DOKUZ EYLÜL UNIVERSITY
GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

APPLICATION OF RISK MANAGEMENT APPROACHES FOR NEW PRODUCT DEVELOPMENT IN CONCURRENT ENGINEERING ENVIRONMENT

by
Sibel UYSAL

April, 2019
İZMİR

APPLICATION OF RISK MANAGEMENT APPROACHES FOR NEW PRODUCT DEVELOPMENT IN CONCURRENT ENGINEERING ENVIRONMENT

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APPLICATION OF RISK MANAGEMENT APPROACHES FOR NEW PRODUCT DEVELOPMENT IN CONCURRENT ENGINEERING ENVIRONMENT

ABSTRACT

In today's increasingly competitive environment, product differentiation is one of the main competition strategies. Through new product development process, managing supply chain risks has a great importance. These processes that are executed by a multidisciplinary team working with an engineering team can provide maximum benefit in the shortest time with the lowest cost. Implementation of appropriate risk management approaches aim to ensure the sustainability of new product development processes. Therefore, they increase the contribution of new products to the competitive advantage of companies by applying a proactive approach.

This study aims to develop a decision support system for deliberating the risks with respect to cost, quality and timeliness dimensions in new product development processes. In order to confirm the viability of the proposed decision support system, a real world application is presented. The new product development process of a manufacturing firm operating in Turkish automotive industry is dealt with in the application, and the risks of each concurrent engineering process are defined. The risks are calculated by multiplying the probabilities and impacts. Then, by using the binary digits, risk interactions expressing the cause-effect relationships between the risks are determined. The binary risk matrix is transformed to the quantitative risk matrix for determining the weighted cause-effect relationships. Therefore, risks can be expressed with easily displayed models instead of complex networks with this approach.

The results confirm that the proposed decision support system can be utilized effectively in new product development processes by providing effective risk management strategies.

Keywords: New product development, risk management, concurrent engineering, risk network analysis

EŞ ZAMANLI MÜHENDİSLİK SÜRECİ İLE YENİ ÜRÜN GELİŞTİRMEDE RİSK YÖNETİMİ YAKLAŞIMLARININ UYGULANMASI

ÖZ

Günümüzün artan rekabet koşullarında, ürün farklılaştırma temel rekabet stratejilerinden biridir. Yeni ürün geliştirme süreci içerisinde, tedarik zinciri risklerini yönetmek büyük önem taşımaktadır. Farklı mühendislik birimlerinden oluşan bir ekip tarafından yürütülen bu süreçler, en düşük maliyetle en kısa sürede maksimum fayda sağlamayı hedefler. Uygun risk yönetimi yaklaşımlarının uygulanması, yeni ürün geliştirme süreçlerinin sürdürülebilirliğini sağlamayı amaçlamaktadır. Bu nedenle, proaktif bir yaklaşım uygulanması yeni ürünlerin firmaların rekabet avantajına katkısını arttırmaktadır.

Bu çalışma, yeni ürün geliştirme süreçlerinde karşılaşılabilecek riskleri maliyet, kalite ve zaman boyutlarına göre değerlendirmek için bir karar destek sistemi geliştirmeyi amaçlamaktadır. Önerilen karar destek sisteminin uygulanabilirliğini doğrulamak için gerçek bir dünya uygulaması sunulmaktadır. Türk otomotiv sektöründe faaliyet gösteren bir imalat firmasının yeni ürün geliştirme süreci, uygulamada ele alınmış ve her bir eş zamanlı mühendislik sürecinin riskleri tanımlanmıştır. Risklerin, olasılık-etki matrisi hesaplanır. Daha sonra, ikili değerler kullanılarak, riskler arasındaki sebep-sonuç ilişkilerini ifade eden risk etkileşimleri belirlenir. İkili risk matrisi, ağırlıklı neden-sonuç ilişkilerini belirlemek için sayısal risk matrisine dönüştürülür. Bu yaklaşımla, karmaşık ağlar yerine, risk modelleri kolaylıkla uygulanabilir.

Sonuçlar, önerilen karar destek sisteminin, etkin risk yönetimi stratejileri ile yeni ürün geliştirme süreçlerinde etkin bir şekilde kullanılabileceğini doğrulamaktadır.

Anahtar kelimeler: Yeni ürün geliştirme, risk yönetimi, eş zamanlı mühendislik, risk ağ analizi

CONTENTS

LIST OF FIGURES

Page

LIST OF TABLES

CHAPTER ONE
INTRODUCTION

Today, companies aim to obtain the highest profit by taking place in the market by adopting cost, time, and quality oriented approaches in the intense competition environment. In the global market, companies are open-minded to continuous improvement and they need to offer new products, services and solutions to the market. Companies that do not adopt this perspective lose their market share.

It is not always easy to offer new products to the market. It is necessary to conduct various studies such as feasibility analysis and brainstorming. It is also essential to create a project team and assign a project manager to the team during the project management. This team is responsible for directing the whole organization, internal and external stakeholders, and being the pioneers of the project idea.

In the development phase of the new products, proactive approach has a great importance. In order to be successful in new products, it is necessary to clarify and analyze all risks in the new product development process and then mitigate those risks. As known, risk management is an approach that must be implemented by companies during each project. Risk management is a topic that has been addressed by many researchers in the literature. There exists different methods, tools and techniques applied in this field. The important thing is to determine and apply convenient method, also analyze the results.

This study contributes to the literature by developing a new risk management model for the new product development process in concurrent engineering environment. The proposed model can effectively be used as a decision support tool by the firms in different sub-sector of manufacturing.

This study is further organized as follows. Chapter 2 presents the new product development process in concurrent engineering environment. Chapter 3 introduces risk management concept while Chapter 4 is devoted to the presentation of an overview of the related literature. The proposed model is introduced in Chapter 5. Chapter 6 presents the implementation of the proposed model in automotive industry. Finally, concluding remarks and future research directions are identified in Chapter 7.

CHAPTER TWO
NEW PRODUCT DEVELOPMENT IN CONCURRENT ENGINEERING ENVIRONMENT

2.1 New Product Development Process

Today, the process of new product development is extremely important for companies. In today's competitive conditions, the ability to offer new solutions to the customers in the shortest time with the lowest cost enables companies to make a difference by taking them one step further. Thus, companies that increase their profitability rate can perform the new product development processes more healthy (Tuli & Shankar, 2015).

The way to achieve a successful new product development process is to determine the needs of the customer correctly and to create the appropriate designs. For this, there exists many new product development tools in the literature (Lin, Lee, & Kang, 2015).

In recent years, companies have sought different solutions for the new product development process. Product lifecycle management providing an engineering perspective that blends people, data and processes is one of these solutions. Successful product lifecycle management prior to introducing the new product to a large extent determines the success of that product in the market (Gmelin & Seuring, 2014).

The new product development process does not always indicate the need to offer a new product to the customer. Disruptions, cost reduction, quality or design improvement studies in an existing product can also be included in the new product development. Although such investments for companies may appear to be small steps, they can be transformed into activities that are highly profitable. Improvement efforts without risk should also be considered during the new product development phase (Tuli & Shankar, 2015).

All of the company's internal organization plays a major role in the new product development process. All units must be integrated in the process effectively from the R&D to supply chain, from production to quality, from finance to method departments (Tuli & Shankar, 2015).

Product lifecycle management is the management system that is established in order to provide easily the materials and information flow within the internal organizations. Fig. 2.1 illustrates the product life cycle management in production environment.

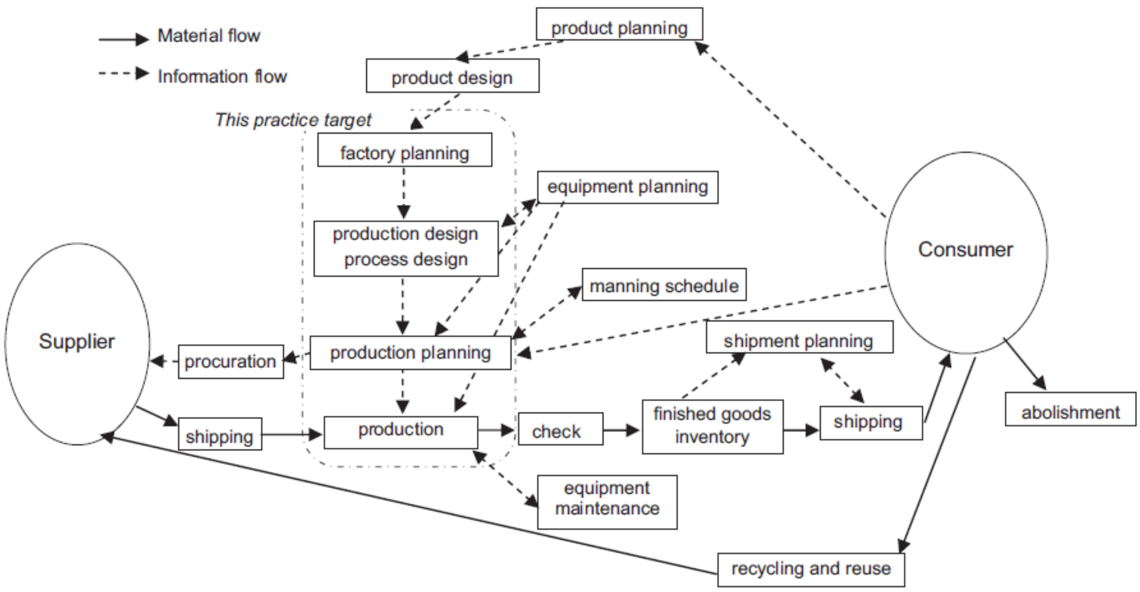


Figure 2.1 Product lifecycle management in production activity (Kakehi, Yamada & Watanabe, 2009)

2.2 Concurrent Engineering in New Product Development

The concurrent engineering approach is an engineering management philosophy that companies apply to be successful under competitive conditions. Concurrent engineering is an approach that the shortens time and increases product quality and reduces product costs in the product development process (Yassine & Braha, 2003).

In the concurrent engineering process, departments for the company contribute to the product development process by carrying out common team work. Tasks are carried out simultaneously rather than one for each department respectively (Pardessus, 2004).

The basic objectives of the concurrent engineering process can be stated as follows.

- Managing complexity; the teams are determined precisely in the product development process.
- Synchronization; execution of team work in parallel.
- Multidisciplinary engineering approach.
- Eliminating inter-organizational boundaries, development of joint working techniques.
- Determination of the process, methods and tools to be used.

Concurrent engineering process consists of three basic stages (see Fig. 2.2).

The first stage; the core management of the senior management to introduce and implement the concurrent engineering concept within the company. This core team is a multidisciplinary team consisting of different departments and should be supported by senior management.

The second stage includes the selection of pilot project. The multidisciplinary core team determine the strategies. All team employees are required to eliminate the conflicting ideas by identifying their tasks.

The last stage includes reviewing the pilot project and implementing the necessary process changes and improvements. At this stage, the concurrent engineering perspective is expanded from the core team to the entire organization (Gao, Manson, & Kyratsis, 2017).

