R10	*soc_chg*	0.568	

Risk Dimension			Risk Factors		Factor Loading	Cronbach's alpha
			R18	*envr_iss*	0.795	
D6	*ORG*	Organisational	R03	*team_cap*	0.703	0.812
			R04	*team_corm*	0.546	
			R07	*org_prio*	0.514	
			R28	*prmg_cplx*	0.650	
D7	*FIN*	Financial	R15	*bdgt_cons*	0.549	0.804
			R16	*cost_err*	0.621	

The first component includes nine factors, viz. *comp_act*, *mrkt_lim*, *prod_via*, *brnd_img*, *ssrv_unf*, *plc_shrt*, *demp_fail*, *user_trng*, and *prod_var*. These risk factors pertain to marketing activities and consumers; hence, this risk dimension is termed as 'market'. Similar kind of risks, related to product variety, marketing efforts, product knowledge, etc. were categorised as 'market risks' by Dewi et al. (2015). The second component is made up of risk factors related to schedule and supply chain network (*sch_unst*, *sup_cap*, *scm_cplx*, *res_aval*, and *sup_rel*), and named as 'supply chain' risk dimension. The third risk dimension termed 'manufacturing' includes *mfg_cap*, *dsgn_chg*, *spec_fail*, *cust_int*, *qa_fail*, *prod_nov*, and *prod_cplx*, which are related to manufacturing processes. Chiang and Che (2010) suggested including manufacturing ability and production complexity in manufacturability risk, while evaluating NPD projects using Bayesian belief network. The next component contains three factors namely, *tech_cap*, *tech_chg*, and *tech_cplx*. These are kept under the risk dimension named 'technological'. The risk factors *leak_sec*, *ipr_pat*, *reg_chg*, *soc_chg*, and *envr_iss* related to form the next component termed as 'regulatory'. The sixth component is termed as 'organisational' risk dimension, which includes risk factors (*team_cap*, *team_corm*, *org_prio*, and *prmg_cplx*) relevant to organisation's internal work system. Dewi et al. (2015) and Song et al. (2013) used the same category for risks related to development team and personnel issues. Aronson et al. (2008) emphasised on organisational factors like role of team leader and senior management in NPD success; and the lack of these factors poses risk to the NPD project. The last component is derived from the risk factors *bdgt_cons* and *cost_err*, which forms the risk dimension 'financial'. Many researchers theoretically categorised various risk factors into similar functional categories in their respective research domains like supply chain management (Prakash et al., 2017), customer integration in product development (Song et al. 2013), student- centered spacecraft development projects (Straub et al., 2013) etc.

Confirmatory factor analysis (CFA): CFA is employed to check the validity of the developed classification structure and to confirm whether the analysed data is reliable with the developed model or not, by testing for construct validity and evaluating the goodness-of-fit (GOF) of the developed model (Hair et al. 2006). The summary of model fit indices along with the acceptable limits is given in Table 3.5. The results of CFA shows that the factor loadings are in accordance with the structure produced by the PCA with acceptable model fit.

Table 3.5: Summary of CFA results

Model fit indices	**CMIN/DF**	**GFI**	**AGFI**	**RMSEA**	**CFI**	**RMSR**
Acceptable limit	*≤ 3.00*	*≥ 0.90*	*≥ 0.80*	*≤ 0.10*	*≥ 0.90*	*≤ 0.14*
Measurements	2.233	0.979	0.937	0.06	0.988	0.132

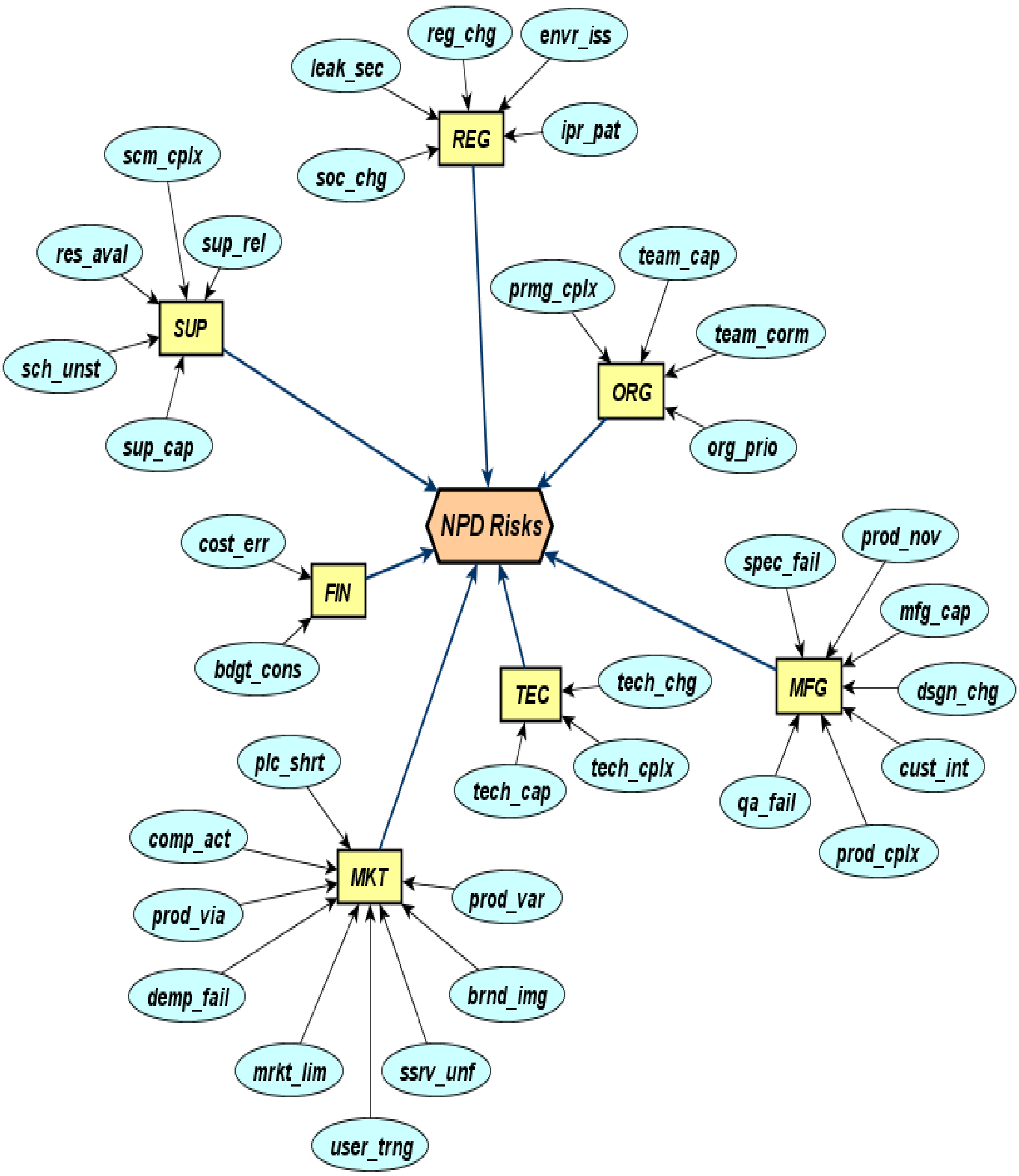
The chi-squared test shows the variation among expected and observed covariance matrices. The value of the ratio of chi-square to degree of freedom (CMIN/DF) closer to zero are considered as better fit (Gatignon, 2010). The value of CMIN/DF for the developed structure is calculated as 2.233, which is within the acceptable limit of 3 (Hair et al., 2006). The root mean square error of approximation (RMSEA) analyses the inconsistency among the developed model and the covariance matrix to circumvent errors due to sample size (Hooper et al., 2008). The value of RMSEA for the developed structure is 0.06 which is within the acceptable limit of 0.1 (Hair et al., 2006). The root mean square residual (RMSR) is square root of the variation between the model and sample covariance matrices (Hooper et al., 2008). A value less than 0.14 is considered acceptable for RMSR. The goodness of fit index (GFI) is a measure GOF between the observed covariance matrix and the developed model (Baumgartner and Homburg, 1996). The adjusted goodness of fit index (AGFI) rectifies the GFI measure, which is affected by the amount of factors of each latent construct (Baumgartner and Homburg, 1996). The values of GFI and AGFI are considered acceptable if they are greater than 0.9 and 0.8 respectively (Hair et al., 2006). In this study the GFI is 0.979 and AGFI is 0.937 which are in excess of the minimum acceptable limit. The comparative fit index (CFI) analyses the model fit by assessing the inconsistency between the observed data and the developed model, while adjusting for the sample size issues inherent in the CMIN/DF test of model GOF (Gatignon, 2010). The CFI for the developed structure is estimated as 0.988 which is greater than the minimum limit of 0.9 (Hair et al., 2006). The values of model fit indices for all the risk dimensions are within the acceptable limits for all the measurement parameters, showing a good fit of data in the developed model. Altogether, these results suggest that, respective risk factors in each risk dimension measured a single construct (dimension) and the various factors, seen as different ways of capturing the same construct, provided the same results confirming the convergent validity of the model.

3.5.3 Risk taxonomy for NPD process and managerial implications

A structured risk taxonomy framework is developed based on the empirical investigation and analysis of the risk factors in NPD process. The taxonomical structure illustrated in Figure 3.4 depicts thirty-five risk factors prevalent in NPD process, divided into seven clusters called ‘risk dimensions’. This taxonomy provides a holistic view of prevalent risks in the NPD process, and the classification of these risk factors into risk dimensions showcases the underlying category to which the risk factors associate. In Figure 3.4, the risk factors are shown as ovals, and the risk dimensions are represented by rectangles; all contributing to overall risk in NPD process.

The risk dimensions (market, supply chain, manufacturing, technological, regulatory, organisational, and financial) derived in this study also indicates different management functions of an organisation. While managing a NPD project, the decision makers can identify the risks in their NPD initiative and map it with the concerned management function for further monitoring and control of the risks.

Figure 3.4: Taxonomy of risks in new product development process



Prior research findings (Akram and Pilbeam, 2015; Mu et al., 2009; Salavati et al., 2016) have suggested that improved knowledge of risk factors would enable better working of NPD teams enhancing organisational performance. Hence, the findings of this work would be appreciated by product development and management professionals. With the knowledge of the intensity of various risk factors, some precautions and mitigating measures may be taken by the engineering managers to control these risk factors which affect the NPD process. The managers can get benefit from the risk taxonomy established in this study by using this model as a reference framework for the risks occurring in the NPD process and evaluate the need for managing the risks that exist in NPD initiatives in their organisation. The risk factors and risk dimensions highlighted in this study would provide a direction to industrial managers for focusing their resources on these risks and further optimize their NPD processes. The normative advice for managers is to cultivate an environment for actively managing risks occurring in various dimensions of NPD process and build confidence among various stakeholders involved in the new product development activities.

3.6 Conclusion

This chapter provided a comprehensive study of different risks existing in new product development process in any organisation. Various risk factors are extracted from literature to conduct empirical investigation in Indian automotive industry, and structured risk taxonomy is established for the aid of researchers and practitioners. The risk taxonomy established in this study will serve as a beneficial resource for engineering management professionals indulged in NPD projects in various manufacturing enterprises. The developed taxonomy might act a reference model for identifying risks prevalent in NPD initiatives in various organizations. The decision makers in an organisation can estimate the risks in their NPD process, and adjudge the resources required to mitigate and control the adverse effects of the various risks in the NPD process. The taxonomy provides a basis for developing and testing hypotheses related to what extent these risks affect various activities in NPD process and how can their mitigation ensure success of the NPD process and product. In forthcoming chapters, the inter-relationships of the identified risk factors will be analysed to understand the mutual influences of these risk factors on the NPD process.

Chapter 4

RISK INTER-DEPENDENCY ANALYSIS

4.1 Introduction

Researchers have been interested in exploring what risk factors could drive towards failure of NPD project and how to prevent them. The complexities in products and processes are increasing day by day leading to more costly and risky NPD process. Literature shows that there exist various risk factors which can hamper the success of NPD process in organisations. But, few studies were reported specifically analysing the inter-dependencies of these risk factors prevalent in NPD process. This study is motivated by the need to explore the underlying interactions among various risks in NPD process and effects they cause on each other; and to establish an integrated hierarchical relationship model of risk factors in NPD process.

