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Tallinn University of Technology

School of Engineering

Department of Mechanical and Industrial Engineering

DMAIC JA FMEA INTEGRATSIOON TARNEAHELA RISKIJUHTIMISES

DMAIC AND FMEA INTEGRATION FOR SUPPLY CHAIN RISK MANAGEMENT

MAGISTRITÖÖ/ MASTER THESIS

Student: Emad Hosseinnejadkeyvani

Student code: 213887 MARM

Supervisor: Alina Sivitski

Co-supervisor Priit Põdra

Tallinn 2023

(On the reverse side of title page)

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Hereby I declare, that I have written this thesis independently.

No academic degree has been applied for based on this material. All works, major viewpoints and data of the other authors used in this thesis have been referenced.

May 2023.

Author: Emad Hosseinnejadkeyvani

/signature/

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"15" May 2023

Supervisor: lecturer PhD Alina Sivitski

Co-supervisor: senior lecturer PhD Priit Põdra

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Department of Mechanical and Industrial Engineering

THESIS TASK

Student: Emad Hosseinnejadkeyvani (213887MARM)

Study programme: Industrial Engineering and Management (MARM)

Supervisor: Lecturer PhD Alina Sivitski,

Co-supervisor: Senior lecturer PhD Priit Põdra

Thesis topic:

(in English) DMAIC AND FMEA INTEGRATION FOR SUPPLY CHAIN RISK MANAGEMENT

(in Estonian) DMAIC JA FMEA INTEGRATSIOON TARNEAHELA RISKIJUHTIMISES

Thesis main objectives:

1. Review DMAIC and FMEA and other similar methods applications for supply chain risk management improvement; benefits and product quality improvement.
2. DMAIC and FMEA integrated applications through conducted questionnaires, DMAIC steps description and risk assessment application using FMEA as analysis step.
3. DMAIC and FMEA integrated application, risk management improvement steps, solutions and control procedures
4. Analysis of propose solutions

Thesis tasks and time schedule:

No	**Task description**	**Deadline**
1.	Literature review to investigate DMAIC and FMEA and other similar methods applications for supply chain risk management improvement	15.03.2021
2.	DMAIC steps definition, automotive industry supply chain managers and engineers conducted questionnaires for waste types and risks types definitions, FMEA risk assessment parameters definitions, risk assessment templates composing	25.03.2021
3.	DMAIC and FMEA integrated application, risk management improvement steps, solutions and control procedures	01.04.2021
4.	Analyze findings and propose solutions	30.04.2021

Language: English **Deadline for submission of thesis:** "20" May 2023

Student: Emad Keyvani .... "......."..............2023

/signature/

Supervisor: Lecturer, PhD Alina Sivitski .... "......."..............2023

/signature/

Head of study programme: Prof. Kristo Karjust .... "......."..............2023

PREFACE

I, Emad Hosseinnejadkeyvani, with years of working experience in the automotive industry in the supplier's quality control area, tried in this thesis by relying on the experiences gained in one of the most important active industries in Iran, which is always under the greatest pressure and also reviewing the previous studies done by others, present a method to identify and eliminate the risks in the material supply chain. This would not have been possible without the help of the supervisors, Alina Sivitski and Priit Põdra, so I would like to express my gratitude to them.

List of abbreviations and symbols

SCM – Supplier chain management

SCRM - Supplier chain risk management

FMEA – Failure mode and effects analysis

DMAIC – Define, Measure, Analyze, Improvement, Control

SCRA - Supply chain risk assessment

DMADV – Define, Measure, Analyze, Design, Verify

RPN – Risk priority number

SD – System dynamic

DES – Discrete event simulation

VSM – Visual stream mapping

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1. INTRODUCTION

1.1. Research problem

The years 2019-2022 can be earmarked as years of global supply chain disruption owing to the outbreak of the coronavirus (COVID-19). It is however not only because of the pandemic that supply chain risk assessment (SCRA) has become more critical today than it has ever been. With the number of supply chain risks having increased significantly over the last decade, particularly during the pandemic and after that, there has been a flurry of literature on supply chain risk management (SCRM), illustrating the need for further classification so as to guide researchers to the most promising avenues and opportunities. Therefore, this study aims to analyze supply chain risk management techniques and their Improvements. The topic of the thesis is supported by the author working experience in the field of Supply chain management, automotive industry.

1.2. Objective and Methodology

In recent years, business analysis approaches have become progressively a significant tool for improving the efficiency, competitiveness and profitability of businesses and their processes. Its positive impact on business performance has led recent studies to explore how to best identify opportunities to use business analytics to achieve optimal performance in supply chain management. Accordingly, it is important to study the effects of business analytics applications on the performance of supply chain risk management and provide the necessary solutions in this area for both managers and scholarships. Therefore, in this study we will analyze a supply chain risk management using DMAIC and FMEA approach. We will evaluate the risk management of the supply chain with the FMEA method and its management performance its improvement with the DMAIC method, so that a comprehensive evaluation of a supply chain management in automotive company as a case study will be studied. Therefore, we investigate the aspects of risk management system "estimation" and "evaluation". In case of risk estimation, we estimate the probability of occurrence and consequences of hazards. We also estimate corresponding risk levels (classes) as well. Then we use FMEA based risk assessment template of supply chain risk assessment (SCRA) to use in the Analyze stage of DMIAC to analyze wastes and risks that occur in the initial to final process stages in supply chain management.

According to what was stated, the objectives of the research were designed as follows:

1) FMEA method will apply to analyze the wastes and risks that occur in the initial to final process stages in supply chain management.

2) To find control ways and standardization in supply chain management to increasing the system output, we will apply Six Sigma DMAIC methods to analyze the FMEA results.

The figure 1.1, shows how to use FMEA as an analysis tool to estimate and measure risk to identify risks and waste in the DMAIC cycle. Then with DMAIC can create a system of tools, procedures integrated into the general quality management system with the possibility of planned and organized continuous improvement of SCM and TQM system.