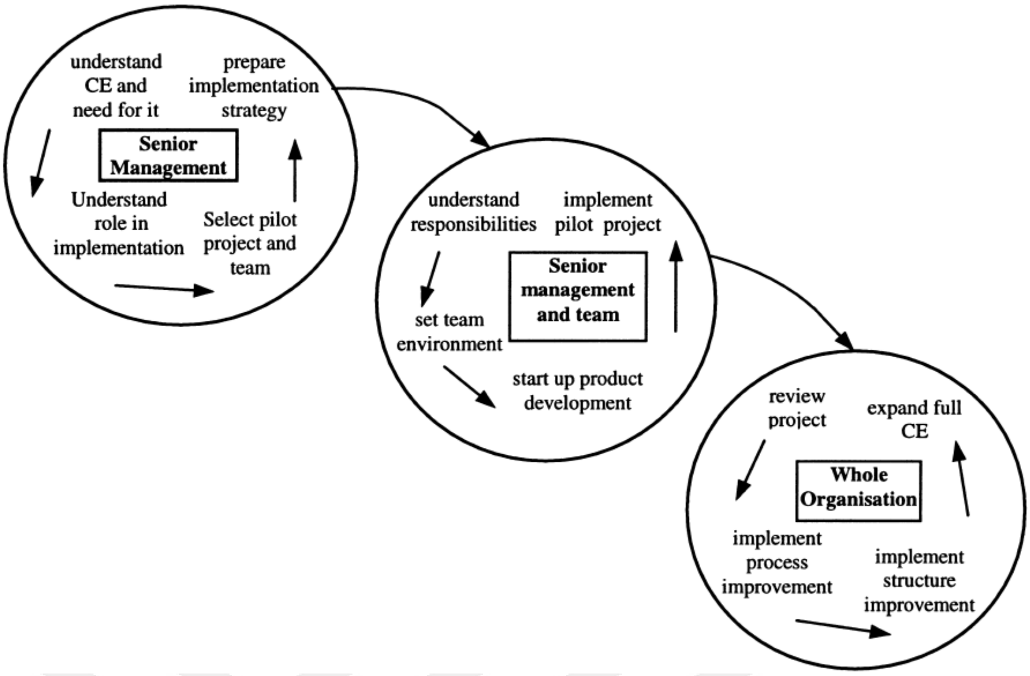


Figure 2.2 Concurrent engineering framework (Gao, Manson, & Kyratsis, 2017)

According to the complexity of the new product, the behavior of multidisciplinary teams in the process of managing the concurrent engineering process is changed. For example, in the process of developing a non-complex product, there may be no need to use any tools between organizations. However, if a complex product will emerge, companies can use different tools such as Quality Function Deployment, Design structure matrix (DSM), Product Lifecycle Management (PLM) (Gao et al., 2017).

The concurrent engineering approach is commonly referred to as R&D activities with CAD / CAM (Computer Aided Design / Computer Aided Manufacturing) applications in companies. However, it is not only design activities that contribute to the product development process, but also the work carried out by other organizations.

As illustrated in Fig. 2.3, there are four basic strategies to improve new product development performance in the concurrent engineering process.

- Providing timely product to the market,

- System thinking and perspective,
- Applying concurrent engineering methods,
- Sustainable resource assignment.

Concurrent engineering approach is an important discipline that enhances the performance of the new product development process (Belay, 2013).

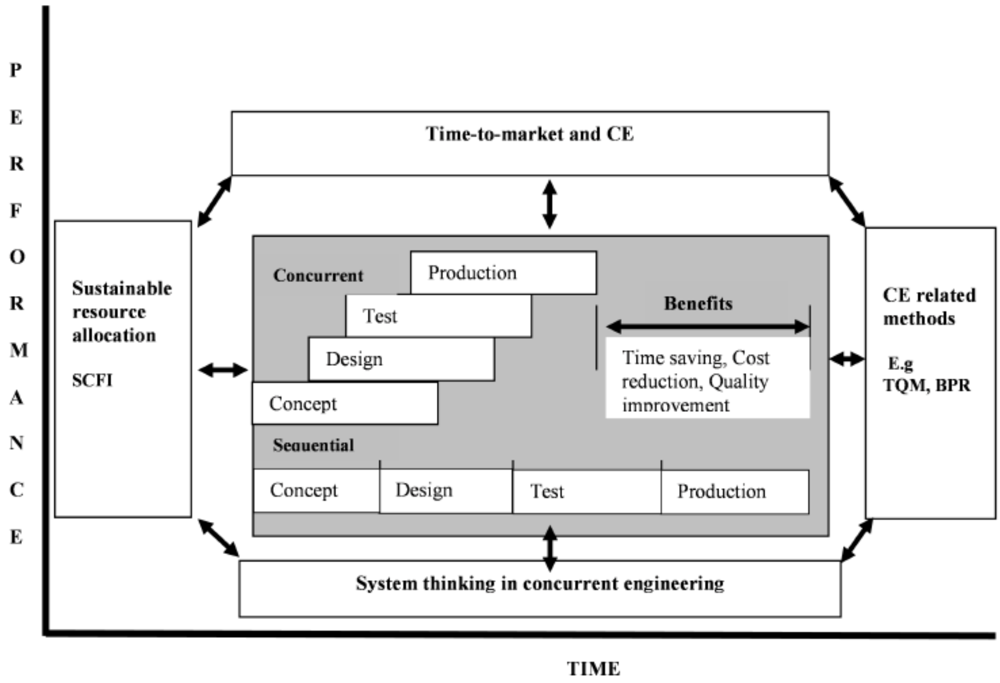


Figure 2.3 Research organization in relation to objectives (Belay, 2013)

Internal and external stakeholders may be involved in the concurrent engineering process. That's important that all stakeholders contribute to the process of developing new products simultaneously. Diversified views of concurrent engineering is illustrated in Fig. 2.4 that also refers to the scope of the conceptual model of the concurrent engineering process (Belay, 2013).

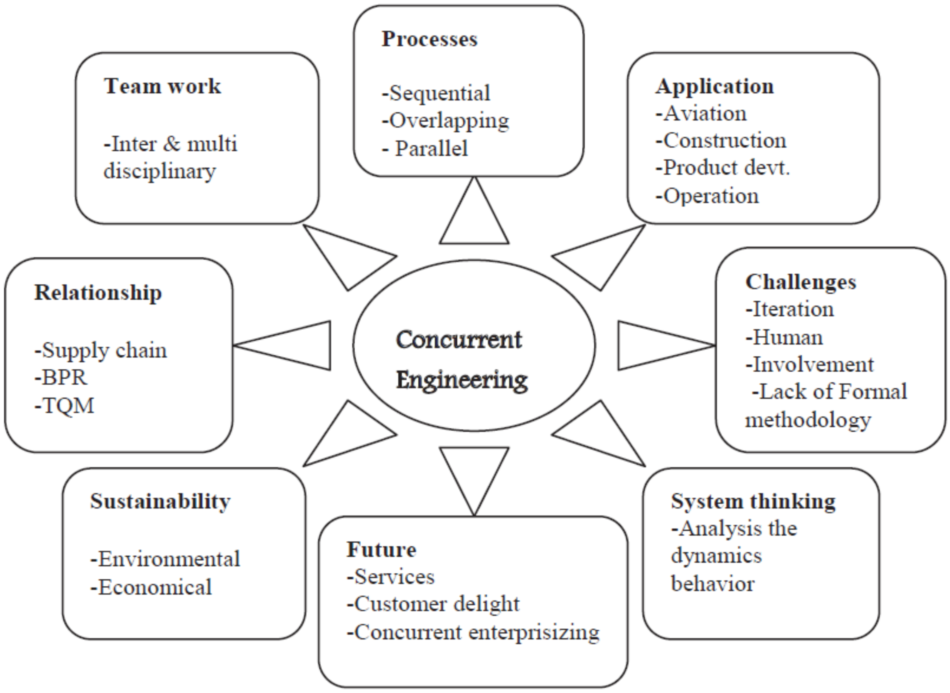


Figure 2.4 Diversified views of concurrent engineering (Belay, 2013)

2.3 Risks in New Product Development Process

Each innovation process involves uncertainty and risk factors. In the new product development process, companies may face some pressure and resistance to change. Companies that can control uncertain environment will be able to successfully manage the new product development process. Not only the uncertain environment, but also the need for the ability to meet the expectations in the market during the new product development process or to provide rapid feedback to the market offers a great challenge. Global market needs to overcome these uncertainties and create new opportunities (Wu, Kefan, Gang, & Ping, 2010).

There exists many studies in the literature about risk factors related to the design complexities or uncertainties caused by new product development process in concurrent engineering environment. In new product development process, especially project managers and project teams should reduce risks to an acceptable level by implementing a proactive approach with suppliers and customers.

New product development process involves many risks from the design stage to the commissioning phase. It is important to identify the risks correctly and to demonstrate a proactive perspective at design stage (Kayis, Arndt, Zhou, & Amornsawadwatana, 2007).

Co-operation between teams in concurrent engineering projects is one of the most important issues. Inter-departmental information sharing and data transfer enable simulated risk scenarios in the new product design process, allowing risks to be recognized and prevented. In the new product development process, managing the risks by providing inter-departmental cooperation is one of the key success factors for this process to be successful (Kayis et al., 2006).

CHAPTER THREE
RISK MANAGEMENT

3.1 Terms and Definitions About Risk Management

Haimes (2009) defined risk as "a measure of the probability and severity of adverse effects". Risk management typically differs from risk assessment, but some terms explain for risk management as a whole process of risk assessment. Howell and Obren (1999) define risk management as "the process of making and carrying out decisions that will minimize the adverse effects of accidental losses". Aven (2008) explains risk management as “a managing process of risks”. Especially, he examined risk management as a precaution to prevent natural hazards and accidents.

As risk management aims to provide a better organizational structure and tries to improve their organizational model for firms, Lalor (2018) states that risk management differ from other managerial systems like planning, quality, finance and so on.

Risk management helps organizations for producing high level products, and it creates a decision making systems for achieving strategic objectives.

Some risk management objectives are listed in the following.

- Sense of belonging and values
- Better organizational culture
- Leadership, organizational relationships and stakeholders
- Effective processes
- Strategic resources

The objective of risk management is to clarify potential problems once they occur. This helps to mitigating risks for achieving goals in new product development process.

Risk management is a forward-looking process of business. It must include the issue of determining critical goals. In addition, risk assessment is a continuous risk management approach.

3.2 Phases of Risk Management

Wu et al. (2010) divide risk management process as identification, analysis and mitigation. These steps need to be implemented one by one in order to carry out the risk management successfully. Fig. 3.1 illustrates the risk management structure within the organizations.