This chapter investigates various risks occurring in the NPD process as identified in previous chapter and develops an integrated framework depicting the mutual relationships between the identified risks. Interpretive structural modeling (ISM), introduced by Warfield (1974), has proved as a potent tool for investigating the interactions between various factors or variables in different areas of research e.g. product development (Kumar et al., 2016), supply chain management (Charan et al., 2008; Soni et al., 2014; Verma et al., 2013), lean manufacturing (Vasanthakumar et al., 2016; Vinodh et al., 2016), smart manufacturing (Khan and Haleem, 2012), mass customization (Purohit et al., 2016), etc. Hence, ISM technique is employed to develop an integrated framework for the risk factors prevalent in NPD process; and identify 'dependent risks' (influenced by other risk factors) and 'driving risks' (influencing others).

This chapter is structured into five sections, starting with the current section providing introduction to the work. Section two provides literature background and theoretical foundations on which this study is grounded. Research methodology and data analysis is described in section three. Fourth section discusses the outcomes of the analysis and provides managerial implications of the results. Lastly, the chapter concludes with the summary of study and establishment of critical driving risk factors in NPD process.

4.2 Background

Risk management acts as a crucial enabler in enhancing the performance of new product development process in manufacturing enterprises (Salavati et al., 2016). Study by Oehmen et al. (2014) concluded that risk management practices have positive impact on the performance of NPD initiatives. The effectiveness of launching new products can be largely improved by acting upon the major risks hindering the success of NPD initiatives (Mu et al., 2009). Many studies are available in the literature related to identification of risk factors and risk sources in NPD process and have listed a number of risks affecting the NPD process (refer to chapter 3).

The identified risk factors according to the risk taxonomy established in previous chapter are taken as input for this analysis. The identified risk factors are renamed, based on the risk dimensions, for the ease of application of ISM methodology and better understanding. The risk factors are summarised in Table 4.1 providing risk dimensions, risk factors, and nomenclature.

Table 4.1: Nomenclature of risks within each risk dimension

Risk dimension	Risk factor
Market	*MT1* Actions of competitors
(MKT)	*MT2* Limited market segment
	MT3 Commercial viability
	MT4 Effect of brand image of the organization
	MT5 Unfamiliar sales and service tasks
	MT6 Short life cycle due to changes in customer needs
	MT7 Inability to predict demand
	MT8 Lack of training to end users
	MT9 Developing many variants at once
Manufacturing	*MG1* Manufacturing capability of the organization
(MFG)	*MG2* Incorporation of late design changes
	MG3 Inability to attain specifications & intended functions

Risk dimension	Risk factor
	MG4 Customer integration in NPD process
	MG5 Lack of quality assurance by the developers
	MG6 Lack of novelty in new product
	MG7 Complexity of production process
Supply Chain	*SP1* Unsuitable product development schedule
(SUP)	*SP2* Capability of supplier
	SP3 Logistic network complexity
	SP4 Availability & allocation of resources
	SP5 Instability in the supplier relations
Regulatory	*RG1* Leakage of technical trade secrets
(REG)	*RG2* Intellectual property rights and patents issues
	RG3 Changes in regulatory requirements
	RG4 Changes in buying behaviour of consumers
	RG5 Environment risk posed by the new product
Organisational	*OG1* Capability of product development team
(ORG)	*OG2* Coordination within the product development team
	OG3 Changing priorities of senior management
	OG4 Complexities in project management
Technological	*TC1* Technological R&D capability
(TEC)	*TC2* Changes in the technology
	TC3 Technical complexity of product design
Financial	*FN1* Product development budget constraint
(FIN)	*FN2* Error in estimation of project cost

4.3 ISM Methodology and Data Analysis

All the identified risk factors are analysed to explore the inter-relations between them and provide distinguished levels of driving risk factors using ISM. The interpretive structural model identifies critical risk factors playing a major role in jeopardising the success of NPD project; and assists decision makers in directing their efforts towards mitigating the adverse effects of these risk factors. A panel of five subject matter experts consisting of two academicians and three industry practitioners is constituted to deliberate on the inter-relationships between various risk dimensions and among different risk factors within each risk dimension. The data analysis methodology of ISM is described in subsequent sub-section.

4.3.1 Interpretive structural modeling (ISM)

ISM was developed as "a computer-assisted learning process that enables individuals or groups to develop a map of the complex relationships between many elements involved in a complex situation" (Janes, 1982, p. 147). In this study, experts from academia and manufacturing enterprises engaged in developing new products have been consulted for the establishment of the contextual relationship between the risk factors.

The steps for implementation of ISM method (adapted from Charan et al., 2009; Kannan et al., 2009; Soni and Kodali, 2016b) are explained below:

1. *Structural Self-Interaction Matrix (SSIM)*: It is a pairwise relationship matrix showing the relationship of "affects" type which means that one risk dimension or factor affects another risk dimension or factor. Table 4.2 shows the SSIM developed on the basis of the contextual relationship between factors *p* and *q* represented by the symbols 'F', 'R', 'E', and 'U'; where 'F' denotes risk dimension or factor *p* affects risk dimension or factor *q*, 'R' denotes risk dimension or factor *q* will affect risk dimension or factor *p,* 'E' denotes risk dimension or factor *p* and *q* affect each other equally, and 'U' denotes risk dimension or factor *p* and *q* are unrelated having no significant influence on each other.

2. *Reachability Matrix*: The SSIM is then converted into initial reachability matrix, which is a binary matrix, by substituting 'F', 'R', 'E', and 'U' values in the cells of SSIM by binary digits (1 or 0) based on the rules of ISM application as demonstrated in Table 4.3. After creating the initial reachability matrix, transitivities in the matrix are checked. If a dimension

or factor *p* affects dimension or factor *q*, and *q* affects another dimension or factor *r*, then *p* would have an indirect effect on *r*; and final reachability matrix is generated by including the transitivities between two or more pair of risk dimensions or factors.

Table 4.2: Structural self-interaction matrix for risk dimensions

Risk dimension		**MKT**	**MFG**	**SUP**	**REG**	**ORG**	**TEC**	**FIN**
Market	*MKT*	E	R	R	R	R	R	R
Manufacturing	*MFG*		E	R	R	R	R	R
Supply Chain	*SUP*			E	R	R	U	U
Regulatory	*REG*				E	F	U	U
Organisational	*ORG*					E	F	F
Technological	*TEC*						E	U
Financial	*FIN*							E

Table 4.3: Rules for converting SSIM into binary matrix

SSIM Value	**Reachability Matrix Value**	
Cell (i , j)	*Cell (i , j)*	*Cell (j , i)*
F	1	0
R	0	1
E	1	1
U	0	0

3. *Level Partitions*: Various levels in the ISM hierarchy are established using the antecedent set and the reachability set for each risk dimension or factor. The antecedent set is made up of dimension or factor itself and the dimensions or factors which affect it; and the reachability set comprises of dimension or factor itself and the dimensions or factors which it affects. The intersection of these two sets is then obtained; and the dimensions or factors containing same elements in the intersection and reachability sets are placed at first level in the ISM hierarchy. The dimensions or factors

which have been assigned level are removed from the sets of remaining dimensions or factors and the iterations are continued till the level of each factor is determined as shown in Table 4.4.

Table 4.4: Level partitions for risk dimensions

No.	Risk Dimension	Reachability Set	Antecedent Set	Intersection Set	Level	Dependence Power	Driving Power
1	MKT	1	1, 2, 3, 4, 5, 6, 7	1	I	7	1
2	MFG	2	2, 3, 4, 5, 6, 7	2	II	6	2
3	SUP	3	3, 4, 5	3	III	3	3
4	REG	4	4	4	V	1	7
5	ORG	5	4, 5	5	IV	2	6
6	TEC	6	4, 5, 6	6	III	3	3
7	FIN	7	4, 6, 7	7	III	3	3

4. Above steps are repeated for analysing the risk factors within each dimension of risk. Table 4.5 shows the SSIMs for each risk dimension for NPD process. The iterations for level partitions for each risk dimension are shown in Table 4.6.

Table 4.5: SSIMs for risk factors within each risk dimension

Risks									
Market	*MT1*	*MT2*	*MT3*	*MT4*	*MT5*	*MT6*	*MT7*	*MT8*	*MT9*
MT1	E	R	U	R	U	R	U	U	R
MT2		E	F	U	U	U	U	U	U
MT3			E	R	R	R	R	U	R
MT4				E	U	U	U	R	E
MT5					E	U	U	F	R
MT6						E	F	R	F
MT7							E	U	U
MT8								E	R
MT9									E

Risks							
Manufacturing	*MG1*	*MG2*	*MG3*	*MG4*	*MG5*	*MG6*	*MG7*
MG1	E	F	F	U	F	U	E
MG2		E	F	E	U	R	E
MG3			E	R	F	U	R
MG4				E	U	U	E
MG5					E	U	U
MG6						E	U
MG7							E
Supply Chain	*SP1*	*SP2*	*SP3*	*SP4*	*SP5*		
SP1	E	U	U	F	E		
SP2		E	U	U	U		
SP3			E	F	E		
SP4				E	R		
SP5					E		
Regulatory	*RG1*	*RG2*	*RG3*	*RG4*	*RG5*		
RG1	E	E	U	U	U		
RG2		E	U	U	U		
RG3			E	F	R		
RG4				E	R		
RG5					E		
Organisational	*OG1*	*OG2*	*OG3*	*OG4*			
OG1	E	U	R	U			
OG2		E	F	F			
OG3			E	E			
OG4				E			
Technological	*TC1*	*TC2*	*TC3*				
TC1	E	R	U				
TC2		E	F				
TC3			E				
Financial	*FN1*	*FN2*					
FN1	E	R					
FN2		E					

Table 4.6: Level partitions for risk factors in each risk dimension

No.	Risk Factor	Reachability Set	Antecedent Set	Intersection Set	Level	Dependence Power	Driving Power
Market							
1	MT1	1,	1, 2, 4, 6, 8, 9,	1,	i	6	1
2	MT2	2,	2,	2,	ii	1	3
3	MT3	3,	2, 3, 4, 5, 6, 7, 8, 9,	3,	i	8	1
4	MT4	4, 5, 8, 9,	4, 5, 6, 8, 9,	4, 5, 8, 9,	ii	5	6
5	MT5	4, 5, 6, 8,	4, 5, 6, 8, 9,	4, 5, 6, 8,	ii	5	5
6	MT6	6, 8, 9,	5, 6, 8, 9,	6, 8, 9,	iii	4	8
7	MT7	7,	6, 7, 8, 9,	7,	ii	4	2
8	MT8	6, 8, 9,	4, 5, 6, 8, 9,	6, 8, 9,	iii	5	8
9	MT9	6, 8, 9,	4, 6, 8, 9,	6, 8, 9,	iii	4	8
Manufacturing							
1	MG1	1, 2, 4, 7	1, 2, 4, 6, 7	1, 2, 4, 7	iii	5	6
2	MG2	1, 2, 4, 7	1, 2, 4, 6, 7	1, 2, 4, 7	iii	5	6
3	MG3	3	1, 2, 3, 4, 6, 7	3	ii	6	2
4	MG4	1, 2, 4, 7	1, 2, 4, 6, 7	1, 2, 4, 7	iii	5	6
5	MG5	5	1, 2, 3, 4, 5, 6, 7	5	i	7	1
6	MG6	6	6	6	iv	1	7
7	MG7	1, 2, 4, 7	1, 2, 4, 6, 7	1, 2, 4, 7	iii	5	6
Supply Chain							
1	SP1	1, 3, 5,	1, 3, 5,	1, 3, 5,	ii	3	4
2	SP2	2,	2,	2,	i	1	1
3	SP3	1, 3, 5,	1, 3, 5,	1, 3, 5,	ii	3	4
4	SP4	4,	1, 3, 4, 5,	4,	i	4	1
5	SP5	1, 3, 5,	1, 3, 5,	1, 3, 5,	ii	3	4
Regulatory							
1	RG1	1, 2	1, 2	1, 2	i	2	2
2	RG2	1, 2	1, 2	1, 2	i	2	2
3	RG3	3	3, 5	3	ii	2	2
4	RG4	4	3, 4, 5	4	i	3	1
5	RG5	5	5	5	iii	1	3

No.	Risk Factor	Reachability Set	Antecedent Set	Intersection Set	Level	Dependence Power	Driving Power
Organisational							
1	OG1	1,	1, 2, 3, 4,	1,	i	4	1
2	OG2	2,	2,	2,	iii	1	4
3	OG3	3, 4,	2, 3, 4,	3, 4,	ii	3	3
4	OG4	3, 4,	2, 3, 4,	3, 4,	ii	3	3
Technological							
1	TC1	1	1, 2	1	i	2	1
2	TC2	2	2	2	ii	1	3
3	TC3	3	2, 3	3	i	2	1
Financial							
1	FN1	1	1, 2	1	i	2	1
2	FN2	2	2	2	ii	1	2

5. *ISM-based Relationship Model*: The model is a hierarchical structure depicting the relations between various factors positioned at various levels of dependence. The dimensions or factors at last level forms the base of the model and all the dimensions or factors are positioned on top of the previous level until the first level dimensions or factors are positioned at the top in the ISM-based model. The elements at any particular level drive towards the factors on levels above them.