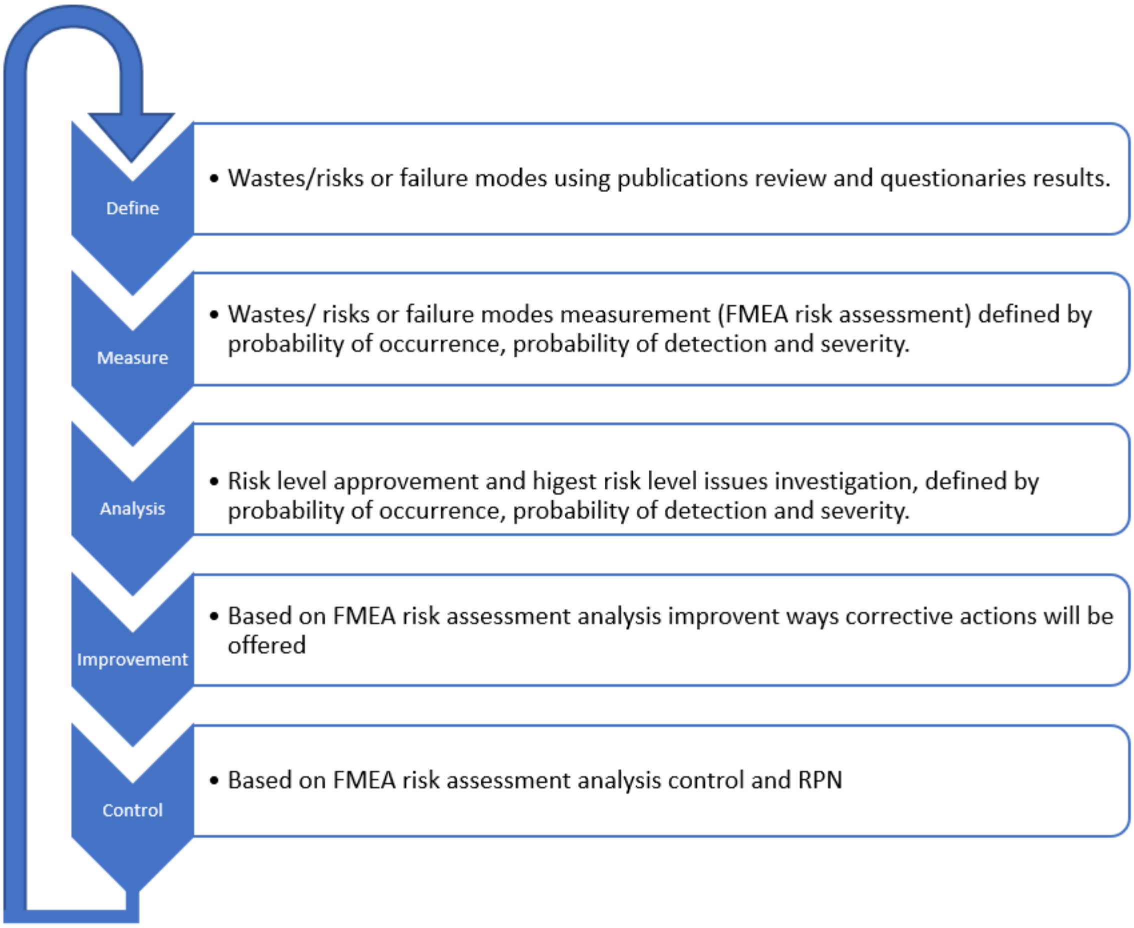

Figure 1.1 Implementing FMEA in DMAIC cycle

1.3. Thesis overview

In the first chapter of the thesis, the introduction and generalities of the research were stated. In this regard, the research problem was explained and the research method was introduced. Also, the background of t the research was examined on a case-by-case basis to determine the importance of focusing on the subject of the research. Basic concepts and analysis of SCM/SCRM improvement methods based on literature review and working experience will present in the second chapter to gain a deep understanding of the researches that has been done. In the third chapter, results of the study will be presented. In this regard, the results of research data analysis with DMAIC and FMEA methods will be presented. In the fourth chapter, a summary of the study will be presented. This chapter will discuss research limitations and implications for future research.

2. Basic concepts and analysis of SCM/SCRM improvement methods based on literature review and working experience

2.1. Principal concepts in SCM/SCRM

2.1.1. Supply Chain Management

Supply chain management has become more important as an academic subject due to globalization trends that lead to the widespread redistribution of production benefits. Due to the large amount of data generated in the global economy, new tools are needed to manage and analyze data as well as monitor organizational performance around the world (Glavee-Geo, 2019). According to one of the most recent and complete theoretical definitions, supply chain management is the integration of key business processes from the end user to the main supplier, who is responsible for providing products, services and information that create added value for the organization's customers and stakeholders (Fransisca et al, 2022). (Humphreys et al,2007) asserted that one of the reasons is that most of successful manufacturing organizations have an opportunity to achieve higher performance in pursuit of supply chain management (SCM), which is a common practice across manufacturing industries from both the practical and academic standpoints, the emphasis in SCM is still strongly skewed toward the manufacturing sector (Bartos et al, 2022).

2.1.2. Supply Chain Risk Management

In recent years, with the intensification of competition in global markets, the appearance of products with a short life cycle, and the rising expectations of customers, organizations and businesses have been forced to invest more in their supply chain and its management (Demiralay and Paksoy, 2022). In addition, the emergence of global factors such as political issues, demand fluctuations, technological changes, financial instabilities, and natural disasters have increased uncertainty and risk in the supply chain, and have increased the importance of implementing supply chain risk management in the organization. Pursuant to theoretical definitions, supply chain risk management is the management of risks in the supply chain through coordination and cooperation between the components of the supply chain in a way that guarantees the profitability and continuity of the supply chain (Makinde et al, 2022). According to the research of (Trkman and McCormack ,2009), risks may be within the supply chain and lead to changes in the relationship between the company and suppliers, such as late delivery, risks of sharing production information or vendors); Or the root of the risk is outside the supply chain, such as inflation rate, terrorist attacks, infectious diseases, labor strikes. (Juttner et al,

2003) put forward four concepts of risk sources, risk consequences, risk drivers and risk reduction strategies to define supply chain risk management. According to their definition, risk reduction strategies are those strategies that organizations deliberately choose to reduce the uncertainties identified from various sources of risk. These strategies are mainly related to risk types in the supply chain.

(Chopra and Sodhi ,2004) divided the risk factors in the supply chain into nine categories: disruptions, delays, information systems failure, forecasting, intellectual assets, procurement, customers, inventory and capacity. (Tang ,2006) divided supply chain risks into two dimensions: operational risks such as customer demand uncertainty, supply uncertainty and cost uncertainty, and disruption risks that refer to major disruptions caused by natural and human disasters such as earthquakes, floods, it has storms and terrorist attacks and/or economic crises such as currency evaluation or strikes. (Dekker et al ,2013) investigated the use of control measures by companies in managing risks related to cooperation and partnership with supply chain partners. These control measures include contingency planning of contracts, operation review, information sharing, supplier support, joint problem solving, and performance-based goal setting. Also, (Ritchie and Brindley ,2007) divided supply chain risk factors into 6 categories, which include supply chain members, supply chain environment, industry variables, industry strategy, problem-specific variables, and decision-maker variables.

2.1.3. System changes in supply chain

Uncertainty caused by demand fluctuations is one of the most fundamental issues in any supply chain, but this factor is not the only factor that affects the flow of materials throughout the supply chain, even when the customer's demand is clearly defined and known (through a contract or agreement), system changes are still one of the problems of managers (Taghizadeh and Hafezi, 2012). Instabilities in issues such as process capabilities, setup times, transportation time, etc. are among the types of losses that affect the flow of materials. There are various factors that make it difficult to control problems caused by system changes, some of which are briefly explained following.

The complexity of the supply chain network

A supply chain network includes warehouse keepers, manufacturers, distributors who can be widely located in any place and this expansion requires precise and complex planning which will be costly in terms of time. There are different institutions in a supply chain that may have different capacities and they are not clear behind the flow of materials. These institutions may also cause disruption and breakdown in the flow of information and materials due to lack of compatibility (Cui et al., 2022).

Standardization

One of the key factors in creating a successful supply chain network is that the organizations that make up this chain, each of which has a unique function, coordinate their processes and business affairs with other organizations that make up the chain. This idea of successful construction of a network will not be realized except by considering the capacities of other processes in the overall chain and having a general map of the process flow. For this purpose, the standardization of business processes is one of the requirements for proper communication and integration between business partners in the supply chain (Zhou and Wang, 2021).

Outsourcing and procurement

Coordination of different processes of a supply chain is only one step forward to integrate the supply chain. The next step is related to strategic decisions in the field of material procurement, which should either be provided from within the chain or procured from external sources and chains. Solving this problem depends on determining the basic competitive factors of each company in the supply chain (Ebrahimi et al., 2021).

Distribution strategy

The decisions that are made regarding the selection of the appropriate distribution strategy for different parts of the supply chain are one of the effective factors in system changes, which usually according to the different policies of the chain, one of the three strategies (1) Direct shipment of goods (2) Warehousing Traditional and (3) "docking-cross" method will be chosen as the distribution system (Cui et al, 2022).