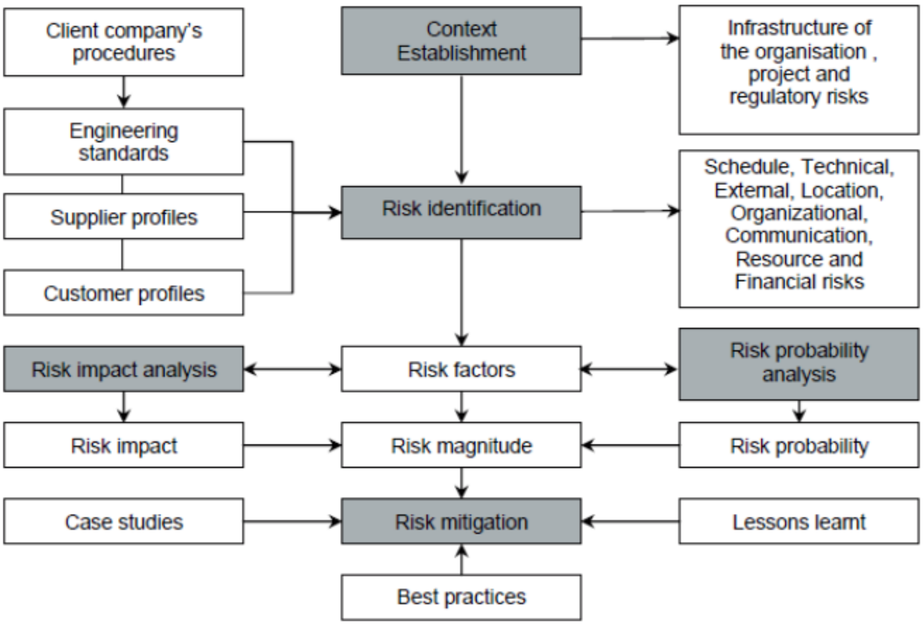


Figure 3.1 Conceptual structure of the project collaboration workbench (Wu et al., 2010)

3.2.1 Risk Identification

The risk identification process enables identification of risk categories to provide an effective risk management system. Wu et al. (2010) describe this process as "discovering, recognition and identification process". The risk identification process focuses on the risks associated with the product, process and project. During the risk identification process, the past experiences and documents contribute greatly.

Wu et al. (2010) categorize risks subgroups as follows.

- Communication risk
- External risk
- Financial risk
- Location risk
- Organizational risk
- Resource risk
- Schedule risk
- Technical risk.

In the risk identification process, interactions and relationships can be analyzed with risk management tools among the risk factors in different categories (Wu et al., 2010). Interactions exist between different risk categories are illustrated in Fig. 3.2.

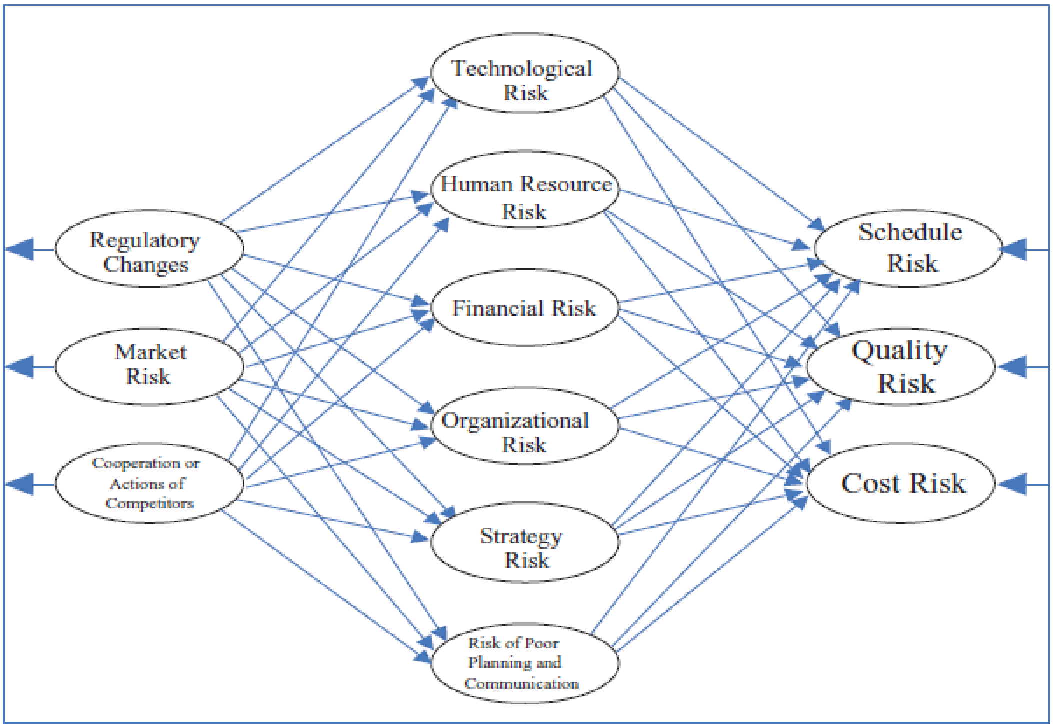


Figure 3.2 The causal relationship among various risks (Wu et al., 2010)

Marle et al. (2013) divide risks into two categories as direct and indirect risks in risk identification process. The direct and indirect risks can be divided into many subgroups, and therefore, hundreds of risks can affect the process of new product development.

3.2.2 Risk Analysis

Once the risks related to the product, process or project are identified, the stakeholders calculate the value of each risk with the help of the risk analysis tool. Qualitative and quantitative techniques can be used to calculate the magnitude of risks.

By doing risk analysis,

- frame risks,
- match different solutions,
- identify critical issues in risk analyses process,
- display effects of results.

Risk analysis can be realized in different steps of the product development process. For example, in early stages of the development, during planning or conclusion stage.

Sometimes, risk analysis process must be carried out for regulatory requirements. Risk analysis is required to be applied in order to be balanced on issues such as safety and cost (Aven, 2008).

Kayis et al. (2006) express that both the likelihood and impact of all identified risks are measured during the risk analysis phase. Marle et al. (2013) prioritize the risks in the risk analysis process according to the probability and impact values. The risk score scale is defined and the probability and impact values of the risks are determined by using this scale. As a result of the risk scoring stage, it is determined which risks have a higher probability and impact for decision makers. Thus, during the risk management phase, firstly, the high-rated risks are considered.

Many different techniques can be used in the risk analysis phase. The most common techniques are listed in the following.

- Failure Modes and Effects Analysis (FMEA)
- Probability and Impact Matrix (P-I Matrix)
- Bayesian Belief Network (BBN)
- Analytical Hierarchy Process (AHP)
- Graphical Evaluation and Review Technique (GERT)
- Design Structure Matrix (DSM)
- Quality Function Deployment (QFD) – House of Quality
- Hazard and Operability (HAZOP)
- Structured What-If Technique (SWIFT)
- Risk Breakdown Structure (RBS)
- Decision Tree Analysis
- Event Tree Analysis
- Fault Tree Analysis
- Scenario Analysis
- Root-Cause Analysis
- Cause and Effect (Ishikawa) Diagrams
- Monte Carlo Simulation
- System Dynamics.

Table 3.1 reports the strengths and weaknesses of the risk assessment techniques.

Table 3.1 Strengths and weaknesses of risk assessment techniques (Project Management Institute, 2009)

Tool	Strengths	Weaknesses
Cause and Effect Analysis	• Visual representation of project promotes structured thinking	• Diagram can quickly become over-complex
FMEA/Fault Tree Analysis	• Structured approach, well understood by engineers • Produces an estimate of overall reliability using quantitative tools • Good tool support	• Focuses on threats, not so useful for opportunities • Requires expert tools not generally available to those except experts
Risk Breakdown Structure (RBS)	• Offers a framework for other risk identification techniques such as brainstorming • Ensures coverage of all types of risk • Tests for blind spots or omissions	• None
Root-Cause Analysis	• Allows identification of additional, dependent risks • Allows the organization to identify risks that may be related because of their common root causes. • Basis for development of pre-emptive and comprehensive responses • Can serve to reduce apparent complexity	• Most risk management techniques are organized by individual risk. This organization is not conducive to identifying the root causes • Can oversimplify and hide existence of other potential causes • There may be no valid strategy available for addressing the root cause once it has been identified.

Table 3.1 continues

System Dynamics	• Exposes unexpected inter-relations between project elements (feedback and feed- forward loops) • Can generate counter- intuitive insights not available through other techniques • Produces overall impacts of all included events and risks	• Requires specialized software and expertise to build models • Focuses on impacts but difficult to include the concept of probability
Probability and Impact Matrix (P-I Matrix)	• Allows the organization to prioritize the project risks for further analysis (e.g., quantitative) or risk response • Reflects the organization's level of risk tolerance	• Does not explicitly handle other factors such as urgency or manageability that may partly determine a risk's ranking. • The range of uncertainty in the assessment of a risk's probability or impact may overlap a boundary
Analytic Hierarchy Process	• Assists in developing a relative weighting for project objectives that reflects the organization's priorities for time, cost, scope and quality for the project • Assists the creation of an overall project priority list of risks created from the risks' priority with respect to individual objectives	• Organizational decisions are often made by committees, and individuals may not agree on relative priority among objectives • Difficult to gather the information about pair-wise comparison of the objectives from high-level management

Table 3.1 continues

Decision Tree Analysis	• Causes the organization to structure the costs and benefits of decisions when the results are determined in part by uncertainty and risk • Solution of the decision tree helps select the decision that provides the highest Expected Monetary Value or expected utility to the organization	• It is sometimes difficult to create the decision structure • Probabilities of occurrences can be difficult to quantify in the absence of historical data • The best decision may change with relatively plausible changes in the input data, meaning that the answer may not be stable • The organization may not make decisions based on a linear Expected Monetary Value basis but rather on a non-linear utility function; utility functions are difficult to specify
Monte Carlo Simulation	• Used primarily for project schedule and cost risk analysis in strategic decisions • Allows all specified risks to vary simultaneously • Calculates quantitative estimates of overall project risk; reflects the reality that several risks may occur together on the project • Provides answers to questions such as (1) How likely is the base plan to be successful? (2) How much contingency in time and cost do we need to achieve our desired level of confidence? (3) Which activities are important in determining the overall project risk?	• Schedules are not simple and often cannot be used in simulation without significant de-bugging by an expert scheduler • The quality of the input data depends heavily on the expert judgment and the effort and expertise of the risk analyst • Simulation is sometimes resisted by management as being unnecessary or too sophisticated compared to traditional project management tools • Monte Carlo simulation requires specialized software which must be acquired and learned, causing a barrier to its use • Will produce unrealistic results unless input data include both threats and opportunities

Table 3.1 continues

Scenario Analysis	• Provides view of the potential effect of the relevant risk and the corresponding response strategy • Forces the participants to analyze the effect of any strategy • Helps to identify secondary risks	• Adds to the list of assumptions • Can betime consuming

Risks are considered in terms of probability and impact. Risk impact can be evaluated by a qualitative or quantitative scale.

Risk is used as an aggregate measure of risk importance, and is often defined as the product of risk probability and impact, or severity. *Probability-Impact Matrix* is one of the commonly used qualitative methods for risk assessment. Probability-Impact Matrix is a series of discrete risk estimates calculated by multiplying probability and impact. This method helps to determine critical risks and their effects for projects (Fang, Marle, & Xie, 2017). In section 6.2.2, an application will be conducted.

$$R = I \times P \tag{3.1}$$

Fang and Marle (2013) define DSM as a tool for analyzing the relationship and dependency between objects. The relationships between the objects are shown in a square matrix.

DSM has proven to be a convenient tool for showing and analyzing relations and dependencies all system components. It is also known as the dependency structure matrix or dependency structure method for task-based system modeling.

AHP is an alternative method that can be used for risk assessment. It contains three principals.

- Hierarchy framework,
- Priority analysis,
- Logical criterion.