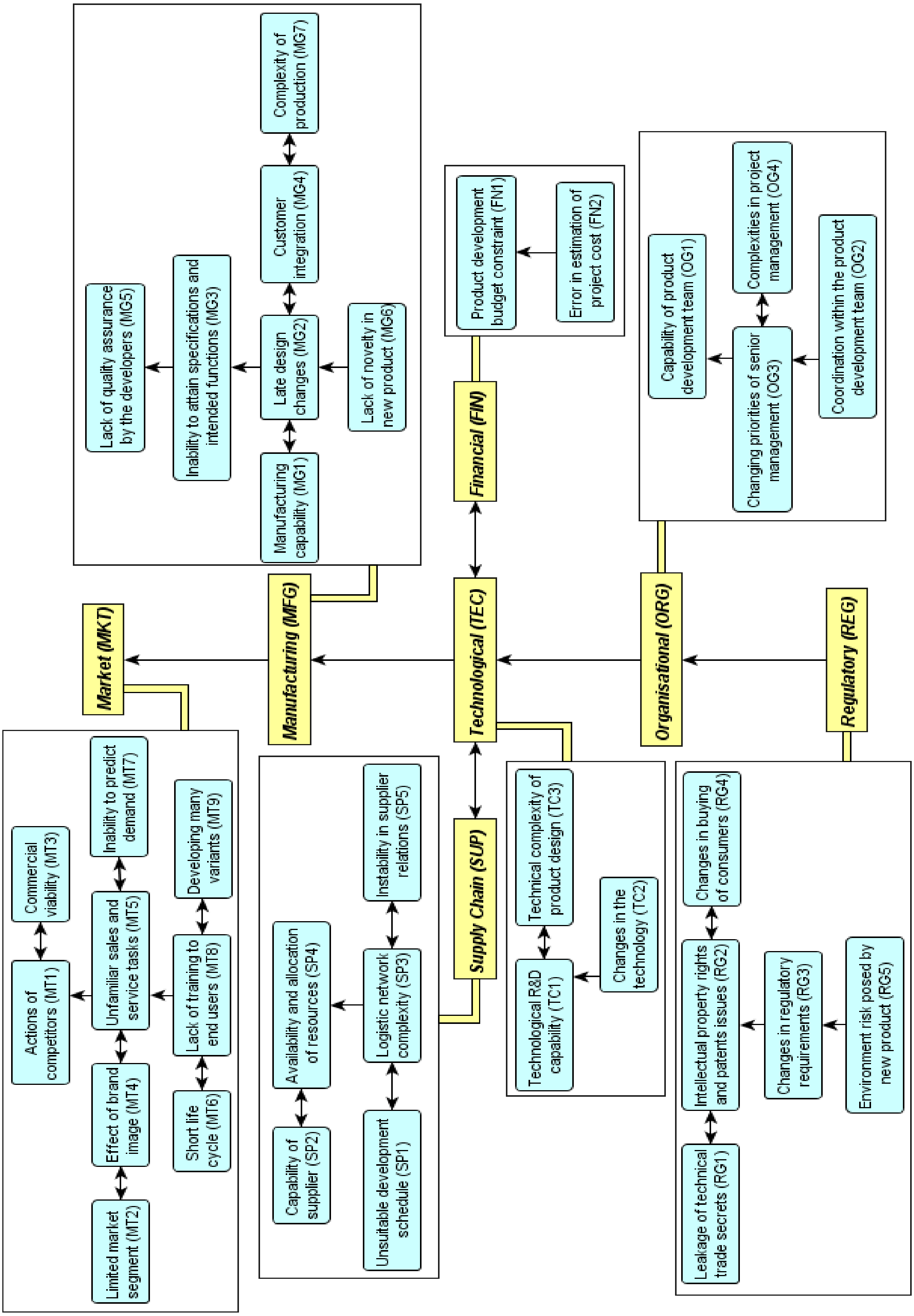
6. *MICMAC (Matriced' Impacts croises-multiplication applique' and classment) Analysis*: The dependence power (total dimensions or factors which influence it) and the driving power (total dimensions or factors which it influences) for each dimension of factor are calculated from the reachability matrix. MICMAC analysis is performed by plotting a scatter graph between dependence and driving powers of the risk dimensions or factors. The dependence and driving powers of the risk dimensions and factors are indicated in Table 4.4 and Table 4.6.

4.4 Development of Integrated Framework and Discussions

All the risk dimensions are structured hierarchically based on the levels (Table 4.4) obtained from ISM analysis. Further, the risk factors under each risk dimension are incorporated into the interpretive structural model developed for the risk dimensions on the basis of hierarchy levels given in Table 4.6. The combined model presents an integrated framework of the prevalent risk factors in NPD process, providing a holistic view of the risks affecting the NPD process. The developed integrated model for risks in NPD process is depicted in Figure 4.1. In the integrated risk model, the risk dimensions or factors at any particular level drive towards the dimensions or factors on levels above them.

The integrated interpretive structural model (Figure 4.1) reveals that 'regulatory' risk dimension forms the base of NPD risks hierarchy indicating a strong influence of regulatory risks on other risks in NPD process. The driving power of regulatory risks is very high which may cause aggravation of other risks if regulatory risks are not under control. Next in model comes 'organisational' risk dimension inferring that organisation or managerial risks play important role in affecting the NPD process outcome. 'Supply chain', 'technological', and 'financial' risk dimensions are placed in the middle of ISM structure. These dimensions are affected by regulatory and organisational risk dimensions. 'Manufacturing' and 'market' are the risk dimensions on which the effectiveness of the NPD projects depend. These are driven by other risks and final success of the NPD process is dependent on the performance of 'market' risks. The 'market' risk dimension appears at the top of the model signifying high dependency with low driving strength. If the enterprises are able to keep the market risk dimension in control, there are better chances of success of NPD project. Lower levels of market risks indicate successful control of other risks which drives towards this dimension at level-I of the model. Similar inferences can be drawn about the risk factors within each risk dimension. The hierarchical levels of risk factors in the integrated model reveals the most driving risk factors requiring mitigation actions on priority basis for controlling the adverse effects of the risks on NPD process.

Figure 4.1: ISM-based integrated model for risks in NPD process



The dependence power versus driving power diagram for seven risk dimensions (Figure 4.2) and for risk factors within each dimension (Figure 4.3) are plotted depicting the distribution of risks in four quadrants. In Figure 4.2 and Figure 4.3, *x*-axis represents the dependence power and *y*-axis represents driving power of the risks. Graphs obtained by MICMAC analysis provide better insights to the decision makers about the risk dimensions as well as the risk factors within each dimension for NPD process. The knowledge of these insights and inter-relationships would assist decision makers in dealing with the risks proactively.

Figure 4.2: MICMAC analysis diagram for risk dimensions

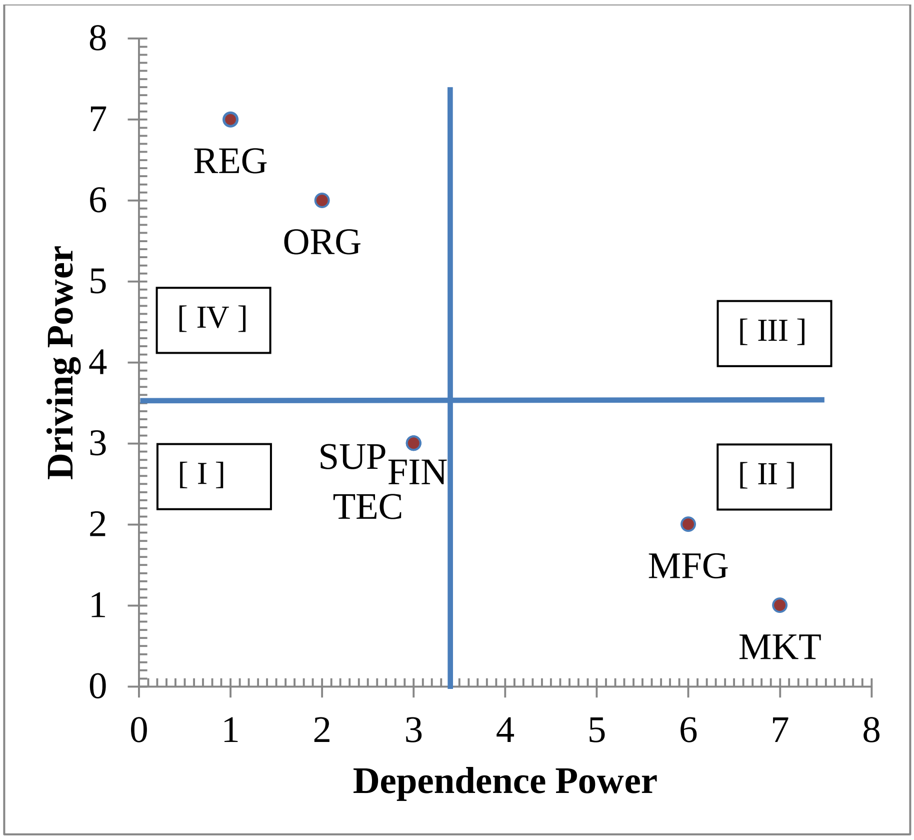
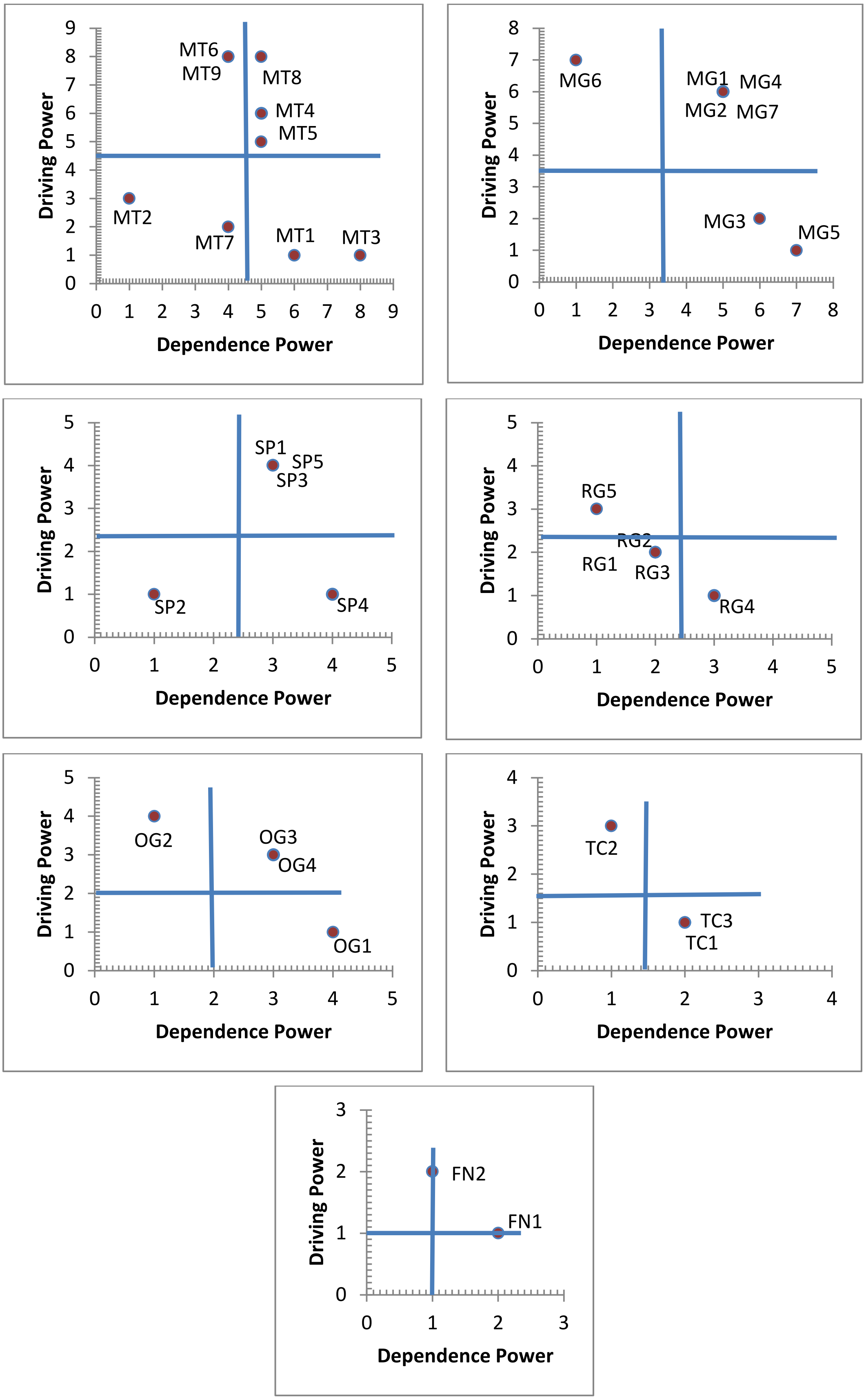