2.1.4. Waste parameters in the supply chain

What parameters are there to measure supply chain waste reduction? In order to answer this question, according to (Simchi-Levi et al,2021), (Decandia et al, 2017) and (Crowe ,2017), factors affecting the supply chain wastes which is composed by different authors opinion are given in Table 2.1.

Table 2.1 Factors affecting waste reduction in a supply chain

Basic wastes	Factors affecting waste reduction	Parameters
Supply chain waste	Customer demand and satisfaction	service level
		The cost of exchanges
	Time to set up the supply chain	The ratio of the time of receiving information to the time of sending an order
	Protective inventory	Standard deviation of customer demand
		coefficient of variation
	Integration of risk in the supply chain	Safety inventory
		Safety culture
	Agility	ability to quickly adjust the strategy, particularly in procurement, inventory management and delivery to meet rapidly changing supply chain requirements
Organizational waste	Material	Losses as a percentage of the total material cost
	Equipment	Cost and preparation time
		The number of cars stops due to breakdowns per time unit
		Machine utilization rate (percentage of ideal machine time)
		Average maintenance cost as a percentage of book value of equipment
	Inventory	Inventory return ratio: the ratio of annual sales to the average amount of inventory

Basic wastes	Factors affecting waste reduction	Parameters
		inventory in progress as a percentage of total production volume or cost
		inventory in progress as a percentage of production efficiency
		Safety inventory as a percentage of the maximum inventory
	Facilities planning	Space utilization ratio
		Material handling time as a percentage of total production time
		Material processing time as a percentage of total setup time
	Quality	Rework rate
		The return rate of products as a percentage of the total products produced
		Return rate of products by customers

To identify the sources of waste, we classified all types of wastes under the heading of non-added value areas or waste types in Table 2.1. The act of categorizing provides the possibility to categorize non-added value activities and to easily recognition of the relationship between them. For this purpose, organizational waste was divided into four groups and supply chain waste was divided into three groups, and each group includes several activities without added value.

2.2. Supply chain risk assessment and analysis methods

Risk assessment is one of the pillars of risk management in the supply chain, and its purpose is to measure risks based on various indicators such as the degree of impact and the probability of occurrence, and the more accurate the results of this step, it can be said that the risk management process is carried out with a higher degree of confidence (Crowe, 2017). On the other hand, one of the key issues in supply chain management is the formation of the supply chain and effective coordination between its components with the aim of customer satisfaction. Carrying out this coordination requires a complex flow of information, raw materials and capital at different levels of the process between different companies in the supply chain. To achieve this goal, different methods of evaluating and analyzing supply chain risks must be identified so that they can be managed. Supply chain risk management (SCRM) is a significant factor for both supply success and firm success as well, and it can be mitigated to a great extent by the selection of the appropriate supplier (Curkovic et al., 2013).

The research results have shown that the sources of risk may be environmental, organizational or caused by the supply chain itself, as a result, it is very difficult to predict their effects with certainty (Bitencourt de Oliveira et al., 2022). Since the sources of chain risks are very numerous and diverse, it is impossible to completely eliminate them, and there are also various internal and external factors and conditions that greatly affect their intensity and weakness (Praharsi et al., 2021). Therefore, it is necessary to conduct researches that investigate and analyze this phenomenon and techniques that used to analyzing Supply chain risk management.

2.2.1. DMAIC Method

When it comes to improving performance, there are two main methodologies: DMAIC and DMADV (Godina et al., 2021). DMADV is a more prescriptive methodology that helps businesses creates new products or services. It stands for Define, Measure, Analyze, Design, and Verify, and is based on the engineering process. It takes a more top-down approach to problem-solving and helps businesses understand what they need to do to create successful products or services (Godina et al., 2021). On the other hand, DMAIC is a data-driven improvement cycle that helps organizations measure and improve their performance. DMAIC is the acronym of five steps: Define, Measure, Analyze, Improve, and Control. The main goal of DMAIC is to identify and eliminate waste in a business process. This can be done through the application of Lean and Six Sigma tools and techniques. DMAIC can be an effective way to improve business performance as it can help to identify and solve problems, make improvements, and track results (Kholil et al., 2021). The goal of this process is to improve the performance of a business by reducing variation and increasing efficiency. DMAIC can be used by organizations of all sizes, and it has been proven to be an effective way to improve the performance of operations (Senthilkumar et al., 2012). (Makinde et al.,2022) improved the SC Performance of an electronic product-manufacturing organization By DMAIC method. This study used the DMAIC methodology to validate a lean supply chain with a discrete-event simulation approach. (Praharsi et al. ,2021) used DMAIC Technique to achieve supply chain resilience. They applied a Lean Six Sigma framework to implementation of supply chain resilience during COVID-19 pandemics in the maritime industry (shipbuilding, logistics services and shipping companies). They stated that the DMAIC technique is an efficient approach to assess supply chain resilience. (Maryadi and Ichtiarto ,2021) explored the application of Lean Six Sigma DMAIC implementation to decrease total lead time internal supply chain process. In this research the Lean Six Sigma DMAIC approach has been efficaciously applied as an approach to decrease the process lead time in the overall internal supply chain.

(Madhani ,2016) used Six Sigma DMAIC approach in Supply Chain Management to enhancing competitiveness. The result showed that "Six Sigma offers a route to creating more robust supply chain processes that reduce the risk of non-conformance and hence produce a more reliable and consistent output". (Senthilkumar et al,2012) used DMAIC methodology in supply chains to reduce customer end-rejections. Results showed that the customer end rejections have been improved from a sigma level of 3.75 to 5 through the implementation of DMAIC methodology.

DMAIC approach is literary used to evaluate the performance of supply chain management, not to measure risk management in the supply chain (e.g. Makinde et al., 2022), therefore, in this research, the integration of this method with the FMEA method is discussed in order to evaluate the risk management of the supply chain with the FMEA method and its management performance is evaluated with the DMAIC method, so that a comprehensive evaluation of the a supply chain management in Automotive company as a case study will be studied.

The steps of DMAIC method are shown in the figure below:

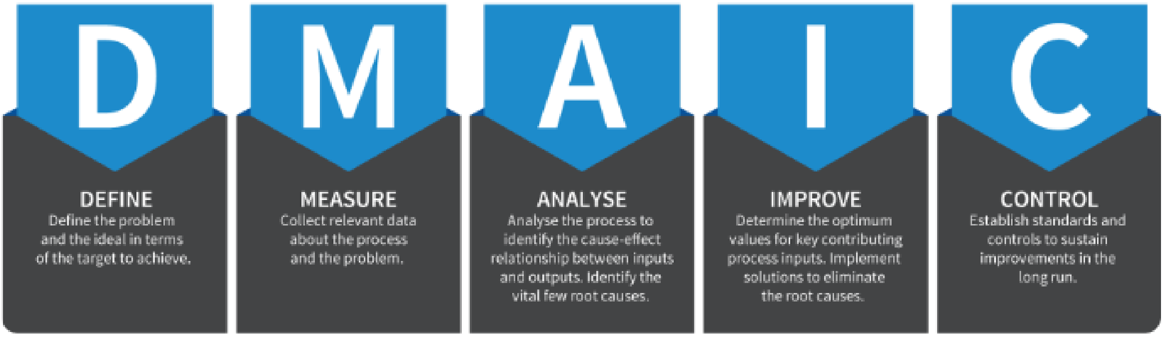

Figure 2.1 Steps of DMAIC method (Godina et al., 2021)

Define: The purpose of the definition phase is to ultimately describe the problems to be solved and align key business decision makers on the project goal.