The first principle of the AHP concept is to establish a functional hierarchy to parse complex systems based on their basic relationships to their components. The elements in the hierarchy are composed of sets of system goals, decision criteria, and alternative solutions. Each item has a hierarchical level set in the function hierarchy.

The top level of the hierarchy consists of a single element, system target. Each of the subsequent levels can have multiple elements, and the elements at each level must be of the same order of magnitude as the elements at a level are compared to the next highest criterion. Therefore, if the elements of a layer cannot be easily compared, a new layer should be created with a finer separation. The second hierarchy level usually contains decision criteria based on the hierarchy level 3 properties. In order to be able to examine the decision characteristics in more detail, the hierarchy must be subordinated to different levels, which extends the hierarchy level. The last level of the hierarchy are alternative solutions which are linked to decision-making features based on the evaluation of the alternative (Ahmed et al., 2008). Fig. 3.3 illustrates the functional hierarchy of AHP.

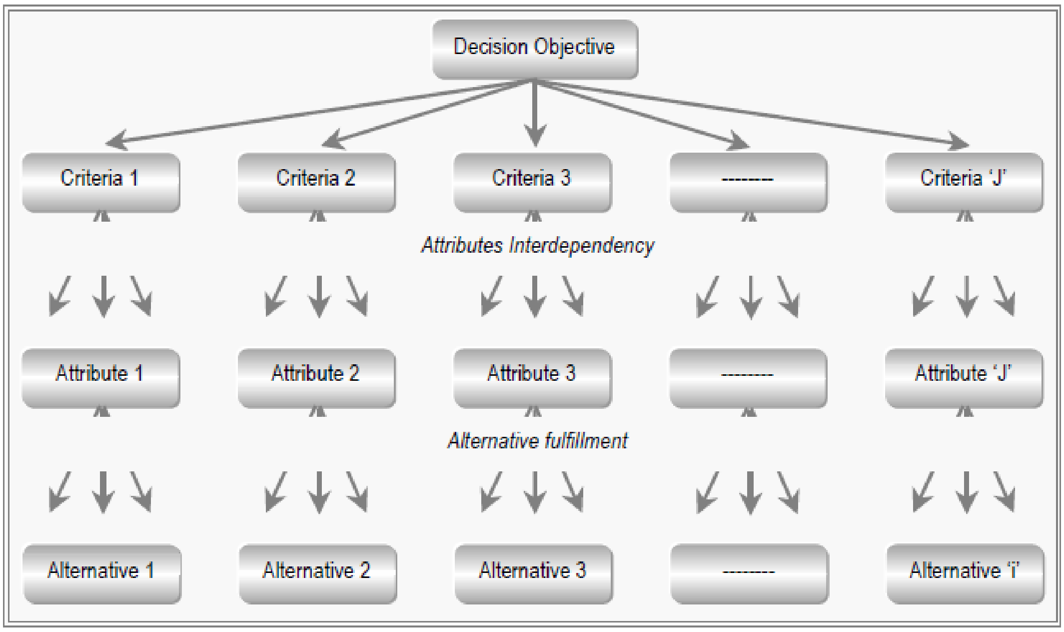


Figure 3.3 The functional hierarchy of AHP (Ahmed et al., 2008)

3.2.3 Risk Mitigation

There exists many studies about concurrent engineering projects for complex systems and product development processes. All stakeholders try to be proactive in the product development process. Engineering and design studies face various high level risks. Therefore, there should be effective strategies for avoiding risks in risk management process (Kayis et al., 2007).

The decision on the performance of risk mitigation strategies can be made at the end of risk evaluation phase. The aim of these strategies is to reduce the impact and/or probability of risky event.

Risk mitigation strategies can be grouped into two types as proactive and reactive strategies. In the proactive approach, some strategies should be taken before risks occur. On the other hand, in the reactive approach, there are no plans or strategies before risk occur (Kirilmaz, & Erol, 2015). Table 3.2. reports examples of some risk mitigation strategies.

Table 3.2 Some risk mitigation strategies (Jüttner et al., 2003)

Avoidance	Dropping specific products/geographical markets/supplier and/or customer organizations
Control	Vertical integration
	Increased stockpiling and the use of buffer inventory
	Maintaining excess capacity in productions, storage, handling and/or transport
	Imposing contractual obligations on suppliers
Co-operation	Joint efforts to improve visibility and understanding
	Joint efforts to share risk-related information
	Joint efforts to prepare continuity plans
Flexibility	Postponement
	Multiple sourcing
	Localized sourcing

Interpretive structure modeling (ISM) is a technique in which the special relationships of the variables and the general structure of the system considered are represented in a model of a digraph. ISM is basically thought of as a group learning process, but can also be used individually.

ISM can be used for clarifying or summing up variables and their relations in a problem. This model helps to analyze and mitigate risks during the new product development process (Faisal, Banwet, & Shankar, 2006). In this, the main objectives of ISM can be stated as follows.

- clarifying risks and their effects in new product development process,
- identifying the risks interactions,
- discussing results and implementations.

CHAPTER FOUR
LITERATURE REVIEW

4.1 Risk Management

Many risk management methods and tools are developed by researchers. For instance, Yang, Shieh, and Tzeng (2013) propose a risk-control assessment model that combines VIKOR, DEMATEL and AHP techniques. Garbolino, Chery, and Guarnieri (2016) use *dynamic risk analysis*. They examine potential improvements in companies by using system dynamics approach. Fan and Yu (2004) review the studies employing Bayesian Belief Networks (BBNs) in risk management. They state that this method supports more objective decisions. Chemweno et al. (2015) investigate the organizational competencies for risk assessment. They use Analytic Network Process (ANP) for deriving the generic selection criteria.

Fang and Marle (2013) use Design Structure Matrix with risks. They use this method in the project management process. They examine the relations and interrelations between project objects. They state that DSM is a useful technique for identifying and evaluating risk interactions.

Ghosh and Jintanapakanont (2004) identify various risk factors related with a mass rapid-transit project. They employ factor-analysis method for their study, and consider time, cost and quality-oriented risk factors.

Table 4.1 reports some risk management techniques which are applied in the literature.

Table 4.1 Risk management techniques

Year	*Authors*	*Risk Management Technique*
2013	Sharma	Analytic Hierarchy Process
2012	Fang and Marle	
2008	Campbell	
2008	Ahmed et al.	
2004	Ha and Seong	
2006	Kayis et al.	
2015	Chemweno et al.	Analytical Network Process
2014	Bott	
2014	Ergu et al.	
2013	Ou et al.	
2008	Campbell.	
2015	Wu et al.	Bayesian Belief Network
2014	Badurdeen et al.	
2014	Goswami et al.	
2012	Liu et al.	
2012	Press and Guo	
2012	Weber et al.	
2009	Lee et al.	
2009	Luu et al.	
2008	Ahmed et al.	
2008	Trucco et al.	
2006	Kayis et al.	
2004	Fan and Yu	
2004	Ha and Seong	
2011	Tang et al.	
2014	Zhao et al.	CRAM matrix, FAST diagram, House of quality, Integrated Evaluation Matrix, Development matrix
2017	Fang et al.	Design Structure Matrix
2013	Marle et al.	
2012	Yang et al.	
2002	Browning and Eppinger	
2004	Ghosh and Jintanapakanont	Factor Analysis
2010	Wu et al.	Failure Modes and Effects Analysis
2008	Segismundo et al.	
2010	Choi and Ahn	Fuzzy Theory, Markov Process
2014	Christopher and Khan	Impact-Likelihood Matrix
2016	Kayis et al.	Intelligent Risk Mapping and Assessment System
2006	Savci and Kayis	
2008	Ahmed et al.	
2007	Kayis et al.	Highest-Risk-First, Least-Cost-First, Random-Search and a Genetic Algorithm, Minimum-Cost-Risk-Ratio-First
2015	Zhang et al.	Rough Number Approach
2006	Tang	Supply Chain Risk Management; Quantitative Models
2016	Garbolino et al.	System Dynamics
2016	Li et al.	
2014	Bott	
2014	Wan and Liu	
2012	Boateng et al.	
2008	Minami et al.	
2008	Nasirzadeh et al.	
2013	Ou et al.	VIKOR, DEMATEL

4.2 Risk Management in New Product Development Process

Risk management during the new product development process can be defined as "the proactive determination and control of unwanted project results". By identifying and eliminating the risks, the impacts on the table and budget will be minimized.

Many researchers have contributed to the literature through the application of risk management on new product development process. For instance, Wu et al. (2010) state that in order to optimize interdisciplinary tasks, information and data sharing, design coordination, design activities of new products and to offer marketing activities to the market in the fastest way, the new product development process should be carried out simultaneously. However, although the new product development process has been accelerated, the concurrent engineering process leads to some uncertainties and risks between interconnected and coordinated departments.

There exists many studies in the literature with different applications about risk management in new product development process. Among these studies, Kayis et al. (2016) examine concurrent engineering in risk management design. They develop The Intelligent Risk Mapping and Assessment System (IRMAS). This system aims to clarify and mitigate potential risks with a framework. They concerned product life cycle with all stages for removing potential failures. In another research, Zhao et al. (2014) develop a decision support system by using QFD for risk assessment. They use Cost and Risk Analysis Method (CRAM) and Functional Analysis System Technique (FAST) diagram. This hybrid decision support system ensures the quantification of product costs, and also clarification of risks during product development.

Browning and Eppinger (2002) conduct Design Structure Matrix (DSM) can also be used to represent a process. The DSM shows interfaces in a concise format. A DSM is a square matrix in which a cell on the diagonal. Also, it represents each activity. This method provides a way for framing the form of an activity network and to compare alternative solutions.

Choi and Ahn (2010) propose a risk analysis model to detecting the risk degrees and their risk factors in product development processes. They developed a fuzzy model which is named Markov process. Fuzzy models defined the impacts of the risk factors, also Markov processes detected the probabilities of risk occurrences. They wanted to find a solution for analyzing effects of risk factors on product development projects.

Wu et al. (2010) analyze a quantitative approach for identifying risks in concurrent engineering project. They used some mix models which is named with failure mode and effect analysis (FMEA), graphical evaluation and review technique (GERT), and product database management (PDM) as a model.

Kayis et al. (2006) present an Intelligent Risk Mapping and Assessment System (IRMAS). This map shows relationships between risks and risk events. Also this map contributes product life cycle. After modeling IRMAS map, they applied Bayesian Belief Networks and used the Analytical Hierarchy Process (AHP) concept. AHP provide a pair-wise comparison between risks and give a risk ranking concept.

One year later, Kayis et al. (2007) study risk management again. But in this study they work on risk quantification, for improving a new risk mitigation methodology. Also they researched relations between concurrent engineering projects and risk management. Firstly, they identified risks in the product life cycle. Then five computational algorithms are developed. They used for finding a feasible solution for mitigating risks: Highest-Risk-First, Least-Cost-First, Random-Search and a Genetic Algorithm, Minimum- Cost-Risk-Ratio- First.

As seen in this section, there are many studies on risk management approach in new product development process in the literature. These studies are investigated and the most appropriate study contributed to the application which is applied in section 6.2.

CHAPTER FIVE
PROPOSED MODEL

5.1 Introduction

In this thesis, Probability-Impact Matrix, Design Structure Matrix and Analytical Hierarchy Process is used for analyzing risks. Also, Interpretive Structural Modeling is employed for mitigating risks in new product development process in concurrent engineering environment. An application in an international company operating in automotive industry is presented to illustrate the practicality of the proposed approach.