Figure 4.3: MICMAC analysis diagrams for risk factors within each dimension



The findings of MICMAC analysis of risks are clustered into four quadrants, based on their driving power and dependence power, as follows:

Quadrant I: Autonomous category consists of such dimensions or factors which have little influence on overall relationship structure as they are weak drivers as well as weak dependents. It can be seen from Figure 4.2 that three risk dimensions viz. supply chain, technological, and financial, fall under this category. These dimensions do not have much impact on other risks but they are important individually and can be dealt without concerning much about the repercussions it might have on other dimensions. It can be observed from Figure 4.3 that this category of factors comprise of two factors (MT2 and MT7) from market, one factor (SP2) from supply chain, and three factors (RG1, RG2, and RG3) from regulatory risk dimensions.

Quadrant II: Two dimensions (manufacturing and market) are labelled under *dependent category*. These dimensions are weak drivers but strongly dependent on others. These dimensions do not need much of direct attention from the decision makers as these can be managed by working upon their driving dimensions. The risk factors MT1, MT3, MG3, MG5, SP4, RG4, OG1, TC1, and TC3 within respective dimension fall under this category.

Quadrant III: No risk dimension is seen under *linkage category* that has high dependence as well as high driving strength. It can be inferred that all the identified risk dimensions of NPD process are stable on their own. Whereas, the risk factors falling under this category within each dimension are unstable and require special attention for managing these risk factors. The risk factors MT4, MT5, MT8, MG1, MG2, MG4, MG7, SP1, SP3, SP5, OG3, OG4, FN1, and FN2 fall under this linkage category, which need immediate actions from product development managers.

Quadrant IV: The *independent category* comprises of those dimensions or factors possessing high driving strength and low dependence. Such elements may be treated as 'key elements' which guide the whole framework. The changes in any of these dimensions or factors will have an effect on other dimensions or factors which are dependent on them. Two dimensions are identified as the independent dimensions viz. 'regulatory' and 'organisational' which have maximum impact on the overall risk environment of the NPD process. These two dimensions are responsible for aggravating other risks in the process. When individual risk dimensions are analysed, it could be observed that the key risks having maximum effect on the NPD process are MT6, MT9, MG6, RG5, OG2, and TC2. These risks require proactive response for elimination or mitigation from the risk managers of the enterprise.

4.5 Conclusion

4.5.1 Critical Risk Factors in NPD Process

The critical risk factors having most influence on the NPD process are identified by appraising the results of industry survey, ISM based model, and MICMAC analysis. As it was discussed earlier, the risk factors placed in '*linkage*' and '*independent*' categories in MICMAC analysis are the factors having more driving power and needs attention from the decision makers. There are six factors in 'independent' and fourteen factors in 'linkage' categories. Most of these factors are placed at the bottom level of ISM based model, depicting their driving power and influence on the overall system. The selection of critical risk factors is further done by considering the importance rating given to these factors in the survey by the practicing industry professional (refer to chapter 3). Hence, ten risk factors from the given seven risk dimensions are chosen as critical driving risk factors for further assessment. These ten risk factors were given an average importance rating of greater than 5 on the scale of 1 to 7 (as discussed in chapter 3). Thus, the critical risk factors identified in NPD process are *leak_sec*, *team_corm*, *reg_chg*, *org_prio*, *tech_chg*, *sup_rel*, *bdgt_cons*, *dsgn_chg*, *plc_shrt*, and *prod_nov* as shown in Table 4.7.

In this chapter, risks influencing the NPD process have been structured into an integrated interpretive structural model to analyse the interactions between the risks. The expertise and experience of industrial practitioners have been utilised in developing the integrated framework. The risks occurring in NPD process are modelled in terms of their dependence and driving powers. The risks demonstrating stronger driving power in the interpretive structural model (Figure 4.1) need to be dealt with priority because they affect other factors as well. The integrated ISM framework for NPD risks would be beneficial for engineering managers and practitioners of NPD for understanding the relationship crux. The utility of the proposed ISM based framework lies in imposing order and direction on the complexity of relationships among these factors which would help the decision makers and practitioners of NPD to better utilize their available resources for success of NPD projects in manufacturing enterprises.

Table 4.7: Critical risk factors in NPD process

S. No.	Notation	Risk factor	Risk Dimension
CR01	*leak_sec*	Leakage of Technical Trade Secrets about New Product before Product Commercialization	REG
CR02	*team_corm*	Coordination and Communication within the Product Development Team	ORG
CR03	*reg_chg*	Changes in Regulatory Requirements for the Product during Development Phase	REG
CR04	*org_prio*	Changing Organizational Priorities and Commitment by Senior Management regarding the Planned New Product	ORG
CR05	*tech_chg*	Changes in the Technology for New Product Development	TEC
CR06	*sup_rel*	Instability in the Supplier Relations affecting New Product Development	SUP
CR07	*bdgt_cons*	Product Development Budget Constraint	FIN
CR08	*dsgn_chg*	Incorporation of Late Design Changes in Product Development Process	MFG
CR09	*plc_shrt*	Short Life Cycle of the New Product due to Changes in Trends and Needs of Customer	MKT
CR10	*prod_nov*	Lack of Novelty in New Product	MFG

Chapter 5
RISK ASSESSMENT APPROACH

Risk assessment is essential to be commenced to recognize the extent of criticality of the risks identified in previous stages and their prioritization order so that relatively higher risks can be dealt with first. It is achieved with the help of fuzzy linguistics process in this chapter to determine the risk degree of the critical risk factors identified in the previous chapter. The risk assessment approach is concerned with the quantification of riskiness of the factors existing in NPD process. The utilization of fuzzy approach is suggested to reduce subjectivity and vagueness in the assessment process for calculating the risk degree of the factors.

5.1 Risk Quantification using Fuzzy Risk Evaluation Method (FREM)

Risk is the expression of the potential for shortcomings which may be realized in the future, with respect to achieving established performance requirements. As per NASA (2008), "risk is operationally defined as a set of triplets: the scenario(s) leading to degraded performance with respect to one or more performance measures; likelihood that an undesired event will occur; and severity of the consequence of the event should it occur". This can be mathematically represented as given in equation 5.1.

$$Risk = [Likelihood * Severity]_{scenario} \tag{5.1}$$

The evaluation of risk degree of the factors is based on the experts' assessment regarding probabilistic likeliness of occurrence and severity of impact of the risk factors, to measure the criticality of the risk factors. Further, calculations are done for finding out the risk degree (*RD*) to identify the criticality of risk factors. *RD* is mathematical grading of the risk of every potential risk source, which is calculated by multiplying the values of the two parameters: likelihood of occurrence of the risk (L) and severity of the effect of the risk (S). A higher *RD* indicates higher risk and vice versa. Thus, the risk factors with higher *RD* values are considered earlier in the mitigation stage of risk management for taking preventive actions due to their criticality.

5.1.1 Variables of Fuzzy Risk Evaluation Method

A risk evaluation sheet is prepared to obtain ratings of likelihood and severity of the risk factors from industry experts. The risk factors selected as variables for the evaluation are listed in the sheet. Responses from product development managers who are directly involved in various phases of NPD are obtained for evaluation of risk factors associated with the NPD process. The experts are provided with the set of risk factors and asked to rate the risk factors according to their likelihood of occurrence (L) and severity of impact (S) on a linguistic scale as shown in Table 5.1. The fuzzy linguistics theory helps in fitting in fuzzy expressions and rough or vague data into decision framework (Liu et al., 2016). A triangular fuzzy membership functions are used to convert linguistic terms into fuzzy values as given in Table 5.1.

Table 5.1: Linguistics for likelihood and severity

Linguistic Scale Terms		**Corresponding**
Likelihood of Occurrence (L)	**Severity of Impact (S)**	**Fuzzy Values**
VLO (very low)	NOS (none)	0, 0, 1.5
LO (low)	SS (slight)	1, 2.5, 4
MO (medium)	MS (moderate)	3.5, 5, 6.5
HO (high)	HS (high)	6, 7.5, 9
VHO (very high)	VHS (very high)	8.5, 10, 10

A sample evaluation table to calculate the risk degrees of each factor is shown in Table 5.2. The average of the lower, medium and upper values of the fuzzy function representing the corresponding value of expert's linguistic rating is calculated to aggregate the group judgment of experts. The defuzzified values for likelihood (DL) and severity (DS) are multiplied to calculate the risk degree (RD) of a particular factor (R_i). There are different algorithms for defuzzification, such as centre of gravity, centre of gravity for singletons, centre of area, left most maximum, right most maximum and mean of maximum. In this study, the defuzzified values for likelihood and severity are calculated using centroid of area method for defuzzification, given in equation 5.2 and equation 5.3, as it yields better results as compared to other defuzzification methods (Lin et al., 2014).

$$DS = \left\{\frac{[(SU-SL)+(SM-SL)]}{3}\right\} + SL \quad (5.2)$$

$$DL = \left\{\frac{[(LU-LL)+(LM-LL)]}{3}\right\} + LL \quad (5.3)$$

where *L*, *M*, and *U* respectively denote *lower*, *medium* and *upper* values of the fuzzy function. *DS* and *DL* are defuzzified severity and likelihood respectively. *RD* is calculated using *DS* and *DL* as given in equation 5.4 below.

$$RD = [DS * DL] \quad (5.4)$$

Table 5.2: Sample risk evaluation table

Risk Factor (R_i)	**Likelihood (*L*)**			**Severity (*S*)**			**Risk Degree (RD_i)**
	LL	*LM*	*LU*	*SL*	*SM*	*SU*	*DL* * *DS*
R_1	…	…	…	…	…	…	…
R_2	…	…	…	…	…	…	…
⋮	…	…	…	…	…	…	…
R_n	…	…	…	…	…	…	…

It is suggested to use harmonic mean of the risk degrees of all factors acting simultaneously in a phase of NPD process, for aggregating the risks in a particular phase. The aggregated risk for a phase of NPD process can be calculated using equation 5.5.

$$R_p = {}^{n_p}\Big/\sum_{i=1}^{n_p} \frac{1}{RD_i * w_{ip}} \;;\; [\,p = \{1,\ 2 \ldots k\}\,] \quad (5.5)$$

where,

R_p = Risk value of phase *p*

n_p = Number of risk factors in phase *p*

RD_i= risk degree of *i* risk factor

w_{ip}= weightage of *i* risk factor in phase *p*

k = number of phases

The integrated risk score for the entire NPD process or NPD project is evaluated as the arithmetic mean of the risk values of all the phases as the phases are in sequence. This can be represented as equation 5.6.

$$R_{NPD} = \sum_{p=1}^{k} R_p \Big/ k \tag{5.6}$$

where,

R_{NPD} = Risk score of entire NPD process

R_p = Risk value of phase *p*

k = number of phases

If the phase-wise distribution and the weightage of the risk factors are not available, cumulative risk score for the entire NPD process can be evaluated as the harmonic mean of the risk degrees of all the risk factors occurring in the NPD process. This is represented in equation 5.7.

$$R_{NPD} = n \Big/ \sum_{i=1}^{n} \frac{1}{RD_i} \tag{5.7}$$

where,

R_{NPD} = Risk score of entire NPD process

n = Number of risk factors in NPD process

RD_i = risk degree of *i* risk factor

The riskiness of a NPD project for a case organization could be evaluated by calculating the score of the risk scenario exposed in that organization. The practitioners could make the decision for pursuing (with risk mitigation) or scrapping the NPD project based on the prevalent risk score (R_{NPD}) for the process. The risk scenario is represented as equation 5.8.

$$\text{Risk Scenario: } ScR_o = \{S_1, S_2, S_3, \ldots, S_t\} \quad (5.8)$$

where,

S_j = t risk elements present in organization; $j = [1,2, \ldots t]$

$ScR_o \subset \{R_i\}$; $i = [1,2, \ldots n]$

The approach would assist decision makers in taking action on their NPD initiatives in accordance with prevalent riskiness in NPD process and the organization's risk profile.