Measure: In the measurement phase, the goal is to gather relevant information to begin the current performance of the product or process. At this stage, we want to identify the level of "defects" or errors that occur and use a baseline to measure progress throughout the project.

Analyze: The purpose of the analysis step is to find out which inputs or process parameters have the greatest influence on the outputs. In other words, we want to identify the root cause(s) so we know what critical elements we need to fix.

Improve: The goal of the improvement phase is to identify a wide range of potential solutions that provide the maximum return on our investment and directly address the identified root cause.

Control: The purpose of the control stage is to control the risks and presenting the solutions (Madhani, 2016).

Benefits of DMAIC

There are a number of benefits to using the DMAIC methodology in business which some of important ones are as follows:

- It can help to clearly define and measure objectives.
- Track and improve performance over time.
- It provides a framework for analyzing data to identify potential improvements.

- See improvements in quality, cycle time, and customer satisfaction.
- Businesses that use DMAIC can experience cost savings and increased profits (Kholil et al., 2021).

By using the DMAIC methodology, businesses can make significant improvements in quality, efficiency, and customer satisfaction. And as we've seen, Lean Six Sigma can have a positive impact on all aspects of a business, from product development and manufacturing to marketing and customer service. Some of these, when applied, result to:

- Creating a focus on customers and building customer loyalty.
- Attaining better performance thus resulting in improved goods and services.
- Creating a fun quality work environment.
- Providing a practical method to achieve greater levels of process quality (Senthilkumar et al., 2012).

2.2.2. FMEA Method

Failure Modes and Effects Analysis (FMEA) is approach for analyzing potential reliability problems early in the development cycle where it is easier to take actions to overcome these issues, thereby improving reliability through design. In fact, FMEA is used to identify potential failure modes, determine their effect on the operation of the product, and identify actions to mitigate the failures (Fransisca et al., 2021). A crucial step is anticipating what might go wrong with a product. While anticipating every failure mode is not possible, the development team should formulate as extensive a list of potential failure modes as possible (Dendera-Gruszka and Kulińska, 2020). The early and consistent use of FMEAs in the design process allows the engineer to design out failures and produce reliable, safe, and customer pleasing products. FMEAs also capture historical information for use in future product improvement. Historically, engineers have done a good job of evaluating the functions and the form of products and processes in the design phase. They have not always done so well at designing in reliability and quality. Often the engineer uses safety factors as a way of making sure that the design will work and protected the user against product or process failure (Curkovic et al., 2013).

(Curkovic et al ,2013) used FMEA method for supply chain risk management assessment. They reported significant performance of the FMEA approach to assessing supply chain risk management. (Dendera-Gruszka and Kulińska ,2020) analyzed supply chain FMEA

Risk for the Heavy Industry Sector. They found that the use of the FMEA approach has enabled the detection of defects in supply chain management. (Choudhary et al, 2022) concluded that FMEA approach is an efficient technique to assess supply chain risk management. (Wu et al, 2021) adopted FMEA approach for the risk assessment to exclude high-risk suppliers. They asserted that FMEA can play a significant role in the process of risk management through supplier evaluation and selection, too.

In some other studies concerning FMEA approach, (Nahavandi and Tavakoli ,2022) used FMEA method to assess risk management of procurement processes in Automotive Supply Chain. Results concluded that "Lack of timely providing of imported," "Failure to timely providing," "Impossibility to provide imported parts," "Failure/Delay in timely clearance of goods" were top identified risks. (Sukwadi and Caesar ,2022) performed an assessment using the FMEA method to measure of the severity, frequency and the level of correlation between the risk and its causes. (Valinejad et al,2022) proposed a hybrid model for Supply Chain Risk Management based on five-dimensional sustainability using FMEA method and Fuzzy VIKOR. (Fransisca et al,2021) measured supply chain risk implementation using FMEA approach. They identified total 40 risks with 21 risks that need to be immediately being look over and improved.

FMEA's provide the engineer with a tool that can assist in providing reliable, safe, and customer pleasing products and processes. Since FMEA help the engineer identify potential product or process failures, they can use it to:

- Develop product or process requirements that minimize the likelihood of those failures.
- Evaluate the requirements obtained from the customer or other participants in the design process to ensure that those requirements do not introduce potential failures.
- Identify design characteristics that contribute to failures and design them out of the system or at least minimize the resulting effects.
- Develop methods and procedures to develop and test the product/process to ensure that the failures have been successfully eliminated.
- Track and manage potential risks in the design. Tracking the risks contributes to the development of corporate memory and the success of future products as well.

- Ensure that any failures that could occur will not injure or seriously impact the customer of the product/process (Godina et al., 2021).

Application of FMEA in SC risk assessment

The FMEA technique for assessing supply chain risks has two phases as follows:

The first phase: In this phase, by focusing on identifying potential risks in the processes within the supply chain obtained through the review of the research literature, the probability of occurrence, the severity of its effect, as well as the probability of discovering each risk is determined. We used 5-point Likert scale to measure the probability of occurrence, the severity of its effect and the probability of discovering each risk. Therefore, we use Table 2.2 to score the probability of occurrence of each risk in the study.

Table 2.2 Scoring the probability of occurrence of each risk in the study

No	The probability of risk occurrence	Score
1	Most likely to occur. Almost every few months	9
2	The chance of occurrence is 50/50. It may occur once every six months	7
3	Can happen by the chance. The chance of happening is once a year	5
4	Happened several times in the past and it can happen once every year	3
5	Impossible. Never happened	1

Table 2.3 has been used to score the severity of each risk:

Table 2.3 scoring the severity of each risk

No	The severity of risk occurrence	Score
1	Severe and irreparable damages inflicted on the company and key stakeholders that can't be compensate	9
2	Damages inflicted on the company and key stakeholders that are difficult to compensate	7

No	The severity of risk occurrence	Score
3	Damages inflicted on the company and key stakeholders that can be compensated	5
4	Moderate damages inflicted on the company that can be compensated	3
5	Slight damages inflicted on the company that can be compensated easily.	1

Table 2.4 is used to score the probability of discovering each of the risks.

Table 2.4 Risk discovery probability score

No	Risk discovery probability score	Score
1	There is no control or, if there is, it is unable to detect the risk	9
2	It is unlikely that the risk will be detected with the existing controls	7
3	In half of the cases, it is possible that the risk will be detected with the existing controls	5
4	There is a relatively high probability that the risk will be detected with the existing controls	3
5	Definitely, with the existing controls, the risk will be tracked and revealed	1

Second phase: This phase includes the calculation and analysis of data collected from the first phase. The main goal in this phase is to obtain the risk priority number from severity, probability of occurrence and probability of discovery scores using following formula (Liu et al., 2013):

Severity of occurrence * probability of occurrence * probability of risk detection = risk priority number.

Severity of effect * probability of occurrence = risk score.

Benefits of FMEA

FMEA is designed to assist the engineer improve the quality and reliability of design. Properly used the FMEA provides the engineer several benefits. Among others, these benefits include:

- Improve product/process reliability and quality
- Increase customer satisfaction
- Early identification and elimination of potential product/process failure modes
- Prioritize product/process deficiencies
- Capture engineering/organization knowledge
- Emphasizes problem prevention
- Document risk and actions taken to reduce risk
- Provide focus for improved testing and development
- Minimizes late changes and associated cost
- Catalyst for teamwork and idea exchange between functions (Fransisca et al., 2021).