The aim of this study is to determine the risks with the highest effect and to reduce the effects of these risks in the new product development process in concurrent engineering environment. To this aim, firstly, risks are associated with each other and then numerical matrix method is used to determine the value of their effects.

5.2 Phases of the proposed model

Fig. 5.1 illustrates the structure of the proposed model, which helps to easily visualize the risk management phases in new product development process.

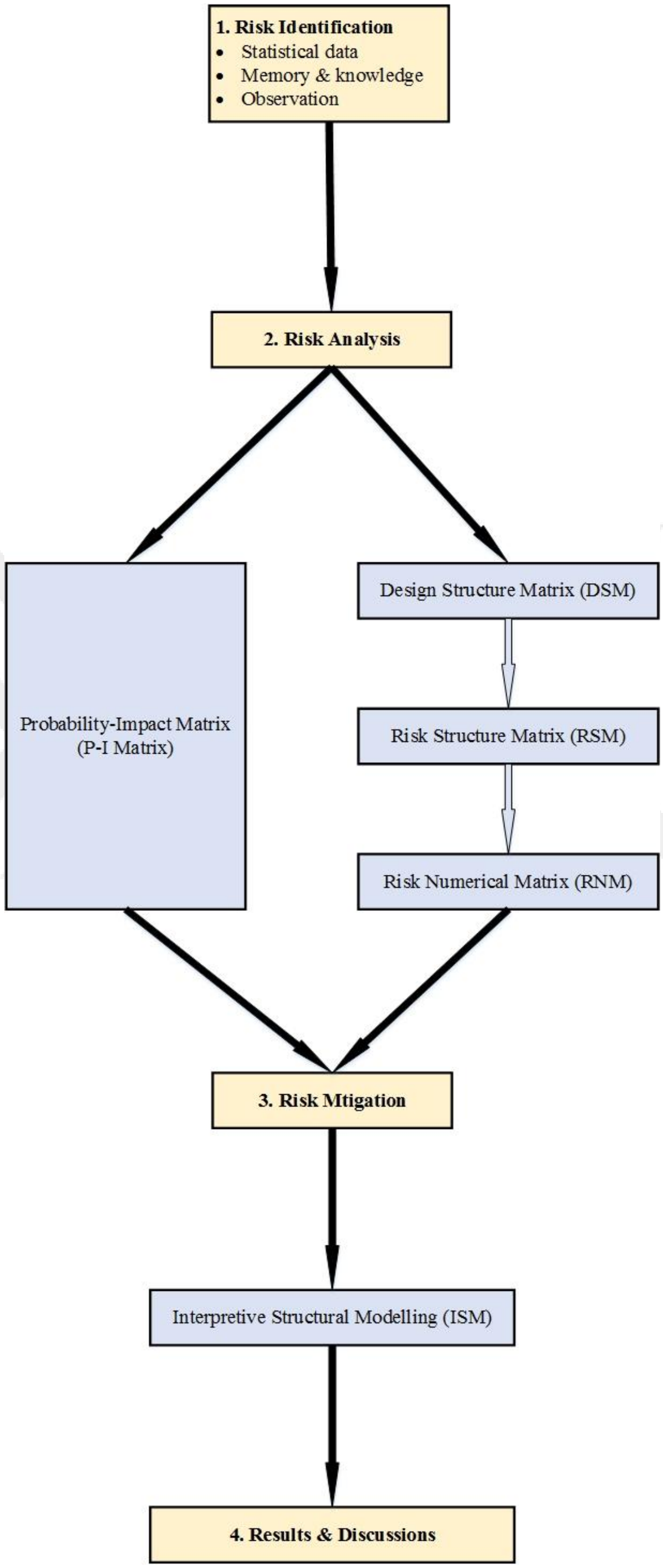


Figure 5.1 Structure of the proposed model

5.2.1 Risk Identification

In order to analyze the risk network of a new product development process, it is necessary to identify individual risks firstly. Risks for new product development process can be identified with the help of experienced managers.

5.2.2 Risk Analysis

After identifying risks, Probability-Impact Matrix is produced. Probability-Impact Matrix provides to determine the risks with the highest effect in risk management process. Scale of the matrix is determined by the user.

Besides Probability-Impact Matrix, Design Structure Matrix (DSM) can be used in risk management applications. Relationships between objects such as tasks, users, and product components make it easier to determine the relationships between the risks associated with these objects.

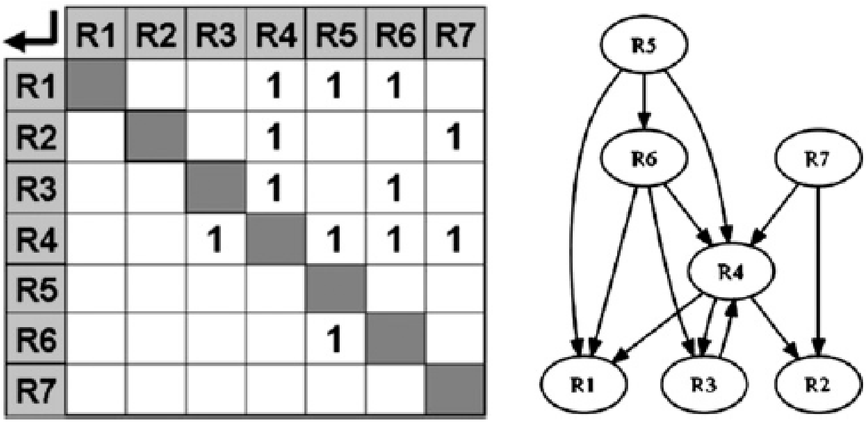
Interaction between two different risk components means that the risks associated with function, quality, latency or cost of a product may be interrelated. That is, a problem in one component may have an effect on another. Thus, identifying the risks that can negatively affect the new product development process makes a major contribution to risk management.

There exists three types of interactions between risks.

- *Dependent risks*: risks are related with one-way.
- *Interdependent risks*: risks are related in dependent relation, directly or within a bigger loop.
- *Independent risks*: risks are not connected.

In addition, a fourth type of interaction can be defined as the one including two or more type of the pre-defined interactions.

Risk interaction is regarded as the possible priority relationships between two risks. The risk structure matrix (RSM) is defined as a square matrix having binary values with RSM_{ij} = 1 when there is a connection state from R_i to R_j. In this interaction, probability or impact condition it is not yet concerned. If risk R_i determines the risk R_j as a cause, there is a discrepancy if risk R_j is not the result of risk R_i. Fig. 5.2 presents an example of risk structure matrix.



	R1	R2	R3	R4	R5	R6	R7
R1				1	1	1	
R2				1			1
R3				1		1	
R4			1		1	1	1
R5							
R6					1		
R7							

Figure 5.2 Illustration of risk structure matrix (Fang et al., 2012)

This numerical structure matrix helps to make the risk analysis in detail. Firstly, binary values are calculated and then quantitative values are measured. This measurement provides to obtain the risk interactions and their effects on risk management process. There are two types of assessments namely direct and relative assessments. The direct one finds all potential interactions, while the relative one includes comparing the causes of a risk which has multiple interactions. It provides pair-wise comparisons in the Analytic Hierarchy Process developed by Saaty (1980). An AHP-based assessment method is proposed by Fang and Marle (2012). They figure out quantitative values of risk interactions. Fig. 5.3 presents the transformation process from Risk Structure Matrix to Risk Numerical Matrix.

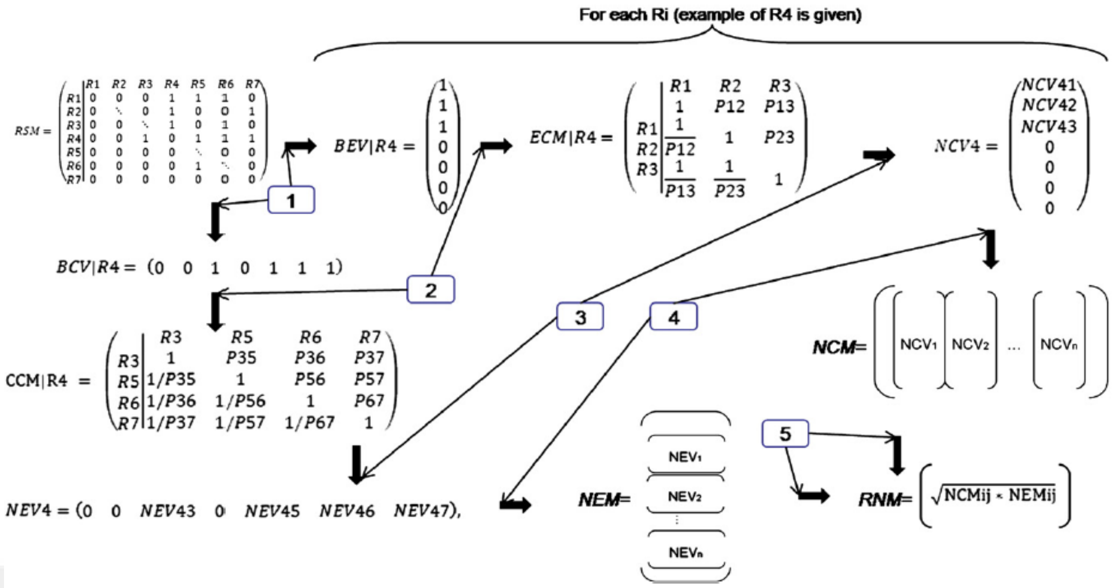


Figure 5.3 Description of the transformation process from RSM to RNM (Fang & Marle, 2012)

Steps of the transformation process from RSM to RNM are explained in the following.

Step 1: In the first step, the row and column vectors are subtracted for each risk of R_i. These matrices are called the column matrix BEV/R_i and the row matrix BCV/R_i.

Step 2: In this step, AHP analysis is performed for the risks that are interacting with the risk of R_i and have taken 1 value. While making this analysis, degree of relationships between risks are determined. These matrices are called Cause or Effect Comparison Matrices (CCM / R_i, ECM / R_i).

Step 3: In this step, the eigenvectors of each ECM / R_i and CCM / R_i matrix are calculated. The maximum eigenvalue of each eigenvector is considered. The matrix of these is called Numerical Cause or Effect Vectors ($NCVi$ and NEV_i). In addition, the results are tested by the consistency index of AHP.

Calculating maximal eigenvalue:

1. Production of the comparison matrix

	A	B	C
A	1	1/2	1/4
B	2	1	1/4
C	4	4	1
Total	7	5.5	1.5

2. Normalization of the comparison matrix

	A	B	C	Row Sum	Row agg. (W)
A	1/7	1/11	1/6	0.40	0.40/3=0.13
B	2/7	2/11	1/6	0.63	0.63/3=0.21
C	4/7	8/11	4/6	1.97	1.97/3=0.66

3. Calculating the consistency ratio

$$\begin{vmatrix} 1 & 1/2 & 1/4 \\ 2 & 1 & 1/4 \\ 4 & 4 & 1 \end{vmatrix} \times \begin{vmatrix} 0.13 \\ 0.21 \\ 0.66 \end{vmatrix} = \begin{matrix} (0.13+0.11+0.17) \\ (0.26+0.21+0.17) \\ (0.52+0.84+0.66) \end{matrix} \; \overset{\text{Row Sum (V)}}{\begin{vmatrix} 0.41 \\ 0.64 \\ 2.02 \end{vmatrix}}$$

$$V/W = \begin{vmatrix} 3.15 \\ 3.05 \\ 3.06 \end{vmatrix}$$

Maximal eigenvalue = (3.15+3.05+3.06)/3=3.09

Random indices for a randomly generated matrix;

n	3	4	5	6
RI	0.58	0.9	1.12	1.24

Now we can calculate the consistency index (*CI*) as follows.

$$CI = (\lambda max - n)/(n - 1) \quad (5.1)$$

where *n* is the number of compared elements (in our example, *n* = 3).