If,

$R_{ScR_o} \leq R_\lambda$, Go (with mitigation measures)

$R_{ScR_o} \geq R_\lambda$, Kill

where,

R_λ = Threshold risk value (at discretion of management)

5.2 Application of Assessment Approach to Critical Risk Factors

The proposed risk assessment approach is applied to the stylized case of the automotive industry having ten critical risk factors identified in previous chapter.

5.2.1 Methodology of Fuzzy Risk Evaluation Method (FREM)

The various steps involved in FREM are given below:

1) Obtain the risk factors in NPD process.
2) Define fuzzy linguistic rating scale for likelihood (*L*) and severity (*S*).
3) Rating of *L* and *S* by experts for the risk factors using linguistic scale.
4) Calculate *L*, *S*, *DL*, and *DS* utilizing fuzzy values.
5) Calculate *RD* for each risk.

6) Rank the risks according to the *RD* in descending order.

7) Divide the risks into priority groups using k-means clustering.

The medium used for collecting ratings was an online interview with the industry experts. The questionnaire was presented to seven professionals working in automotive companies in India. These companies are prominent automotive organizations having wide customer base in India. A total of five out of these seven responses were further considered for analysis as only these five responses were complete in all aspects.

The assessment of *L* and *S* for the ten identified critical risk factors prevalent in NPD process performed by five industry experts (E) using fuzzy linguistic scale terms is presented in Table 5.3. The aggregated fuzzy evaluation for the critical risk factors in NPD process is exhibited in Table 5.4.

Table 5.3: Rating of *L* and *S* by industry experts

Risk Factor		Expert	Severity (S)	Likelihood (L)
CR01	*leak_sec*	E1	MS	ML
		E2	VHS	VHL
		E3	HS	VHL
		E4	HS	HL
		E5	MS	HL
CR02	*team_corm*	E1	MS	ML
		E2	MS	HL
		E3	SS	ML
		E4	MS	ML
		E5	SS	ML
CR03	*reg_chg*	E1	VHS	VHL
		E2	VHS	ML
		E3	MS	VHL
		E4	HS	HL
		E5	HS	ML
CR04	*org_prio*	E1	MS	HL
		E2	MS	HL
		E3	MS	ML

		E4	HS	HL
		E5	HS	ML
CR05	*tech_chg*	E1	VHS	VHL
		E2	VHS	ML
		E3	VHS	HL
		E4	MS	HL
		E5	MS	HL
CR06	*sup_rel*	E1	HS	HL
		E2	SS	VHL
		E3	MS	HL
		E4	MS	ML
		E5	MS	HL
CR07	*bdgt_cons*	E1	MS	ML
		E2	MS	HL
		E3	SS	ML
		E4	MS	ML
		E5	HS	LL
CR08	*dsgn_chg*	E1	VHS	VHL
		E2	HS	VHL
		E3	HS	ML
		E4	VHS	HL
		E5	HS	VHL
CR09	*plc_shrt*	E1	VHS	VHL
		E2	VHS	LL
		E3	MS	VHL
		E4	HS	HL
		E5	HS	ML
CR10	*prod_nov*	E1	HS	HL
		E2	HS	LL
		E3	MS	VHL
		E4	MS	HL
		E5	HS	HL

Table 5.4: Aggregated fuzzy evaluation for risks in NPD process

Risk	Expert	Fuzzy Rating						***RD***	**Rank**
		SL	***SM***	***SU***	***LL***	***LM***	***LU***		
	E1	3.5	5	6.5	3.5	5	6.5		
	E2	8.5	10	10	8.5	10	10		
CR01	E3	6	7.5	9	8.5	10	10		
	E4	6	7.5	9	6	7.5	9	53.82	4
leak_sec	E5	3.5	5	6.5	6	7.5	9		
	Aggregate	5.5	7	8.2	6.5	8	8.9		
	Defuzzfied Value		6.9			7.8			
	E1	3.5	5	6.5	3.5	5	6.5		
	E2	3.5	5	6.5	6	7.5	9		
CR02	E3	1	2.5	4	3.5	5	6.5		
	E4	3.5	5	6.5	3.5	5	6.5	22	10
team_corm	E5	1	2.5	4	3.5	5	6.5		
	Aggregate	2.5	4	5.5	4	5.5	7		
	Defuzzfied Value		4			5.5			
	E1	8.5	10	10	8.5	10	10		
	E2	8.5	10	10	3.5	5	6.5		
CR03	E3	3.5	5	6.5	8.5	10	10		
	E4	6	7.5	9	6	7.5	9	56.94	3
reg_chg	E5	6	7.5	9	3.5	5	6.5		
	Aggregate	6.5	8	8.9	6	7.5	8.4		
	Defuzzfied Value		7.8			7.3			
	E1	3.5	5	6.5	6	7.5	9		
	E2	3.5	5	6.5	6	7.5	9		
CR04	E3	3.5	5	6.5	3.5	5	6.5		
	E4	6	7.5	9	6	7.5	9	39	7
org_prio	E5	6	7.5	9	3.5	5	6.5		
	Aggregate	4.5	6	7.5	5	6.5	8		
	Defuzzfied Value		6			6.5			

Risk	Expert	Fuzzy Rating						RD	Rank
		SL	***SM***	***SU***	***LL***	***LM***	***LU***		
	E1	8.5	10	10	8.5	10	10		
	E2	8.5	10	10	3.5	5	6.5		
CR05	E3	8.5	10	10	6	7.5	9		
	E4	3.5	5	6.5	6	7.5	9	56.98	2
tech_chg	E5	3.5	5	6.5	6	7.5	9		
	Aggregate	6.5	8	8.6	6	7.5	8.7		
	Defuzzfied Value		7.7			7.4			
	E1	6	7.5	9	6	7.5	9		
	E2	1	2.5	4	8.5	10	10		
CR06	E3	3.5	5	6.5	6	7.5	9		
	E4	3.5	5	6.5	3.5	5	6.5	37	8
sup_rel	E5	3.5	5	6.5	6	7.5	9		
	Aggregate	3.5	5	6.5	6	7.5	8.7		
	Defuzzfied Value		5			7.4			
	E1	3.5	5	6.5	3.5	5	6.5		
	E2	3.5	5	6.5	6	7.5	9		
CR07	E3	1	2.5	4	3.5	5	6.5		
	E4	3.5	5	6.5	3.5	5	6.5	25	9
bdgt_cons	E5	6	7.5	9	1	2.5	4		
	Aggregate	3.5	5	6.5	3.5	5	6.5		
	Defuzzfied Value		5			5			
	E1	8.5	10	10	8.5	10	10		
	E2	6	7.5	9	8.5	10	10		
CR08	E3	6	7.5	9	3.5	5	6.5		
	E4	8.5	10	10	6	7.5	9	68.06	1
dsgn_chg	E5	6	7.5	9	8.5	10	10		
	Aggregate	7	8.5	9.4	7	8.5	9.1		
	Defuzzfied Value		8.3			8.2			

Risk	Expert	Fuzzy Rating						RD	Rank
		SL	***SM***	***SU***	***LL***	***LM***	***LU***		
	E1	8.5	10	10	8.5	10	10		
	E2	8.5	10	10	1	2.5	4		
CR09	E3	3.5	5	6.5	8.5	10	10		
	E4	6	7.5	9	6	7.5	9	53.04	5
plc_shrt	E5	6	7.5	9	3.5	5	6.5		
	Aggregate	6.5	8	8.9	5.5	7	7.9		
	Defuzzfied Value		7.8			6.8			
	E1	6	7.5	9	6	7.5	9		
	E2	6	7.5	9	1	2.5	4		
CR10	E3	3.5	5	6.5	8.5	10	10		
	E4	3.5	5	6.5	6	7.5	9	44.85	6
prod_nov	E5	6	7.5	9	6	7.5	9		
	Aggregate	5	6.5	8	5.5	7	8.2		
	Defuzzfied Value		6.5			6.9			

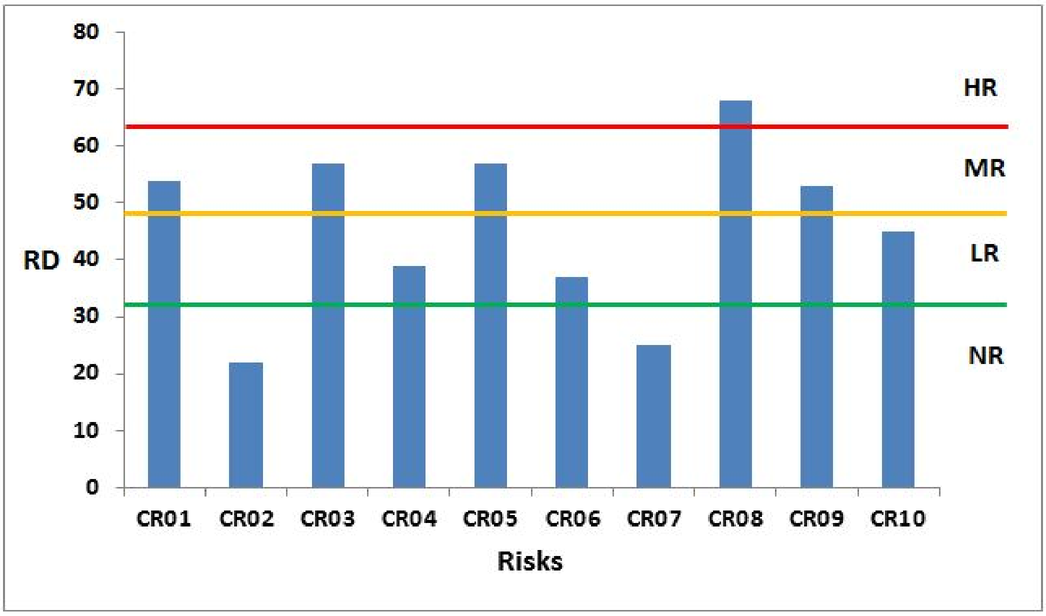
Table 5.4 shows the quantified risk values (*RD*) and ranking for all the identified critical risk factors in NPD process using equation 5.4. Greater the *RD* value of the risk factor, higher is its risk. Thus, the risk factor with highest fuzzy *RD* has been ranked 1, with second highest 2 and so on to ensure that the risk sources with higher risks are dealt earlier.

Further, the critical risks occurring during the NPD process have been categorized as negligible risks (NR), low risks (LR), moderate risks (MR) and high or critical risks (HR) as per the *RD* values obtained. The categorization of risks in four clusters is done statistically using k-means clustering approach (Laseter and Ramdas, 2002). Figure 5.1 shows the clustering of risks into priority groups.