The FMEA is a living document. Throughout the product development cycle change and updates are made to the product and process. These changes can and often do introduce new failure modes. It is therefore important to review and/or update the FMEA when:

- A new product or process is being initiated (at the beginning of the cycle).
- Changes are made to the operating conditions the product or process is expected to function in.
- A change is made to either the product or process design. The product and process are inter-related. When the product design is changed the process is impacted and vice-versa.
- New regulations are instituted.

➢ Customer feedback indicates problems in the product or process (Godina et al., 2021).

2.2.3. Other methods for SCRM improvement

In the field of supply chain risk management techniques, various methods will be presented in the research. According to the results of the research, some of the most important of which are discussed in the following section, the FMEA and the DMAIC method are among the two efficient and effective approaches that have been used in numerous researches. Although, there is other methods to analyze supply chain risk management. For example, (Meyer et al, 2022) conducted a risk assessment using the Delphi method and noted that the COVID-19 pandemic has caused significant disruptions to global supply chains, leading to major procurement challenges. They highlighted how non-critical items have become critical blockages, making it challenging for organizations to operate efficiently. In response to these challenges, the authors suggested that Additive Manufacturing (AM), an emerging technology, could serve as a local supply source and help to mitigate some of these blockages. One advantage of the Delphi method is its flexibility - it can be adapted to a wide range of research questions and is not limited by geographic location or time constraints. Additionally, the method provides a platform for anonymous input, which can help to minimize bias or influence from other group members or the facilitator. However, there are also some limitations to the Delphi method. The process can be time-consuming and resource-intensive, requiring multiple rounds of data collection and analysis. Additionally, the Delphi method relies heavily on the expertise and subjective opinions of the participants, which can lead to potential biases or limitations in the scope of the study, (Hsu, C.-C., & Sandford, B. A, 2007).

(Crowe ,2017) presented an integrated retail supply chain risk management framework. This paper analyzed retail supply chain risk management using the techniques of System Dynamics (SD) and Discrete Event Simulation (DES) modeling. This study validates using simulation as an effective risk assessment tool. But, in the current research, we are examining the results of two methods, FMEA and DMAIC, so in the following, the latest research conducted using this approach in the field of supply chain management evaluation will be discussed. System dynamics provides a powerful means to represent, explore and communicate understanding of complex systems. The method is particularly suited to problems that involve feedback, nonlinearity, time delays, and the interactions between multiple levels and types of variables (Lane, D. C., & Husemann, E, 2005). Despite the many strengths of system dynamics, there are also limitations and challenges to its use in policy formulation. System dynamics models are often time-consuming and resource-intensive to develop, requiring significant data collection and stakeholder engagement, (Padgham, L., & Miotto, J. M, 2019). One of the main advantages of DES is it can be used to model complex systems that involve multiple events occurring at different times. Additionally, DES can be used to test different scenarios and strategies, allowing for the evaluation of the effectiveness of different policies or processes , but DES models can become complex and difficult to understand, especially when modeling complex systems with many variables and interactions and also it is limited by the quality and availability of data, and inaccuracies in the input data can lead to unreliable simulation results, (Banks, J., Carson, J. S., Nelson, B. L., & Nicol, D. M, 2010).

2.3. Comparison of improvement methods

By studying and analyzing various methods used for supply chain risk analysis, it can be concluded that SD and DES are simulation-based methods that are used to model complex systems and understand how changes in the system can affect its behavior. While SD and DES are useful for modeling complex systems, they are not as effective in identifying potential failures and mitigating risks as FMEA and DMAIC. Therefore, they may not be the best choice for risk assessment in SCRM. Also, The Delphi method is a qualitative method that is used to reach a consensus among experts. It involves a series of rounds in which experts provide their opinions on a particular issue, and the results are aggregated and fed back to the experts in subsequent rounds. While the Delphi method can be useful for reaching a consensus among experts, it may not be as effective in identifying potential failures and mitigating risks as FMEA and DMAIC. Therefore, it may not be the best choice for risk assessment in SCRM.

Table 2.5 is used to compare the advantages and disadvantages of each risk assessment method.

Table 2.5 Method's advantages and disadvantages comparison

Method	Advantages	Disadvantages
FMEA	Identifies potential failures and their effects	examination and documentation of failures, wastes with low consequences significance
	Prioritizes risks based on severity and frequency	Requires significant expertise

Method	Advantages	Disadvantages
	Develops a plan to mitigate risks	General SCM improvement system cannot be created based only on that method
DMAIC	Analyzes data to identify root cause of problems	Need for resources (additional audits; additional working time for planning and analysis, control and improvement)
	Develops solutions to address identified problems	need for management high involvement for success
	Improves processes and reduces defects	not reliable analysis method selection, in the analysis step of DMAIC
FMEA + DMAIC	Comprehensive Analysis	time-consuming process
	Systematic Approach	
	Continuous Improvement	
SD	Models complex systems and their behavior	May not be suitable for identifying potential failures
	Allows for testing of different scenarios	Can be time-consuming
	Helps to understand how changes affect the system	Requires significant expertise
DES	Models complex systems and their behavior	May not be suitable for identifying potential failures

Method	Advantages	Disadvantages
	Allows for testing of different scenarios	Can be time-consuming
	Helps to understand how changes affect the system	Requires significant expertise
Delphi	Reaches consensus among experts	May not be suitable for identifying potential failures
	Incorporates a variety of viewpoints	Results can be influenced by group dynamics and biases
	Can be used in situations where there is limited data	Results may not be representative of the population as a whole

In conclusion, FMEA and DMAIC can be considered a comprehensive approach for risk assessment in SCRM, as they allow organizations to identify potential failures, assess the risk associated with each failure, analyze data to identify the root cause of problems, and develop solutions to address those problems. On the other hand, SD, DES, and Delphi method may not be as effective in identifying potential failures and mitigating risks.

3. RESEARCH METHOD AND DATA ANALYSIS

3.1. SCM Improvement Method Application in the company

One of the most important parts of any research is data analysis. In this chapter, in order to achieve the goals and answer the research questions, data analysis has been done.

3.1.1. Basic wastes in the supply chain management

In the research literature of lean production, any type of activity that lacks added value is called "waste". According to the principles of lean management, eight types of waste sources are introduced for the supply chain:

- **Waste from excessive production**: The existence of this type of waste leads to an increase in the accumulation of inventory and also to an increase in the amount of product waste.

- **Waiting time**: the waiting factor leads to wasted time and energy resources; Such as workers' wasted time waiting for the production line to start.

- **Inventory loss**: In this type of waste, due to the accumulation of inventory, the risk of damage to the final product or the raw materials in the warehouses is greatly increased.

- **Excessive processing waste**: sometimes adding an unnecessary and non-value-added feature leads to waste of raw materials and energy. Packaging overlays are a good example of this type of waste.

- **Waste in transportation**: material and energy waste can also be caused by non-value-added transportation. Among the factors that cause it, we can mention wrong routing or setting up facilities such as warehouses in the wrong place.

- **Waste in arrangement and delivery**: non-value-added delivery of tools and people can lead to waste. For example, the bad arrangement of the goods in the warehouse makes the forces to move a longer distance to get the desired goods.

- **Waste of defective goods**: In the production of defective goods, a lot of time, raw materials, and energy are wasted; it doesn't matter if the defective product can be recovered or not, in any case, it has wasted some resources.

- **Waste of knowledge resources**: The lack of optimal use of knowledge and skills in the organization and its human resources leads to the waste of knowledge resources.

Figure 3.1 shows the supply chain of a car fender production in the form of a value stream mapping, in this figure possible places for wastes occurrence is showed with a red cross.