Therefore,

$$CI = (3.09\text{-}3)/3\text{-}1)=0.045$$

Now we can calculate the consistency ratio as follows.

$$CR = CI/RI \quad (5.2)$$

Therefore,

CR = 0.045/0.58=0.078

As the value of CR is less than 0.10, we can assume that the judgments matrix is consistent. Therefore, we can continue to apply the proposed approach.

Step 4: Numerical Cause / Effect Vectors are obtained in this step by taking the weighted averages and combining the row and column vectors.

Step 5: In the final step, The Risk Numerical Matrix (*RNM*) is obtained by using the geometrical weighting operation.

$$RNM(i,j) = \sqrt{NCM(i,j) \times NEM(i,j)}\ , \forall(i,j)\ ,\ 0 \leq RNM(i,j) \leq 1 \quad (5.3)$$

The Risk Numerical Matrix allows the synthesis of the presence and strength of local priority relationships between risks, since it combines the cause-oriented vision of an interaction with consequence-oriented vision. It is useful to avoid any prejudice or misunderstanding that may arise when looking at a problem at one sight. In the risk network model, the quantitative values of cause-effect interactions in the RNM can also be interpreted as the probability of transition between risks. For example, if the element RNM (4,3) is equal to 0.25, then the probability of risk 4 originating from risk 3 is considered to be 25% under the condition that risk 3 emerges.

5.2.3 Risk Mitigation

After identifying and analyzing risks with the highest effect, Interpretive Structural Modeling (ISM) can be used in risk mitigation phase. ISM aims to mitigate risks by using enabler relationships. Enablers can be strategies, decisions, individuals, products or services in risk management.

There are five steps for the ISM applications.

1. Creation of the structural self-interaction matrix (SSIM)

This matrix is employed to determine relationships between two enablers and their status. Four symbols can be used for indicating the relationships.

V: enabler *i* will ameliorate enabler *j*
A: enabler *j* will be ameliorated by enabler *i*
X: enabler *i* and *j* will ameliorate each other
O: enablers *i* and *j* are unrelated.

2. Creation of the reachability matrix

The SSIM matrix is converted to the reachability matrix by using the following rules.

- "if the (*i*, *j*) entry in the SSIM is *V*, then the (*i*, *j*) entry in the reachability matrix becomes 1 and the (*j, i)* entry becomes 0"
- "if the (*i*, *j*) entry in the SSIM is A, then the (*i*, *j*) entry in the reachability matrix becomes 0 and the (*j*, *i*) entry becomes 1"

- "if the (*i, j*) entry in the SSIM is X, then the (*i, j*) entry in the reachability matrix becomes 1 and the (*j, i*) entry also becomes 1"
- "if the (*i, j*) entry in the SSIM is O, then the (*i, j*) entry in the reachability matrix becomes 0 and the (*j, i*) entry also becomes 0".

3. Level partitions

In level partitions step, the enablers are appointed to the levels according to the interactions in final reachability matrix.

4. Building the ISM-based model

Using the final reachability matrix, the direct graph is created with nodes and edges according to relationships between the enablers *i* and *j*.

5. MICMAC analysis

This analysis aims to resolve "the driver power and the dependence power" of variables. Herein, four clusters are generated and variables are assigned to these clusters. First cluster includes the “autonomous enablers” that have "weak driver power" and "weak dependence". Second cluster includes the "dependent enablers" that have "weak driver power" but "strong dependence". Third cluster has the "linkage enablers" that have "strong driving power" and also "strong dependence". Fourth cluster includes the "independent enablers" having "strong driving power" but "weak dependence" (Faisal et al., 2006).

Driver power and dependence diagram is presented in Figure 5.4.

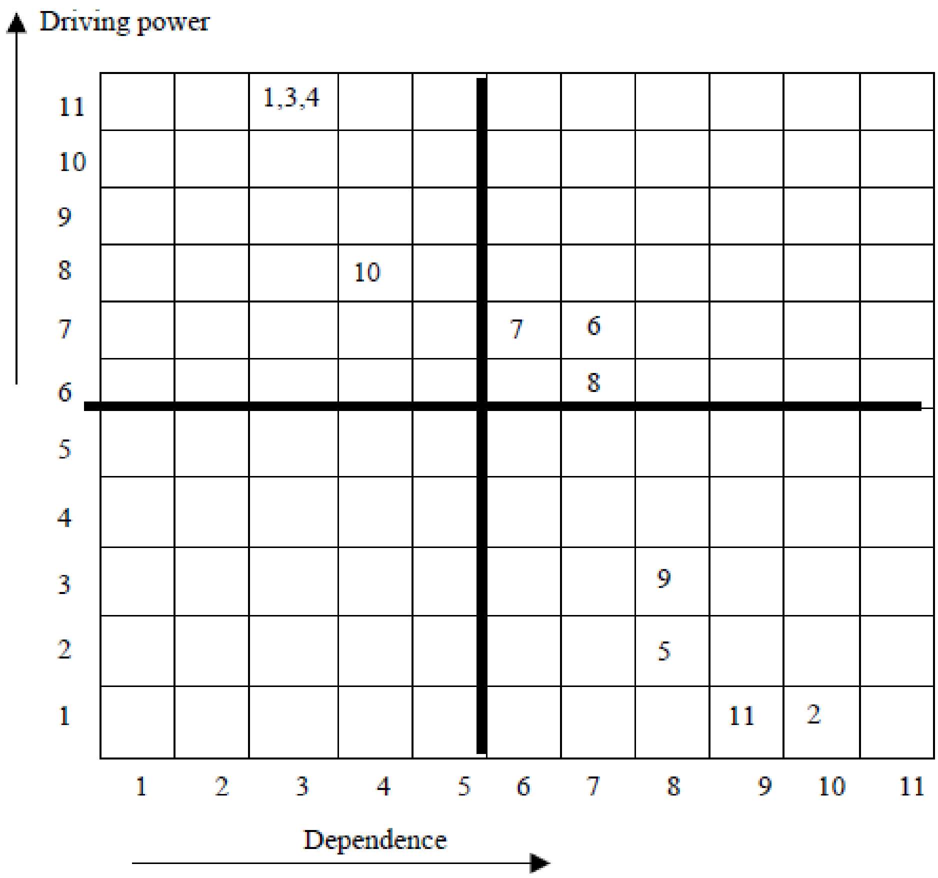


Figure 5.4 Driver power and dependence diagram (Faisal et al., 2006)

CHAPTER SIX
IMPLEMENTATION OF THE PROPOSED MODEL IN AUTOMOTIVE INDUSTRY

6.1 Introduction

The proposed model is implemented in an international automotive company operating in Turkey. The company designs commercial and defense industry vehicles. The products are buses, trucks and military vehicles.

The Company have different units as illustrated in Figure 6.1. All these units are working in an integrated way for achieving high quality products.

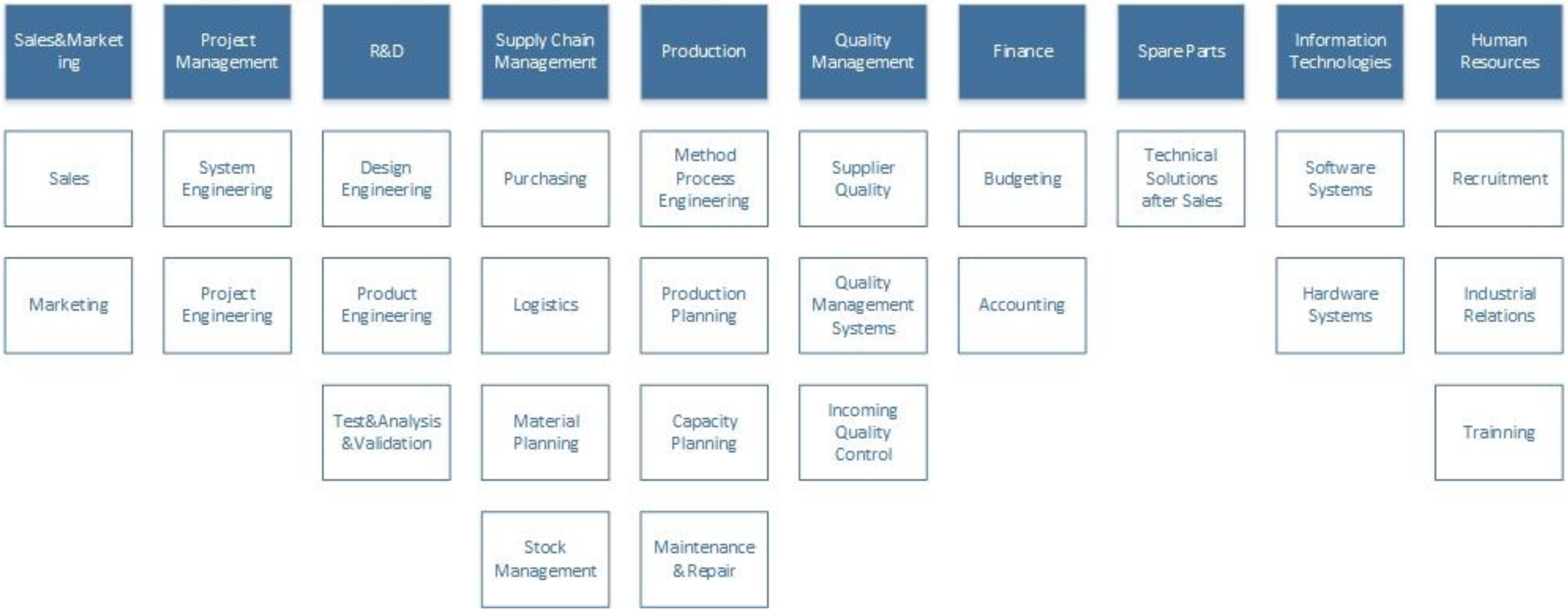


Figure 6.1 The Company's organization structure

6.2 Implementation of the proposed model

Implementation phases the proposed model are presented in the following sections.

6.2.1 Risk Identification

In this phase, possible risks that may emerge during the new product development process are listed according to the units they are involved in. They are also classified in terms of the phase of the concurrent engineering process where they may emerge.

The risks are identified based on the opinions of managers and experts from different units. The risks under concern are actually may be exposed in many other companies operating in different industries. Related to the new product development process, 35 risks are identified on the basis of company units.

6.2.2 Risk Analysis

In this phase, firstly, the Probability-Impact Matrix is defined. The Probability Index and the Impact Index are determined as reported in Tables 6.1 and 6.2. Using the ratings in these tables, each risk is scored.