Figure 5.1: (a) Output of k-means clustering; (b) Categorization of critical risk factors based on RD values

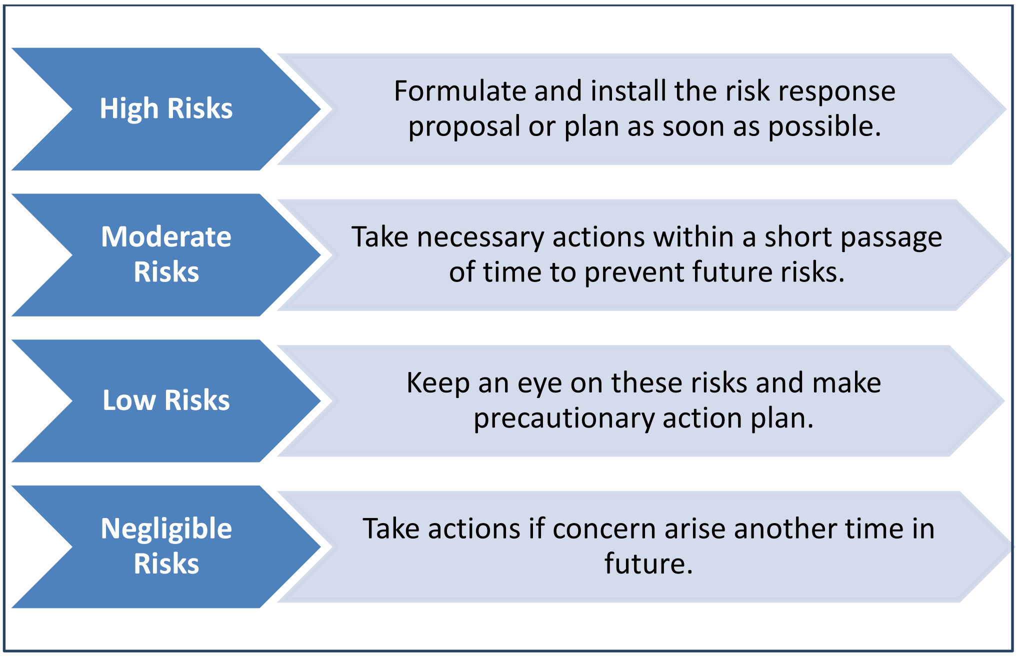
Cluster Membership

Case Number	Risk	Cluster	Distance
1	CR01	1	1.375
2	CR02	2	1.500
3	CR03	1	1.745
4	CR04	4	1.283
5	CR05	1	1.785
6	CR06	4	3.283
7	CR07	2	1.500
8	CR08	3	.000
9	CR09	1	2.155
10	CR10	4	4.567



From Table 5.4 and Figure 5.1, it is clear that CR08 (*dsgn_chg*) is the factor possessing high risks and thus it is required to eliminate or minimize it first. CR01 (*leak_sec*), CR03 (*reg_chg*), CR05 (*tech_chg*) and CR09 (*plc_shrt*) should be treated next, as they come in the next priority group of ‘moderate risks’. ‘Low risk’ factors CR04 (*org_prio*), CR06 (*sup_rel*) and CR10 (*prod_nov*) can be avoided by taking required preventive measures. There is no need to spend much resource on the risk factors in 'negligible risks' priority group. This prioritization and categorization of risk sources helps in directing the resources of an organization towards the risks deemed more critical. A normative risk mitigation strategy is suggested in Figure 5.2 for dealing with different priority groups of risks as per the resource availability and occurrence of risk events.

Figure 5.2: Normative risk alleviation strategy



5.3 Conclusion

This study provided a risk evaluation approach using FREM for NPD process. A case of automotive industry is presented to demonstrate the risk assessment approach in NPD process. The critical risk factors have been prioritized and categorized on the basis of their criticality assessed through the application of FREM approach. The outcome of this study reveals one high, four moderate, three low and two negligible risk factors. The risks related to changes in design, technology, and regulations are deemed as the most significant risks, which needs attention from the risk managers on priority basis. Consequently, a risk alleviation strategy framework has been suggested (Figure 5.2) to propose risk mitigation measures for different clusters of risks in NPD process for the aid of engineering managers.

Chapter 6

RISK MITIGATION STRATEGY

Most of the approaches available for mitigation or control of risks in NPD process are normative action plans developed on case basis. A number of risk responses may be generated by developers to control the risk factors at various phases of product development. It may sometimes be difficult for decision makers to select the best response to the risk factors. A framework for prioritization of actions for mitigating risks in NPD process might serve as a utilitarian tool for optimizing the responses to risk factors based on availability of resources and the strategic priorities of the organization. This chapter puts forward a framework for selecting the appropriate risk mitigation plan weighing in the selection parameters like cost and effectiveness of the actions in response to the risk factors.

6.1 Introduction

There exist a number of risk elements at various stages of NPD process, which needs to be systematically dealt with, to ensure successful product development (Kardes et al., 2013). These prevalent risk factors are identified and assessed for their criticality and adverse effects on the process. The risk managers have to judge the necessity of attacking all the risk factors or only the critical risk factors having high impact. A number of response actions might be available for attacking the risks occurring during the NPD process. The risk mitigation actions need to be prioritized for efficient use of mitigation budget and time. Appropriate actions taken in a timely manner against the risks can substantially improve the chances of success of a NPD initiative in any organization (Mu et al., 2009).

Risk mitigation or treatment stage is a crucial phase of risk management process since this stage constitutes of activities that deal with adoption and implementation of mitigation measures for controlling the effects of risks in NPD process. There exist a number of qualitative as well as quantitative risk evaluation and prioritization methods for assessing the criticality and impact of risk factors occurring in NPD process. These risks need to be mitigated in order to ensure successful NPD process. Contemporary risk mitigation methods used by researchers in the past have been already discussed in chapter 2.

This chapter proposes a structured approach to tackle risks in new product development process. The research contribution of this approach is to provide a systematic framework to assist decision makers in selection of effective risk mitigation plans and drive their new product endeavor towards success with reduced adversities caused by various risk factors. The framework would help in selection of a strategy to implement risk mitigation actions preventing further time delay and budgetary loss caused due to risks prevalent in an NPD project.

6.2 Framework for Developing Risk Mitigation Strategy

A structured approach is presented in this section for the selection of risk mitigation plan. The proposed approach considers the list of various critical risk factors and their risk degree as an input for the framework. These identified and quantified risks are obtained from the approaches discussed in previous studies. The current approach focuses on prioritizing the response actions to mitigate the risks in NPD process. This approach presents an empirical model for prioritizing the risk mitigation actions. Figure 6.1 depicts the proposed framework.

The methodology for selecting the appropriate risk mitigation strategy is explained below.

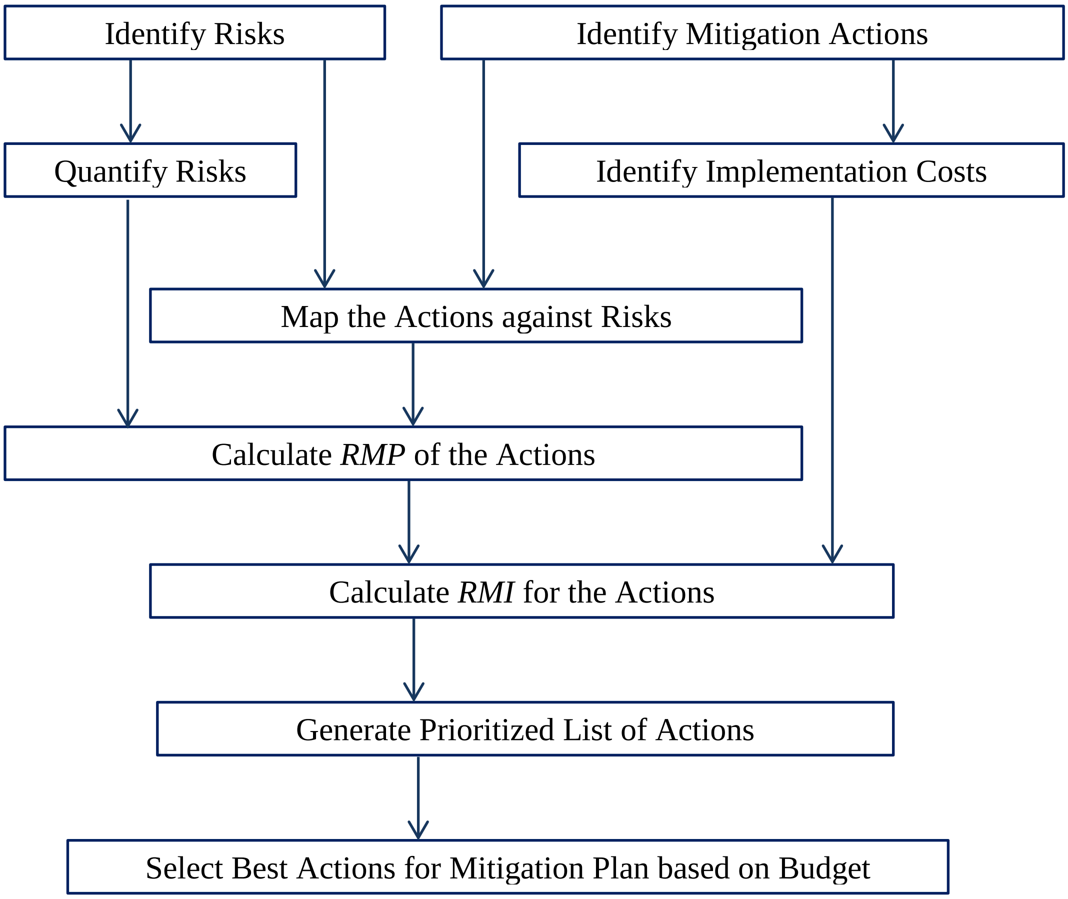
Let the set of *n* identified risk factors (R_i) in the NPD process are represented by equation 6.1.

$$\{R_i\} = \{R_1, R_2, \ldots., R_{n-1}, R_n\} \tag{6.1}$$

The quantified values of the criticality of the *n* risks are represented as risk degrees (RD_i) in equation 6.2.

$$\{RD_i\} = \{RD_1, RD_2, \ldots., RD_{n-1}, RD_n\} \tag{6.2}$$

Figure 6.1: Risk mitigation strategy framework



The available m mitigation actions (A_j) are identified as shown by equation 6.3.

$$\{A_j\} = \{A_1, A_2, \ldots., A_{m-1}, A_m\} \tag{6.3}$$

These mitigation actions are mapped across the risks determining the effectiveness (E_{ji}) of the mitigation action (A_j) against the risk factor (R_i). This mapping is done using expert evaluation regarding the extent of effectiveness of the mitigation action against the risk factors. The matrix $[E]$ representing the mapping of effectiveness of actions against the risks is shown in Table 6.1.

Table 6.1: Mitigation action effectiveness mapping matrix

	R_1	R_2	…	…	R_n
A_1	E_{11}	E_{12}	…	…	E_{1n}
A_2	E_{21}	E_{21}	…	…	E_{2n}
⋮	…	…	…	…	…
A_m	E_{m1}	E_{m2}	…	…	E_{mn}

The effectiveness value (E_{ji}) is rated by subject matter experts on a scale of *'0'* (zero) to *'1'* (one), with *'0'* meaning no effect of action *j* on risk *i* and *'1'* signifying complete mitigation of the risk *i* by action *j*. The subjectivity in this mapping process can be diminished by utilizing fuzzy approach for expert evaluation.

Using the values of effectiveness of actions against the risks and the risk degrees, *risk mitigation potential* (*RMP)* for each mitigation action (A_j) is calculated as given in equations 6.4, 6.5, and 6.6.

$$RMP_j = [E_{j1} * RD_1 + E_{j2} * RD_2 + \dots + E_{jn} * RD_n] \quad (6.4)$$

$$RMP_j = \sum_{i=1}^{n} (E_{ji} * RD_i) \quad (6.5)$$

$$\{RMP_j\} = \{RMP_1, RMP_2, \dots, RMP_{m-1}, \ RMP_m\} \quad (6.6)$$

The implementation cost (C_j) associated with mitigation action (A_j) is identified as represented in equation 6.7.

$$\{C_j\} = \{C_1, C_2, \dots, C_{m-1}, C_m\} \quad (6.7)$$

A *risk mitigation index* (*RMI*) is established for prioritizing the available mitigation actions for selecting the appropriate risk mitigation plan. The risk mitigation index (RMI_j) is evaluated for all mitigation actions (A_j) as per equation 6.8.

$$RMI_j = {RMP_j}/{C_j} \tag{6.8}$$

$$\{RMI_j\} = \{RMI_1, RMI_2, \ldots., RMI_{m-1},\ RMI_m\} \tag{6.9}$$

The set of risk mitigation indexes $\{RMI_j\}$ thus generated are ranked in descending order to get a prioritized list ($[A_j]^P$) of risk mitigation actions (A_j) as shown in equation 6.10.

$$[A_j]^P = [A_{p1}, A_{p2}, \ldots., A_{pm}] \tag{6.10}$$

$$where,\ RMI_{p1} \geq RMI_{p2} \geq \ldots. \geq RMI_{pm}$$

The risk mitigation actions of any organization are highly dependent on availability of mitigation budget. The scenarios with low mitigation budget (B_{LOW}), normal mitigation budget (B_{NORMAL}), and high mitigation budget (B_{HIGH}) availability have to be assessed to plan the mitigation strategy for an organization.

The optimal risk mitigation plan ($[M_{\mathrm{OP}}]$) would be a set of actions (A_{K}) following the given condition for respective budget scenario. The selection process starts with action with highest *RMI* and the iteration continues to next action in the prioritized list ($[A_j]^P$) until the budget constraint is fulfilled.