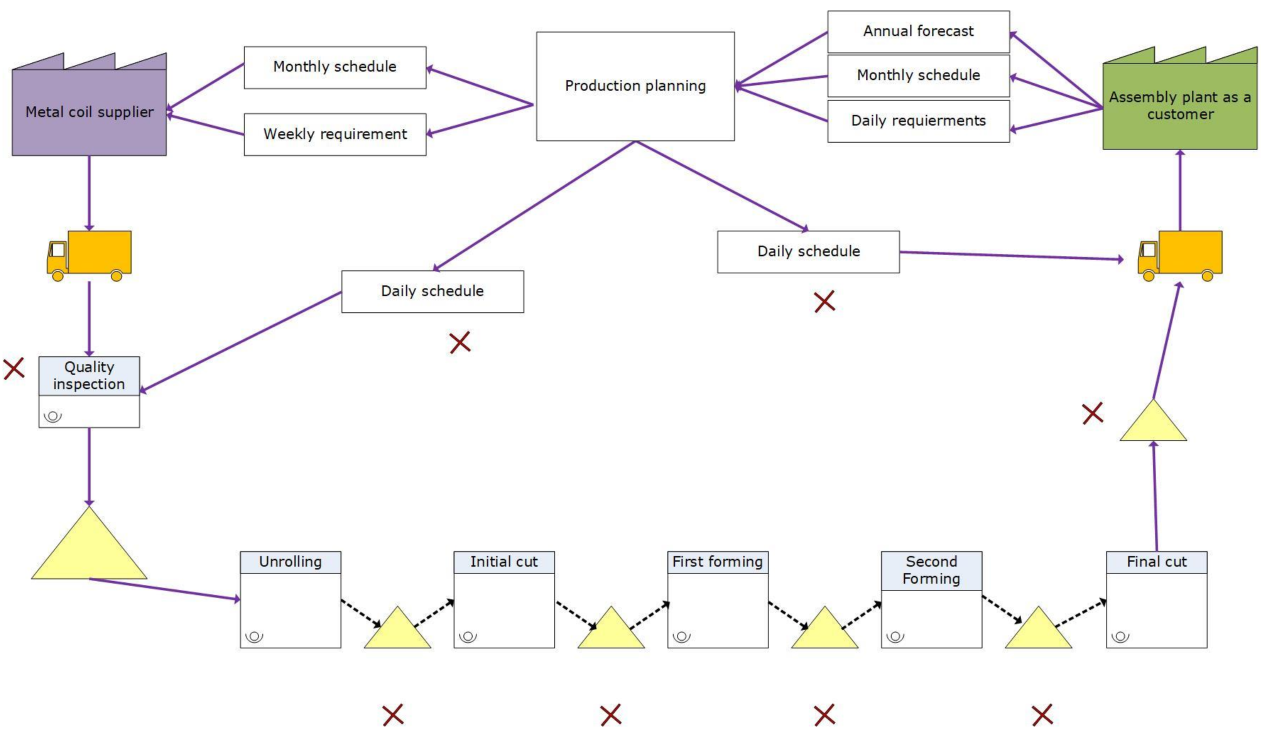

Figure 3.1 Car fender fabrication VSM sample

3.1.2 SCRM in automotive industry

Among Iranian industries, the automotive industry is facing various crises and risks in its value chain due to its special importance in Iran economy and having a complex supply chain cycle. In this context, the intensification of political sanctions has caused the supply chain of this industry to face many problems in recent years. Considering these issues, the need to use a systematic and complete method for supply chain risk assessment that is in harmony with the characteristics of this industry is felt more and more. On the other hand, a look at the background of research related to supply chain risk assessment shows that, although the theoretical foundations of research in the field of supply chain risk management have generally been facing growth, there is little evidence of practical examples of supply chain risk management in the automotive industry. Therefore, in this research, we decided to benefit from the combination of FMEA and DMAIC methods to analyze supply chain risks in the automotive industry. After the oil industry, the automotive industry is the largest industry in Iran and its survival is very important in this country. But various factors, including currency market fluctuations, have caused many uncertainties in this industry. In addition, other factors such as increasing the variety of products and services, reducing the product life cycle, demand fluctuations, increasing costs, technological changes, political issues, financial instability, and natural disasters have increased uncertainty and risk in the supply chain of the automotive industry.

On the other hand, the automobile industry faces many risks due to its long supply chain and the existence of a variety of companies that interact with each other from the stage of supplying materials to the delivery of the final product to the customer. Therefore, the issue of risk management of the supply chain of this industry is very important with the aim of identifying and evaluating risks and providing solutions to reduce their adverse effects. Iran Khodro Automobile Group is known as the largest car supplier in Iran, with a share of more than 40% of the Iranian car market. This company is considered a large member of the mother automobile industry in Iran, whose impact on the downstream industries and the economy of the country is very noteworthy. Considering the issues stated at the beginning of this chapter, Iran Khodro Company is facing many risks, so one of the important concerns of the managers of this company is to identify and evaluate the risks of the company's supply chain and its effective management. In this research, we have tried to identify and evaluate the risk and wastes of the supply chain of the automobile industry so that the senior managers of the automobile companies can have a more effective performance in dealing with the important risks of the supply chain according to the suggestions of the research. So far, various models have been identified and used for risk assessment, but in general, the important point in all the presented models is that they evaluate and analyze the risks, their importance and their impact on the performance of the company or on the performance of the supply chain, regardless of the priority of the risks and wastes. Also, due to the fact that quantitative research or qualitative research alone can face different limitations in addition to their advantages, therefore, the need to use methods that are implemented in the form of mixed methods (quantitative and qualitative) is felt. On the other hand, in addition to identifying risks and determining indicators such as severity, occurrence and detection of risks, there is also a need to provide solutions to reduce risks and wastes in the supply chain. Therefore, in this research, the combination of FMEA and DMAIC methods was used to assess the supply chain risk in the automotive industry. The results obtained from the applications of the above methods are presented in the following sections. However, before delving into that, it is worth examining how raw materials are handled within the company. A flowchart is presented in figure 3.1, outlining the process of receiving, inspecting, and utilizing imported raw materials in the company. The figure illustrates that the production process and the final product's quality are highly dependent on the timely delivery and the quality of the raw materials received. This highlights the crucial role of raw material management in ensuring the efficiency and effectiveness of the production process.