Table 6.1 Probability Index

Probability Category (Qualitative)	*Probability Index*
Once per week	4
Once per month	3
Once per year	2
Once in ten years	1

Table 6.2 Impact Index

Impact Category	*Impact Index*
Catastrophic (irreversible level of financial loss, market loss, etc.)	4
Critical (resolvable level of financial loss, market loss, etc.)	3
Low (minor damage level of financial loss, market loss, etc.)	2
Negligible (insignificant level of financial loss, market loss, etc.)	1

Probability-Impact Matrix is then formed by multiplying the probability and impact values (see Table 6.3).

Table 6.3 Probability-Impact Matrix

	Impact Index				
Probability Index		1	2	3	4
	1	1	2	3	4
	2	2	4	6	8
	3	3	6	9	12
	4	4	8	12	16

Risks with the high risk index are examined primarily as reported in Table 6.4.

Table 6.4 Risk Indexes

Risk Index	*Explanation*
0-4	no need to investigate
4-8	can be investigated
8-12	should be investigated
12-16	must be investigated

Fig. 6.2 presents the risks and their sources determined by the proposed model.

Nr	Source of Risks	Nr	Concurrent engineering process	Risks during new product development process	Probability	Impact	P x I
1	External Factor	EX1	During production	Worldwide crisis of economies	1	3	3
2	Human Resources	HR1	Before production	Risk of not finding sufficient / qualified workforce	2	2	4
3	Information Technologies	IT1	Before production	The risk of incorrect constructed ERP system	2	2	4
4	Sales&marketing	SM1	After production	Customer's risk of not being satisfied with the product	3	3	9
5		SM2	Before production	Risks of substitude products in the market	3	1	3
6		SM3	Before production	Risk of market anticipation changing or not being well analyzed	2	2	4
7		SM4	Before production	Risk of not being able to compete with competitors in terms of quality, price, costs, performance etc.	2	3	6
8		SM5	Before production	The uncertainty of future product range (diversity) and the risk of loss due to infrastructural preparations that can not be done accordingly	1	1	1
9	Project management	PM1	Before production	Risk of misunderstanding or overlooking technical specification requests	3	3	9
10		PM2	Before production	The risk of not having appropiate schedule plan	4	3	12
11		PM3	Before production	Risk of failure to plan, mistakes about prioritization	4	2	8
12		PM4	Before production	Risk of not providing conflict management on the project team	4	2	8
13		PM5	Before production	The risk of missing optimization work due to major / minor faults	1	3	3
14	R&D	RD1	After production	Risks of the production prototype failure in the test / analysis process	3	4	12
15		RD2	During production	Supply material and design dispute risk	4	3	12
16		RD3	Before production	Risk of wrong design	4	3	12
17		RD4	Before production	Risks of incorrect / incomplete bill of material	4	3	12
18		RD5	During production	The risk of losing time when changing a large part of the design due to later requests	4	2	8
19		RD6	During production	Risks of wrong material use due to the fact that design revisions are not delivered to supplier	4	3	12
20		RD7	During production	Risks of error in the prototype production after the design is completed and turnaround of the design cycle	4	4	16
21		RD8	After production	The risk of not being able to integrate subsequent requests into the system	3	2	6
22	Supply Chain Management	SC1	Before production	Risk of not finding a firm to supply materials	2	4	8
23		SC2	Before production	Risks of working with a single supplier	1	3	3
24		SC3	During production	Due to the lack of domestic resources in the design process, the dependence on abroad and the long supply durations risk	3	2	6
25		SC4	During production	Risk of inability in supplying materials on time	4	3	12
26		SC5	During production	Risk of improper application / stock follow-up of inventory management	2	2	4
27	Method/Production control	MP1	Before production	Risks of improper capacity planning for prototype production	1	1	1
28		MP2	During production	The risk of deterioration of the machines to produce prototype	2	2	4
29		MP3	Before production	The risk of falling behind the technology in prototype production	2	1	2
30		MP4	During production	Risks of inappropriate prototype manufacturing method / process	2	1	2
31		MP5	During production	Risk of incorrect assembly of operator for prototype production	3	2	6
32		MP6	Before production	Risks of time loss in the integration of new investments into prototype production time	1	2	2
33	Quality control	QM1	During production	Risk of rejection of prototype materials in the input quality control	4	3	12
34	Finance management	FM1	During production	Risk of incapability to cover the project cost from the budget	3	4	12
35		FM2	After production	Risks of not achieving profits with project costs exceeding the sales revenue	2	3	6

Figure 6.2 Risk list of the proposed model

The following risks have the highest Probability-Impact scores. Therefore, they should be evaluated primarily to take proactive actions in new product development process.

- Risks of error in the prototype production after the design is completed and turnaround of the design cycle
- The risk of not having appropriate schedule plan
- Risks of the production prototype failure in the test / analysis process
- Supply material and design dispute risk
- Risk of wrong design
- Risks of incorrect / incomplete bill of material
- Risks of wrong material use due to the fact that design revisions are not delivered to supplier
- Risk of inability in supplying materials on time
- Risk of rejection of prototype materials in the input quality control
- Risk of incapability to cover the project cost from the budget

Then, the bilateral relations between the risks are discussed. Risks with the direct cause-effect relationship are determined. Binary values (0,1) are used within the risk structure matrix. Since the same risk cannot reveal the cause-effect relationship, there is no double relation definition in the cross columns of the matrix. Figure 6.3 presents the Risk Structure Matrix of the proposed model.

CAUSE (columns) / EFFECT (rows)

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35
		EX1	HR1	IT1	SM1	SM2	SM3	SM4	SM5	PM1	PM2	PM3	PM4	PM5	RD1	RD2	RD3	RD4	RD5	RD6	RD7	RD8	SC1	SC2	SC3	SC4	SC5	MP1	MP2	MP3	MP4	MP5	MP6	QM1	FM1	FM2
1	EX1																																			
2	HR1	1																																		
3	IT1																																			
4	SM1					1	1	1														1														
5	SM2																																			
6	SM3																																			
7	SM4																																			
8	SM5						1																													
9	PM1																																			
10	PM2																																			
11	PM3												1																							
12	PM4																																			
13	PM5																																			
14	RD1									1				1			1														1	1				
15	RD2																1																			
16	RD3									1			1																							
17	RD4									1			1				1																			
18	RD5																																			
19	RD6																																			
20	RD7									1							1														1	1				
21	RD8																																			
22	SC1																																			
23	SC2																																			
24	SC3																							1												
25	SC4																						1	1			1									
26	SC5			1																																
27	MP1																																			
28	MP2																																			
29	MP3																																			
30	MP4																																			
31	MP5		1																																	
32	MP6																																			
33	QM1															1	1			1																
34	FM1																												1							
35	FM2				1														1		1															

Figure 6.3 Risk Structure Matrix of the proposed model

The Risk Structure Matrix alone is not sufficient for risk assessment. It is necessary to find out the risks triggering the other risks most and the interaction values. Therefore, the Risk Structure Matrix is transformed into the Risk Network Matrix. The proposed model is used for this transformation. During the transformation process, Excel and MATLAB are utilized as the tools. The Risk Structure Matrix is then converted to Risk Network Matrix by applying the steps explained in Section 5.2.2. An example of the transformation process from RSM to RNM is presented for the risk of R16 is presented in Figs. 6.4 and 6.5.

ROW	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35
BCV/R16	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

COLUMN	BEV/R16
1	0
2	0
3	0
4	0
5	0
6	0
7	0
8	0
9	0
10	0
11	0
12	0
13	0
14	1
15	1
16	0
17	1
18	0
19	0
20	1
21	0
22	0
23	0
24	0
25	0
26	0
27	0
28	0
29	0
30	0
31	0
32	0
33	1
34	0
35	0

ECM/R16

	14	15	17	20	33
14	1	7	7	1	7
15	0,14	1	0,2	0,14	1
17	0,14	5	1	0,14	5
20	1	7	7	1	7
33	0,14	1	0,2	0,14	1
TOP	2,42	21	15,4	2,42	21

CCM/R16

	9	12
9	1	3
12	0,33	1
TOP	1,33	4

	9	12
9	0,75	0,8
12	0,25	0,3

TOP	W	V	V/W	
1,5	0,75	1,5	2,0	0,5
0,5	0,25	0,5	2,0	0,5
			4	

	14	15	17	20	33
14	0,41	0,33	0,45	0,41	0,33
15	0,06	0,05	0,01	0,06	0,05
17	0,06	0,24	0,06	0,06	0,24
20	0,41	0,33	0,45	0,41	0,33
33	0,06	0,05	0,01	0,06	0,05

TOP	W	V	V/W	AGG
1,95	0,39	2,25	5,78	0,222
0,22	0,04	0,22	4,81	0,185
0,66	0,13	0,64	4,87	0,187
1,95	0,39	2,25	5,78	0,222
0,22	0,04	0,22	4,81	0,185
			26,03	

NEV/16	0	0	0	0	0	0	0	0	2	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NEM/16	0	0	0	0	0	0	0	0	0,5	0	0	0,5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

NCV/16	NCM/16
0	0
0	0
0	0
0	0
0	0
0	0
0	0
0	0
0	0
0	0
0	0
0	0
0	0
5,8	0,222
4,8	0,185
0	0
4,9	0,187
0	0
0	0
5,8	0,222
0	0
0	0
0	0
0	0
0	0
0	0
0	0
0	0
0	0
0	0
0	0
0	0
4,8	0,185
0	0
0	0

Figure 6.4 Example of the transformation process from RSM to RNM

CAUSE

EFFECT

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	0	0,71	0	0	0	0	0	0	0,33	0	0	0,33	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0,30	0	0	0,30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0,31	0	0	0,31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0,71	0	0	0	0	0	0	0,33	0	0	0,33	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
25	0	0	1,00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31	0	1,00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33	0	0	0	0	0	0	0	0	0,30	0	0	0,30	0	0	0	1,00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35	0	0	0	0	0,52	0,49	0,47	0	0,50	0	0	0	0	0	0,50	0	0	0	0	0	0,52	0	0	0	0	0	0	0	0,50	0,50	0	0	0	0	0

Figure 6.5 Risk Numerical Matrix

The following risks have the highest Risk Numerical Matrix scores. Therefore, they should be evaluated primarily to take proactive actions in new product development process.

The causal risks with the highest Risk Numerical Matrix scores are listed in the following.

- Risk of not finding sufficient / qualified workforce
- The risk of incorrectly constructed ERP system
- Risks of substitute products in the market
- Risk of market anticipation changing or not being well analyzed
- Risk of not being able to compete with competitors in terms of quality, price, costs, performance etc.
- Risk of misunderstanding or overlooking technical specification requests
- Risk of not providing conflict management on the project team
- Supply material and design dispute risk
- Risk of wrong design
- The risk of not being able to integrate subsequent requests into the system
- The risk of falling behind the technology in prototype production
- Risks of inappropriate prototype manufacturing method / process

The affected risks with the highest Risk Numerical Matrix scores are presented in the following.