Equation 6.11 depicts the mitigation plan selection strategy.

$$[M_{OP}] = Select\ [A_k]^P \tag{6.11}$$

such that, $\sum_{k=p1}^{pf} C_k \leq B_{LOW}$ *(for low budget)*

or $\sum_{k=p1}^{pg} C_k \leq B_{NORMAL}$ *(for normal budget)*

or $\sum_{k=p1}^{ph} C_k \leq B_{HIGH}$ *(for high budget)*

where, $[A_k]^P \subset [A_j]^P\ and\ k \in \{\, p1, p2, .. pf, .. pg, .. ph, .., pm\}$

The mitigation strategy is incomplete without developing a system to monitor and review the actions taken for treating risks in the NPD process; and assuring that the risk factors do not resurface. The practitioners and decision makers may include other parameters (e.g. time to implement action, ease of implementation, etc.) as well while prioritizing the actions, depending upon their organization's priorities. This could be incorporated by introducing values of new parameters into the *RMI*, considering the direct/indirect relation of the parameter.

6.3 Application of Risk Mitigation Strategy: A Case

This section presents the case of an automotive new product development (ANPD) process to illustrate the risk mitigation framework developed in this study. The critical risk factors prevalent in the ANPD process along with their risk degree are identified in consultation with a panel of three managers from the case automotive industry. The industry delegates are provided with the risk taxonomy developed earlier in this study (chapter 3), and a list of five risks, as shown in Table 6.2, is identified according to the risk scenario in their organization.

Some mitigation actions (shown in Table 6.3) are identified for tackling the risks occurring in the NPD process. The mitigation actions are decided on the basis of the management actions suggested by the case industry's managers. The costs associated with the implementation of these actions are also indicated. These actions are further mapped across the prevalent risk factors for establishing the effectiveness of the actions against various risks. The effectiveness mapping matrix is shown in Table 6.4. The mapping is done by brainstorming with a group of academicians and industry practitioners.

Table 6.2: Identified risks in ANPD process

Risk Factor (CR_i)		Risk Degree	
R_1	Financial deficit	RD_1	18.3
R_2	Inadequacies and delays due to suppliers	RD_2	12.9
R_3	Lack of technological expertise and resources	RD_3	26.9
R_4	Regulatory risk due to copyrights / patents dispute	RD_4	16.4
R_5	Risks due to competition (price wars)	RD_5	30.6

Table 6.3: Available mitigation actions

Response Action (A_j)		Cost (in million Rupees)	
A_1	Monitor competitors' activities	C_1	2.7
A_2	Hire experts (experienced resource personnel)	C_2	3.9
A_3	Supplier performance assessment/review	C_3	1.4
A_4	Market research	C_4	3.6
A_5	Periodic estimation of the project outcomes.	C_5	1.3
A_6	Optimize resource utilization	C_6	1.2
A_7	Outsourcing to substitute vendors/suppliers	C_7	3.2
A_8	Evaluation of pricing strategy	C_8	1.1

Note: "The monetary values used in the case do not reflect the actual financial figures due to confidentiality and are suggestive in nature"

Table 6.4: Effectiveness mapping matrix for automotive industry case

E_{ji}	R_1	R_2	R_3	R_4	R_5
A_1	0	0	0.2	0.3	0.8
A_2	0.2	0	0.8	0.7	0
A_3	0	0.7	0.1	0	0
A_4	0.1	0	0.2	0.4	0.5
A_5	0.2	0.1	0	0.1	0.1
A_6	0.5	0	0.2	0	0
A_7	0	0.8	0.3	0	0
A_8	0.2	0	0	0	0.3

Next steps involve calculation of risk mitigation potential (RMP_j) and risk mitigation index (RMI_j) for the mitigation actions with the help of risk degrees (RD_i), effectiveness values (E_{ji}) and cost estimates (C_j). The summary of calculations is shown in Table 6.5. Hence, the prioritized list of risk mitigation actions is obtained by ranking the actions in descending order of *RMI* as shown in Table 6.6.

Table 6.5: *RMP* and *RMI* for mitigation actions

Action (A_j)	***RMP***	***RMI***
A_1	34.78	12.88
A_2	36.66	9.40
A_3	11.72	8.37
A_4	29.07	8.08
A_5	9.65	7.42
A_6	14.53	12.11
A_7	18.39	5.75
A_8	12.84	10.70

Table 6.6: Prioritized list of actions

$[A_j]^P$	A_{p1}	A_{p2}	A_{p3}	A_{p4}	A_{p5}	A_{p6}	A_{p7}	A_{p8}
A_j	A_1	A_6	A_8	A_2	A_3	A_4	A_5	A_7
RMI_j	12.88	12.11	10.70	9.40	8.37	8.08	7.42	5.75
C_j	2.7	1.2	1.2	3.9	1.4	3.6	1.3	3.2

The appropriate risk mitigation plan ($[M_{\mathrm{OP}}]$) for three possible budget scenarios is suggested below:

$If\ B_{LOW} = Rs.6\ million,$

$$[M_{OP}] = [A_1, A_6, A_8];\ C_{OP} = Rs.5.1\ million < B_{LOW}$$

$If\ B_{NORMAL} = Rs.12\ million,$

$$[M_{OP}] = [A_1, A_6, A_8, A_2, A_3];\ C_{OP} = Rs.10.4\ million < B_{NORMAL}$$

$If\ B_{HIGH} = Rs.18\ million,$

$$[M_{OP}] = [A_1, A_6, A_8, A_2, A_3, A_4, A_5];\ C_{OP} = Rs.15.3\ million < B_{HIGH}$$

Hence, a risk mitigation strategy could be formulated with the help of the proposed approach according to organizational priorities and resources.

6.4 Conclusion

The approach presented in this chapter presents a method to choose appropriate mitigation actions for eliminating or reducing the adverse effects of the risks prevalent in NPD process. A tool termed as risk mitigation index (*RMI*) is introduced for achieving the objectives of appropriate mitigation plan with least cost and most effectiveness for the NPD project. The proposed approach is demonstrated using a case example. This framework would assist decision makers in directing the organization's resources towards right direction for improving the success chances of the NPD initiative. The advantage of this approach lies in its simplistic nature. This method is different from other decision-making tools like analytic hierarchy process (AHP) and analytic network process (ANP) in terms of computational ease. AHP and ANP require multiple loops of pairwise comparisons to be done by decision makers, making problem structuring complex (Ishizaka and Labib, 2009). The approach demonstrated in this chapter can be easily utilized by the practitioners to prioritize risk mitigation actions according to their organizational priorities.

Chapter 7
DISCUSSION AND CONCLUSION

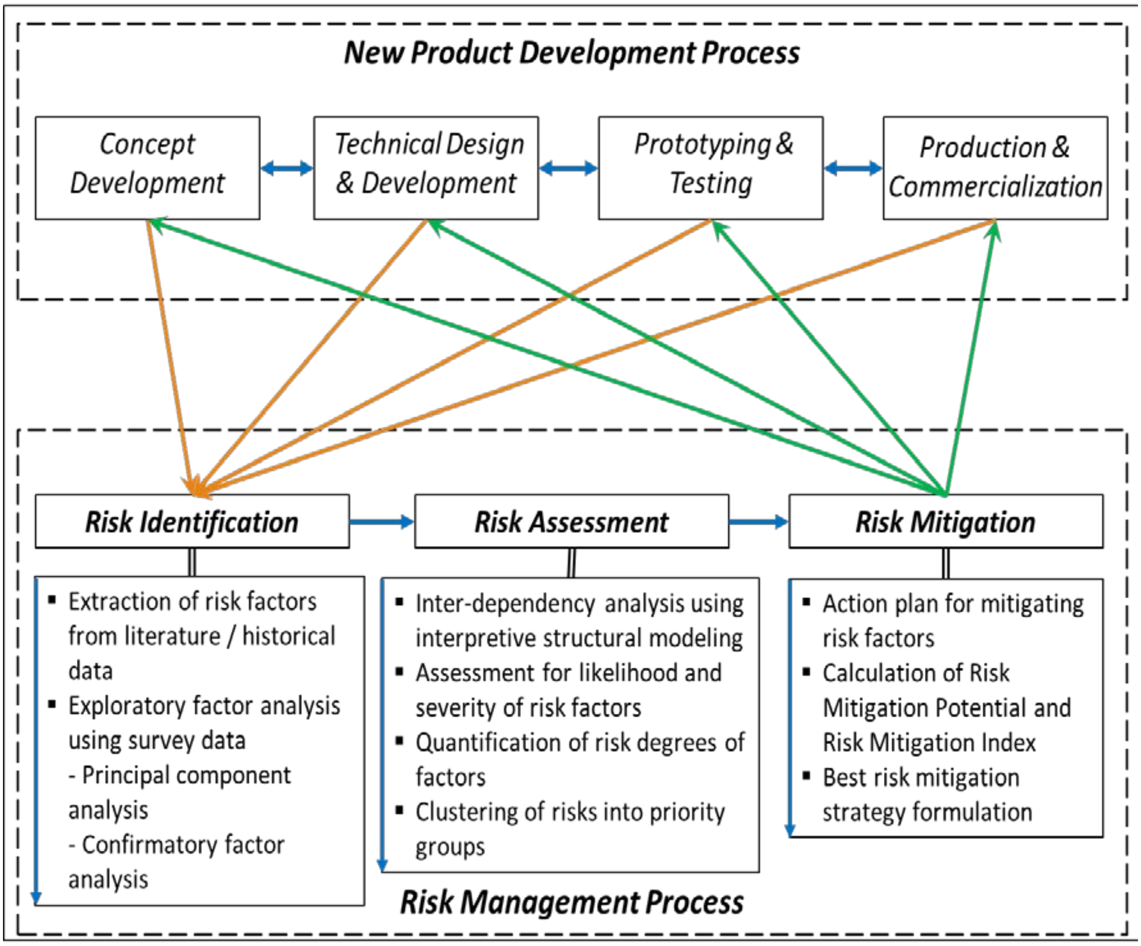
In this era of increased competition in a globalized marketplace, it is imperative for organizations to implement a structured risk management approach and tackle the risks involved in the product development process to ensure success of their NPD initiatives. An early indication of crucial risk sources would help decision makers to take necessary actions pre-emptively and avoid unfavorable consequences of the risk events. In this study, an attempt has been made to explore major risk factors affecting the NPD process and provide a holistic approach towards risk management in new product development process. This chapter presents an integrated risk management model for new product development process based on the approaches demonstrated in this study and the major findings of this research. The major research contributions of this study are also discussed along with the limitations and future research scope of the study.

7.1 Integrated Risk Management Model for NPD Process

The findings and implications of this research are consolidated in the form of an integrated model for risk management in new product development process, depicted in Figure 7.1.

In the integrated model (Figure 7.1), the NPD process is divided into four phases: concept development, technical design and development, prototyping and testing, and commercialization; while the risk management process consists of three stages: risk identification, risk assessment, and risk mitigation. The blue coloured arrows represent process flow in both NPD process and risk management process; and the green and orange coloured arrows represent flow of information.

Figure 7.1: Integrated model for risk management in NPD process



In order to implement an integrated risk management approach to NPD process, decision makers need to study and identify risks for each phase of NPD process; which is shown using orange coloured arrows in the model. The approach for identification of risks starts with extraction of risks from past literature and/or historical data available with the organizations. Then multivariate factor analysis tools are utilized for statistical analysis and classification of the identified risk factors. Once the risks are identified, interpretive structural modeling of those risks is performed for analysing the inter-dependency and mutual influences that these factors have on each other. This helps in identification of major driving risk factors which have the most impact on the NPD process. The risk assessment stage then comprises of quantification of the risk factors for evaluating the severity of the risks. It is based on the likelihood of occurrence and severity of impact of the risk factors. The quantified risk degree of risk factors is calculated using fuzzy risk evaluation method and the risk factors are clustered into priority groups for further mitigation actions. The strategy for risk mitigation involves generating a pool of mitigation actions for tackling different risk factors and these actions are mapped to indicate the relation between the mitigation actions and the risk factors. The cost associated with each mitigation measure is identified. Using these parameters, the mitigation strategy is formulated with the action plan having the goal of least cost with most effectiveness of the mitigation measures. The optimal mitigation strategy identifies risk factors with high risk impact value to mitigation cost ratio. Risk mitigation potential and risk mitigation index are estimated for the mitigation actions and prioritization is done based on the different parameters according to organizational priorities. The green coloured arrows depict the implementation of risk mitigation measures in various phases of the NPD process.