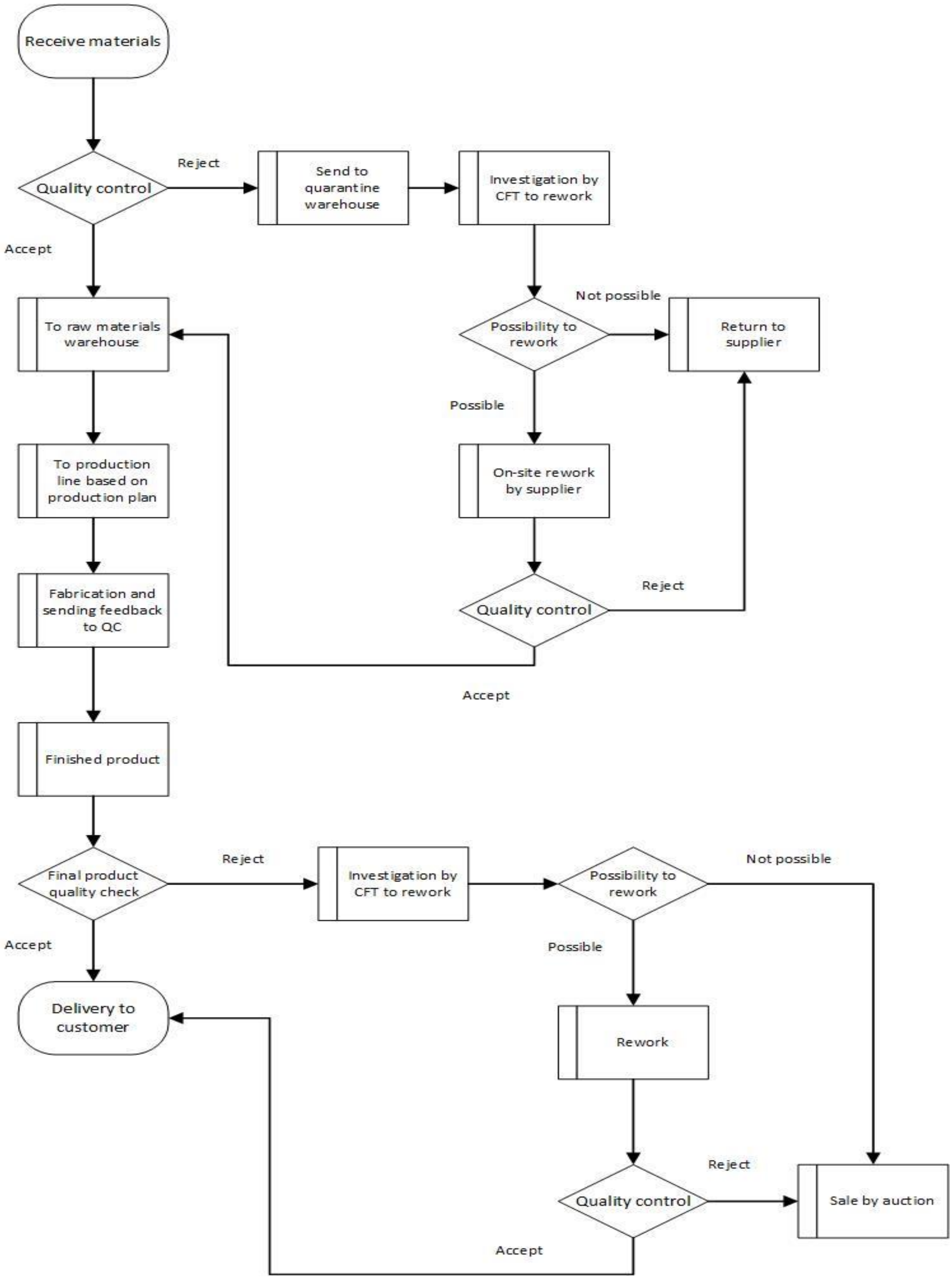

Figure 3.2 Raw material receiving flowchart

3.1.3 FMEA Application

As explained in the previous section, there is a possibility of waste throughout the supply chain, and it is not limited to the steps related to logistics and transportation. Given that logistics operations, from supply logistics to warehousing and transportation, identifying ways to reduce waste in these sectors is of particular importance. Therefore, in the following, we will examine the three main areas of waste in logistics and ways to manage it, and as a result, it will be possible to reduce the cost of products.

- **Supply lead time**: The most important factor that leads to the increase of lead time is the problems of supplying raw materials from foreign or domestic suppliers. One of the solutions to reduce the lead time in supplying from abroad is to set up appropriate supply contracts and create diversity in supply channels. One of the most important services of logistics companies in this field is timely supply of raw materials. On the other hand, the lead time related to supply from within the organization is more related to warehouse layout problems. For example, if raw materials and semi-finished inventory are improperly arranged and placed in the warehouse, it may take more time to load a crane or truck or other vehicles. By organizing its warehouse, it is possible to reduce the costs caused by internal lead time.

- **Inventories**: the main effort of lean businesses is directed to reducing the need for inventory of raw materials and semi-finished products; the reduction in inventory costs can significantly reduce the cost of products. Inventory costs include the cost of lost opportunity, capital sleep, corruption and deterioration of inventory and other such things.

- **Transportation and routing**: wrong routing can lead to delays in the process of sending goods to intermediate and final customers. In addition to wasting energy and money, this issue can also lead to wasting goods; this is why in the perishable and food supply chain, "transportation and routing" is several times more important than other supply chains. By accurately routing and optimizing the transportation process (such as using different types of transportation or taking advantage of the economic advantage of freight consolidation), an acceptable reduction in the final consumer price can be made; Because statistics show that on average 6% of the finished price of products is related to transportation.

Considering that the major part of the cost of products is related to transportation and inventory maintenance, by properly managing these parts and reducing waste in the relevant processes, a significant reduction in the final price of products can be made.

For this reason, waste management and reduction are a vital matter. This is necessary not only to deal with the increase in inflation, but also to reduce the final price of products and also to protect the food security of the human society.

Table 3.1 shows the organizational position of the managers of the company who were interviewed:

Table 3.1 Interviewed Managers demographic

No.	Position	Number
1	Manager of supply chain process improvement office	3
2	Deputy of supply, planning and logistics	3
3	Director of the Management Systems Development office	2
4	Quality control manager	2
5	Manager of studies and strategic planning	2

After long meetings with the above managers, all the known risks in the company's documents and previous projects were also provided to the researcher. At this stage, 62 risks were identified. After applying the managers' opinion, some risks were merged with each other and some were eliminated. Therefore, we identified 17 risks, of which 8 risks were among the wastes identified in the research literature section. In the following, the implementation of the FMEA method will be explained.

Table 3.2 shows the FMEA Worksheet of the study:

Table 3.2 FMEA Worksheet of the study

Cause Problem statement	Severity	Occurrence	Detection	Action Item	Assigned to	Target Date

Figure 3.3 shows the supply process of FMEA:

Item / Function	Potential Failure Mode(s)	Potential Effect(s) of Failure	Sev	Potential Cause(s)/ Mechanism(s) of Failure	Prob	Current Design Controls	Det	RPN	Recommended Action(s)	Responsibility & Target Completion Date	Action Results				
											Actions Taken	New Sev	New Occ	New Det	New RPN
Circuit Block 4.1.1	Output loss from pre-amp	Receiver & output data loss; track loss; GPS shut-down	5	C1 short	1	PR-20 & HW-5	2	10	QA Proc 20-6	R. Jones, 11/30/92	Added to control plan	2	1	1	2
			5	C88 short	2		2	20	QA Proc 20-6	R. Jones, 11/30/92	Added to control plan	2	1	1	2
			5	L1 open/short	3		2	30	QA Proc 20-3	R. Jones, 11/30/92	Added to control plan	2	2	1	4
			5	U21 function	4		2	40	Test 147	R. Jones, 11/30/92	Added to control plan	2	3	1	6
								0							0
Circuit Block 4.1.2	Undetected & insignificant component failure mode	No noticeable system effect	1	C1open/chg val.	2	None	8	16	None						0
			1	C88open/chg val	2		8	16	None						0
								0							0
Circuit Block 4.2.1	Loss of signal from 2nd RF amplifier & 1st down converter	Loss of position, velocity & time output data; track loss; GPS shut-down	4	C2 short	1	PR-20 & HW-5	2	8	QA Proc 20-6	B. Howell 10/15/92	Added to control plan				0
			4	C3 short	1	PR-20 & HW-5	2	8	QA Proc 20-6	B. Howell 10/15/92	Added to control plan	2	1	1	2
			4	C4 open/short	2	PR-20 & HW-5	2	16	QA Proc 20-6	B. Howell 10/15/92	Added to control plan	2	1	1	2
			4	C5 short	2	PR-20 & HW-5	2	16	QA Proc 20-6	B. Howell 10/15/92	Added to control plan	2	1	1	2
			4	C66 open/short	2	PR-20 & HW-5	2	16	QA Proc 20-6	B. Howell 10/15/92	Added to control plan	2	1	1	2
			4	C99 short	3	PR-20 & HW-5	2	24	QA Proc 20-6	B. Howell 10/15/92	Added to control plan	2	2	1	4
			4	FL1 short/open	5	None	2	40	100% Insp.	B. Howell 10/15/92	Added to control plan	2	2	2	8
			4	FL2 short/open	5	None	2	40	100% Insp.	B. Howell 10/15/92	Added to control plan	2	2	2	8
			4	R2open/chg val	2		2	16	None						0
			4	R18 open/chg val	2		2	16	None						0