- Risks of the production prototype failure in the test / analysis process
- Supply material and design dispute risk
- Risks of incorrect / incomplete bill of material
- Risks of error in the prototype production after the design is completed and the turnaround of the design cycle
- Risk of not being able to supply materials on time
- Risk of incorrect assembly of operator for prototype production
- Risk of rejection of prototype materials in the input quality control

- Risks of not achieving profits with project costs exceeding the sales revenue

6.2.3 Risk Mitigation

During the risk analysis phase, the risks that have the highest impact on the new product development process are identified. These risks have the highest cause-effect interaction in risk network analysis. In the risk mitigation phase, the strategies that are necessary to reduce these risks and their effects are determined. To this aim, Interpretive Structural Modeling (ISM) is utilized.

Firstly, the enablers to be utilized for eliminating the risks that have the highest impact on the new product development process are identified.

The enablers are presented in the following.

1. Improve the company culture and information sharing
2. Achieve correct market analysis
3. Provide alternative suppliers and improve the main suppliers
4. Improve project schedule and communication amongst the project team members
5. Improve the costs of resources
6. Improve coordination with product design team
7. Provide effective maintenance for the facilities
8. Improve communication between internal and external stakeholders

After identifying enablers, Interpretive Structural Modeling steps are applied. The proposed model is conducted with the support of related managers and experts in the company.

Creation of the structural self-interaction matrix (SSIM)

Firstly, SSIM is created as in the following according to Section 5.2.3. It is iterated for each enabler with configuration of symbols.

Table 6.5 Structural self-interaction matrix

Enablers	8	7	6	5	4	3	2
1. Improve the company culture and information sharing	X	V	V	O	X	X	V
2. Achieve correct market analysis	X	O	V	V	V	O	
3. Provide alternative suppliers and improve the main suppliers	X	O	A	V	O		
4. Improve project schedule and communication amongst the project team members	X	O	X	V			
5. Improve the costs of resources	A	A	A				
6. Improve coordination with product design team	X	O					
7. Provide effective maintenance for the facilities	O						
8. Improve communication between internal and external stakeholders							

Creation of the reachability matrix

After creating SSIM, reachability matrix is formed as presented in Table 6.6.

Table 6.6 Reachability matrix

	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*Driver*
1	1	1	1	1	0	1	1	1	7
2	0	1	0	1	1	1	0	1	5
3	1	0	1	0	1	0	0	1	4
4	1	0	0	1	1	1	0	1	5
5	0	0	0	0	1	0	0	0	1
6	0	0	1	1	1	1	0	1	5
7	0	0	0	0	1	0	1	0	2
8	1	1	1	1	1	1	0	1	7
Dependence	*4*	*3*	*4*	*5*	*7*	*5*	*2*	*6*	

Level partitions

In level partitions phase, the enablers are aligned to the levels step by step.

Table 6.7 Level partitions structure

	Enabler	*Reachability set*	*Antecedent set*	*Intersection set*	*Level*
	1	1,2,3,4,6,7,8	1,3,4,8	1,3,4,8	
	2	2,4,5,6,8	1,2,8	2,8	
	3	1,3,5,8	1,3,6,8	1,3,8	
	4	1,4,5,6,8	1,2,4,6,8	1,4,6,8	
	5	5	2,3,4,5,6,7,8	5	1
	6	3,4,5,6,8	1,2,4,6,8	4,6,8	
	7	5,7	1,7	7	
	8	1,2,3,4,5,6,8	1,2,3,4,6,8	1,2,3,4,6,8	
Iteration	*Enabler*	*Reachability set*	*Antecedent set*	*Intersection set*	*Level*
ii	7	7	1,7	7	2
iii	3	1,3,8	1,3,6,8	1,3,8	3
iv	6	4,6,8	1,2,4,6,8	4,6,8	4
v	2	2,4,8	1,2,8	2,8	5
v	4	1,4,8	1,4,8	1,4,8	5
vi	1	1,8	1,8	1,8	6
vi	8	1,8	1,8	1,8	6

Building the ISM-based model

This phase provides a framework that is about enablers' flow in the ISM model.

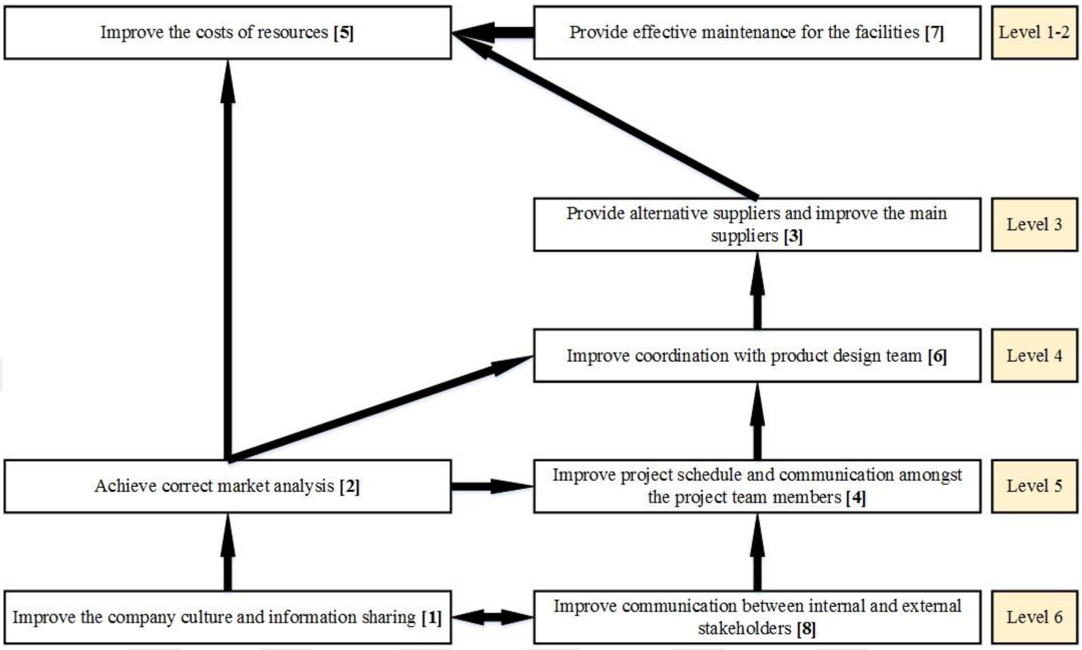


Figure 6.6 ISM-based model

This leveling frame presents the strategies that should be implemented bottom up through the ISM-based model.

MICMAC analysis

The results of the application (see Fig. 6.7) reveal that enablers 3 and 7 are autonomous enablers taking places in the first cluster that have "weak driving power" and "weak dependence". These enablers differentiate from the other enablers with their few strong links. Enabler 5 is a "dependent enabler" that have "weak driving power" but "strong dependence" taking place in the second cluster. Enablers 4, 6 and 8 have the "linkage enablers" that have "strong driving power" and also "strong dependence" representing the third cluster. These enablers are unbalanced and they have an effect on the others and also a feedback on themselves. Enablers 1 and 2 are the "independent enablers" having "strong driving power" but "weak dependence" in fourth cluster. They are assessed as the key enablers.

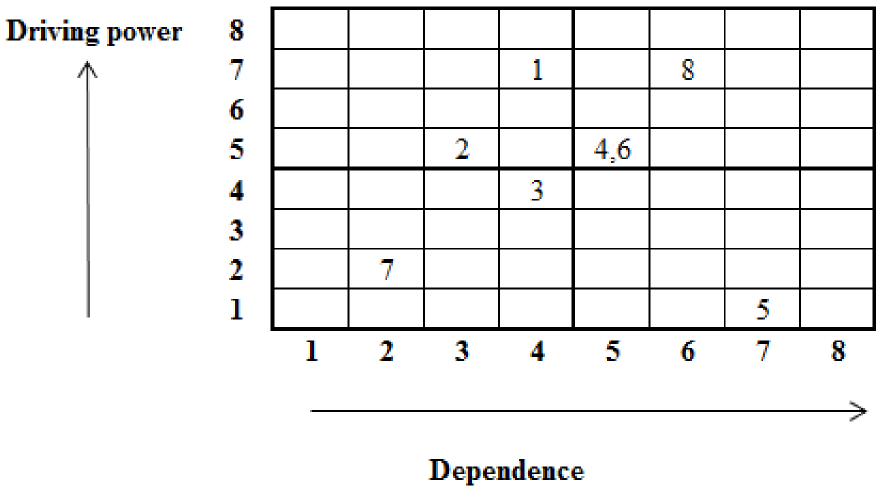


Figure 6.7 MICMAC Analysis

The ISM-based framework, which is created as a result of the ISM model, illustrates the strategies that the company should focus on in order to mitigate risks in the new product development process.

As reported in Fig. 6.7, enablers 1,8,4 and 6 have relatively more priority. More specifically, information sharing, communication and coordination have vital importance in new product development.

These results and strategies are shared with the company. In accordance with these enabler strategies, the company begun proactively manage the risks that may be incurred during the new product development process.

CHAPTER SEVEN
CONCLUSION

This study deals with the risk management for new product development in concurrent engineering environment. In this regard, a decision support system is developed for deliberating the risks with respect to cost, quality and timeliness dimensions in new product development processes. Probability-Impact Matrix and Design Structure Matrix are applied in the risk analysis phase. In addition, Interpretive Structural Modeling Technique is applied in the risk mitigation stage. The risks can be expressed with easily displayed models instead of complex networks with the proposed approach.

In order to expose the practicality of the proposed decision support system, a real world application is presented. The new product development process of a manufacturing firm operating in Turkish automotive industry is handled in the application. The risks are defined, the probability and impact values of these risks are specified and their interactions are calculated. After determining the highest risk values, risk mitigation study is performed to reduce the effects of these risks. A road map is offered to the company by using Interpretive Structural Modeling technique.

This study can be extended in some aspects. More specifically, conducting a sensitivity analysis can provide a comprehensive view for the risk interactions. The proposed approach is based on subjective evaluations in essence. Therefore, utilization of fuzzy approaches can provide reflection of the managers' subjective judgments in decision making process effectively.

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APPENDICES

Appendix 1: Abbreviations

AHP	Analytical Hierarchy Process
ANP	Analytical Network Process
BBN	Bayesian Belief Network
BCV	Binary Cause Vector
BEV	Binary Effect Vector
CAD / CAM	Computer Aided Design / Computer Aided Manufacturing
CCM	Cause Comparison Matrix
CE	Concurrent Engineering
CI	Consistency Index
CR	Consistency Ratio
DEMATEL	The Decision Making Trial and Evaluation Laboratory
DSM	Design Structure Matrix
ECM	Effect Comparison Matrix
FMEA	Failure Modes and Effects Analysis
GERT	Graphical Evaluation and Review Technique
HAZOP	Hazard and Operability
IRMAS	The Intelligent Risk Mapping and Assessment System
ISM	Interpretive Structural Modeling
NCM	Numerical Cause Matrix
NCV	Numerical Cause Vector
NEM	Numerical Effect Matrix
NEV	Numerical Effect Vector
PDM	Product Database Management
PLM	Product Lifecycle Management
P-I Matrix	Probability and Impact Matrix
QFD	Quality Function Deployment
RBN	Risk Breakdown Structure
RM	Risk Management

RNM	Risk Numerical Matrix
RSM	Risk Structure Matrix
SSIM	Structural Self-Interaction Matrix
SWIFT	Structured What-If Technique