7.2 Research Contributions

The research contributions of this study are summarised as follows:

- ✓ The study provided a state-of-art literature review and examined the state of risk management research in new product development process.
- ✓ Comprehensive risk taxonomy for NPD process is developed in this study based on the empirical investigation in Indian automotive industry, which can act as a risk reference framework for researchers and practitioners.
- ✓ Inter-dependency analysis is carried out and an integrated interpretive hierarchical model is developed in this research for analysing the relationship crux of the risk factors prevalent in the NPD Process.
- ✓ A risk assessment approach is developed for quantification of risks in NPD process.
- ✓ A framework is developed for formulating risk mitigation strategy for tackling risks in the NPD process.

- ✓ Finally, an integrated model for risk management in NPD process is established for the aid of researchers and practicing engineering management professionals.

7.3 Limitations and Future Scope

The empirical investigation and cases considered in this study are devoted to Indian automotive industry alone, which can be seen as a limitation of the research. The approach used in this study could be extended to other industrial sectors as well in different geographic locations to increase generalization of the findings. The framework of the methodology can be applied to examine same problem in other industries. Furthermore, studies based on multiple industries can be performed for generalization of the results. Phase-wise distribution of risks can be studied in future to examine the significance and inter-relationship of various risks prevalent in different phases of NPD process. Further research can be done to perform path analysis on the developed interpretive model in this study. In the risk mitigation strategy, the practitioners and decision makers may include other parameters (e.g. time to implement action, ease of implementation) as well while prioritizing the actions, depending upon their organization’s priorities. This could be incorporated by introducing values of new parameters into the *RMI*, considering the direct/indirect relation of the parameter. The selection of appropriate mitigation actions proposed in this study may be further optimized with the use of heuristic methods like genetic algorithm and other programming methods.

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ANNEXURE A: Survey Questionnaire

Investigation of Risk Factors in Automotive New Product Development Process

Dear Respondent,

This survey is intended to capture the perception of industry professionals pertaining to the *Risk Factors* prevalent in *New Product Development Process* in *Indian Automotive Industry*. Kindly spare 10-12 minutes of your valuable time to take part in this research and provide responses to following questions related to various risk attributes in NPD process.

Part - I

Name (optional): ___________________________________

Email-id (optional): ___________________________________

Organization: ___________________________________

Designation: ___________________________________

Location: ___________________________________

Department / Function: ___________________________________

Work Experience (in years): ___________________________________

1. To what extent does your organization put emphasis on New Product Development and R&D?
   - ☐ Insignificant
   - ☐ Very Little
   - ☐ Somewhat
   - ☐ Reasonable
   - ☐ Very Much

2. Whether you follow any 'Formal Risk Management System' for Product Development Process in your organization?

   ☐ Yes

   ☐ No

3. In your opinion, does Risk Management Practices contribute towards success of New Products? (Effect of Risk Management on NPD excellence)

   ☐ Insignificant

   ☐ Very Little

   ☐ Somewhat

   ☐ Reasonable

   ☐ Very Much

<u>Part - II</u>

Risk Factors Affecting New Product Development Process

Please rate the *Level of Risk* posed by following Factors on *New Product Development Process* (on a scale of 1 to 7) [1= Not Risky at all, 7= Very Risky].

The sequence of questions (factors) was kept in shuffle mode while designing the online survey form.

1. Product Development Budget Constraint

	1	2	3	4	5	6	7
Risk	○	○	○	○	○	○	○

2. Error in Estimation of Project Cost

	1	2	3	4	5	6	7
Risk	○	○	○	○	○	○	○

3. Lack of Manufacturing Capability of the Organization with respect to Planned Initiative

	1	2	3	4	5	6	7
Risk	○	○	○	○	○	○	○

4. Incorporation of Late Design Changes in Product Development Process

	1	2	3	4	5	6	7
Risk	○	○	○	○	○	○	○

5. Technical Complexity of Product Design for Manufacturing

	1	2	3	4	5	6	7
Risk	○	○	○	○	○	○	○

6. Inability to Attain Specifications & Intended Functions in Final Product

	1	2	3	4	5	6	7
Risk	○	○	○	○	○	○	○

7. Customer Integration in Development Process

	1	2	3	4	5	6	7
Risk	○	○	○	○	○	○	○

8. Lack of Quality Assurance by the Developers for the New Product

	1	2	3	4	5	6	7
Risk	○	○	○	○	○	○	○

9. Lack of Novelty in New Product

	1	2	3	4	5	6	7
Risk	○	○	○	○	○	○	○

10. Complexity of Production Process for the New Product

	1	2	3	4	5	6	7
Risk	○	○	○	○	○	○	○

11. Actions of Competitors and Potential Price Wars

	1	2	3	4	5	6	7
Risk	○	○	○	○	○	○	○

12. Limited Market Segment for the Planned New Product

	1	2	3	4	5	6	7
Risk	○	○	○	○	○	○	○

13. Effect of Brand Image of the Organization on Acceptance of New Product by Consumers

	1	2	3	4	5	6	7
Risk	○	○	○	○	○	○	○

14. Unfamiliar Sales and Service Tasks Requirements for the New Product

	1	2	3	4	5	6	7
Risk	○	○	○	○	○	○	○

15. Short Life Cycle of the New Product due to Changes in Trends and Needs of Customer

	1	2	3	4	5	6	7
Risk	○	○	○	○	○	○	○

16. Inability to Predict Demand for the New Product

	1	2	3	4	5	6	7
Risk	○	○	○	○	○	○	○

17. Lack of Training to End Users for the New Product

	1	2	3	4	5	6	7
Risk	○	○	○	○	○	○	○

18. Developing Many Variants of the New Product at Once

	1	2	3	4	5	6	7
Risk	○	○	○	○	○	○	○

19. Low Commercial Viability of the Planned New Product

	1	2	3	4	5	6	7
Risk	○	○	○	○	○	○	○

20. Lack of Capability of Product Development Team to Create the New Product as per Requirements

	1	2	3	4	5	6	7
Risk	○	○	○	○	○	○	○

21. Lack of Coordination and Communication within the Product Development Team

	1	2	3	4	5	6	7
Risk	o	o	o	o	o	o	o

22. Complexities in Project Management for the Planned New Product

	1	2	3	4	5	6	7
Risk	o	o	o	o	o	o	o

23. Changing Organizational Priorities and Commitment by Senior Management regarding the Planned New Product

	1	2	3	4	5	6	7
Risk	o	o	o	o	o	o	o

24. Leakage of Technical Trade Secrets about New Product before Product Commercialization

	1	2	3	4	5	6	7
Risk	o	o	o	o	o	o	o

25. Intellectual Property Rights (IPR) and Patent Issues pertaining to the New Product

	1	2	3	4	5	6	7
Risk	o	o	o	o	o	o	o

26. Changes in Regulatory Requirements for the Product during Development Phase

	1	2	3	4	5	6	7
Risk	o	o	o	o	o	o	o

27. Changes in Social and Economic Conditions of Consumers Affecting their Buying Behaviour

	1	2	3	4	5	6	7
Risk	o	o	o	o	o	o	o

28. Environment Risk posed by the New Product Technology and the Development Process

	1	2	3	4	5	6	7
Risk	○	○	○	○	○	○	○

29. Unsuitable or Unrealistic Schedule of the Product Development Process

	1	2	3	4	5	6	7
Risk	○	○	○	○	○	○	○

30. Lack of Capability of Supplier to Deliver Good Quality Components within Stipulated Time Frame

	1	2	3	4	5	6	7
Risk	○	○	○	○	○	○	○

31. Complexity of Logistic Network for Distribution of New Product

	1	2	3	4	5	6	7
Risk	○	○	○	○	○	○	○

32. Non-availability and Inappropriate Allocation of Required Resources for New Product

	1	2	3	4	5	6	7
Risk	○	○	○	○	○	○	○

33. Instability in the Supplier Relations affecting New Product Development

	1	2	3	4	5	6	7
Risk	○	○	○	○	○	○	○

34. Lack of Technological R&D Capability of the Organization and Development Team for the Planned New Product

	1	2	3	4	5	6	7
Risk	○	○	○	○	○	○	○

35. Changes in the Technology for New Product Development

	1	2	3	4	5	6	7
Risk	○	○	○	○	○	○	○

Relevant Comments: ____

____

ANNEXURE B: List of Publications

<u>Published / Accepted Papers</u>:

1. **A. S. Chauhan**, O. P. Yadav, A. P. S. Rathore, G. Soni (2018), "A Framework for Selecting Optimal Action Plan to Mitigate Risks in NPD Process", *IEEE 64th Annual Reliability And Maintainability Symposium (RAMS)*, Jan 22-25, Reno (USA). (In Press) ***(CPCI)***

2. **A. S. Chauhan**, O. P. Yadav, A. P. S. Rathore, G. Soni (2017), "Analysis of Risk Sources in New Product Development Process using Fuzzy Failure Mode Analysis", *IEEE 24th International Conference on Industrial Engineering and Engineering Management (IEEM)*, Dec 10-13, Singapore. (In Press) ***(CPCI)***

3. **A. S. Chauhan**, G. Soni, A. P. S. Rathore (2017), "Interpretive Structural Modelling of Risk Factors in New Product Development Process: Development of an Integrated Framework", *International Journal of Intelligent Enterprise*, Vol. 4, No. 4, pp. 361-377. ***(Scopus)***

4. **A. S. Chauhan**, O. P. Yadav, G. Soni, R. Jain (2017), "A Holistic Approach to Manage Risks in NPD Process", *IEEE 63rd Annual Reliability And Maintainability Symposium (RAMS)*, Jan 23-26, Orlando (USA), pp. 1-5. ***(CPCI)***

5. **A. S. Chauhan**, A. P. S. Rathore, G. Soni (2016), "A Review of Contemporary Approaches for Risk Management in New Product Development Process", *International Conference on Emerging Trends in Mechanical Engineering (ICETiME)*, Sep 23-24, Hyderabad (India), pp. 394-398.

***SCI*:** Science Citation Index Expanded (Web of Science)

***SSCI*:** Social Science Citation Index (Web of Science)

***CPCI*:** Conference Proceedings Citation Index (Web of Science)

***Scopus*:** Scopus Index (Elsevier)

Communicated Papers:

1. **A. S. Chauhan**, B. Nepal, G. Soni, A. P. S. Rathore, "Examining the State of Risk Management Research in New Product Development Process", *Engineering Management Journal*. ***(SCI, SSCI, Scopus)*** (Minor Revision Submitted)

2. "Development of Risk Taxonomy for New Product Development Process: An Empirical Study in Indian Automotive Industry", *IEEE Transactions on Engineering Management.* ***(SCI, SSCI, Scopus)***

3. "An Integrated Approach for Quantification and Mitigation of Risks in NPD Process: A Case of Indian Automotive Industry", *Production Planning and Control.* ***(SCI, Scopus)***

SCI**:** Science Citation Index Expanded (Web of Science)

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CPCI**:** Conference Proceedings Citation Index (Web of Science)

Scopus**:** Scopus Index (Elsevier)

ANNEXURE C: Biographical Profile of the Candidate

Avanish Singh Chauhan was born on 16th September, 1988 in Bhind (Madhya Pradesh), India. He received his Bachelor of Engineering (B.E.) degree in Industrial & Production Engineering from SGSITS, Indore (Madhya Pradesh), India and Master of Technology (M.Tech.) degree in Manufacturing System Engineering from MNIT Jaipur (Rajasthan), India. He pursued his doctoral research at Malaviya National Institute of Technology Jaipur (Rajasthan), India. He is currently working as an Assistant Professor (under TEQIP-III project of NPIU, Ministry of HRD) in Production and Industrial Engineering Department of MBM Engineering College, JNV University, Jodhpur (Rajasthan), India. He has worked in the past with CASE New Holland Construction Equipment (India) Pvt. Ltd. in Product Design Department for a brief period after completing his bachelor degree. His areas of research and teaching interests are focussed around Product Design and Development, Innovation, Operations Management, Lean Manufacturing, Process Improvement, and Supply Chain Management. He has authored over 10 papers for reputed international journals and conferences. He has acted as a reviewer for various journals and conference proceedings like IJIE, IJOPM, IEEM, etc. He is a member of Indian Institution of Industrial Engineering, Production and Operations Management Society (USA), and Society of Automotive Engineers India.