Figure 3.3 Supply process of FMEA template

The “item and function column” in the FMEA would be populated using the terms recorded during the interviews with twelve of Iran Khodro Company, which is one of the main car manufacturing brands in Iran, so that the process and issues would be familiar to all of them. Each project would have a new set of topics that were derived from the interviews. Each major heading in the FMEA has a comment box that provides instructions. Scales were developed for the severity, likelihood of occurrence and likelihood of detection columns as shown in Tables 3.3, 3.4 and 3.5.

Table 3.3 FMEA Degree of Risk Severity Ranking

Degree of Severity Ranking		
Degree	**Description**	**Median Rating**
Very High	When a potential failure mode affects safe operation of the product and/or involves non-conformance with government regulations. May endanger people or product. Assign "9" if there will be a warning before failure, assign "10" if there will NOT be a warning before failure.	10 9
High	When a high degree of customer dissatisfaction is caused by the failure. Does not involve safety of people or product or compliance with government regulations. May cause disruption to subsequent processes/operations and/or require rework.	8 7
Moderate	When a moderate degree of customer dissatisfaction is caused by the failure. Customer is made uncomfortable or is annoyed by the failure. May cause rework or result in damage to equipment.	6 5 4
Low	When a failure will cause only slight annoyance to the customer.	3 2
Minor	When a failure is not likely to cause any real affect on subsequent processes/operations or require rework. Most customers are not likely to notice any failure. Any rework that might be required is minor.	1

Table 3.4 FMEA Degree of Risk Occurrence Rating

Degree of Occurrence Ranking			
Chance	**Description**	**Probability**	**Median Rating**
Very High	Failure is almost inevitable	1 in 2 1 in 3	10 9
High	Process is "similar" to previous processes with a high rate of failure	1 in 8 1 in 20	8 7
Moderate	Process is "similar" to previous processes which have occasional failures.	1 in 80 1 in 400 1 in 2000	6 5 4
Low	Process is "similar" to previous processes with isolated failures	1 in 15000	3
Very low	Process is "similar" to previous processes with very isolated failures	1 in 150000	2
Remote	Process is "similar" to previous processes with no known failures	1 in 1500000	1

Table 3.5 FMEA Degree of Risk Detection Ranking

Degree of Detection Ranking			
Degree	**Degree in %**	**Description**	**Median Rating**
Detection is not possible	0	Control method(s) cannot or will not detect the existence of a problem.	10
Very Low	0 to 50	Control method(s) probably will not detect the existence of a problem.	9
Low	50 to 60 60 to 70	Control method(s) has a poor chance of detecting the existence of a problem.	8 7
Moderate	70 to 80 80 to 85	Control method(s) may detect the existence of a problem.	6 5
High	85 to 90 90 to 95	Control method(s) has a good chance of detecting the existence of a problem.	4 3
Very High	95 to 100	Control method(s) will almost certainly detect the existence of a problem.	2 1

Participants generally agreed to and understood the meaning of the scales, but there was often disagreement regarding actual assignment of a number to a risk or a waste. The probability ranking was the most difficult since the ranges are more challenging to interpret and agree upon. Although the most advantage of the process was the discussions enabled the team to identify the critical issues from a cross functional point of view. It was expected that people from different functions would perceive risk differently, so the discussions gave the team an opportunity to explore what the issues really were from a variety of perspectives. This process facilitates a fact-based decision-making agreement by following a process of engaging all the managers in a formal risk review.

According to the interviews with senior managers, the most important supply chain risks were identified as follows:

1. The risk of not providing imported parts on time: This risk is related to the field of foreign trade (imports) and the process of providing foreign products and services for the company's products. Considering that the main parts of Iran-made automobiles are full CKD[2], so their timely supply is essential for the production lines. Not providing them on time will cause long-term stoppages in the production lines.

2. The risk of increasing the cost of imported parts: This risk is related to the field of foreign trade (imports) and the process of providing foreign products and services.

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[2] "Completely Knocked-Down (CKD) stands for Completely Knocked Down (CKD), which means that the car was completely assembled in a local manufacturing plant.

Considering the current political and economic conditions of Iran, the risk of the increase in the cost of purchasing parts from abroad (imports) is always one of the most important risks in the supply chain.

3. The risk of quality non-compliance of imported parts with the required specifications: This risk is related to the field of foreign trade (imports) and the process of providing foreign products and services. Due to the fact that most of the foreign sources for the supply of materials required by Iranian companies are Chinese products, therefore the risk of the desired quality of the required parts is very high.

4. The risk of physical non-compliance of imported parts with the required specifications: As mentioned, the main sources of supply of imported parts are Chinese companies, so the amount of deviation of the parts sent by them is increasing because the evidence shows that 100% of Chinese products do not match with their packing.

5. The risk of not being able to supply imported items: This risk is related to the foreign trade department and the process of supplying imports. Due to the long lead time of supplying foreign parts, their timely supply is considered as an important risk. The occurrence of this risk will stop the production process.

6. Customs clearance risk: This risk is related to the process of clearance imports from customs, which may cause delays due to legal problems and obstacles.

7. The risk of shortage of parts due to the instability of the supplier: This risk is related to the procurement department of the company and the planning process of supplying car parts. Due to the increase in the production costs of car parts, many manufacturers and suppliers do not want to produce some parts, and therefore the risk of shortage of such parts affects the procurement unit.

8. Risk of logistics performance: Logistics includes information integration, transportation, inventory, warehousing, moving goods, etc. Therefore, their weaks or average performance will cause weak or severe risks for the company's procurement department.

9. The risk of not passing the warranty: This risk is related to the supply and engineering department of the company. Considering the high costs of the molds

designed for the production of car parts, passing the mold warranty by the mold designer is one of the important challenges of the parts supply and production unit, because if the mold warranty is not passed, the mold will quickly depreciate.

Also, according to the theoretical framework and research background, eight types of waste sources are introduced for the supply chain:

10. Waste from excessive production: The existence of this type of waste leads to an increase in the accumulation of inventory and also to an increase in the amount of product waste in the production line.

11. Waiting time: the waiting factor leads to wasted time and energy resources; Such as workers' wasted time waiting for the production line to start.

12. Inventory loss: In this type of waste, due to the accumulation of inventory, the risk of damage to the final product or the raw materials in the warehouses is greatly increased.

13. Excessive processing waste: adding an unnecessary and non-value-added feature which leads to waste of raw materials and energy.

14. Waste in transportation: waste caused by non-value-added transportation like wrong routing.

15. Waste in arrangement and delivery: Waste in arrangement and delivery of every imported or local supplied goods.

16. Waste of defective parts: Defective parts cause a lot of time and energy consumption.

17. Waste of knowledge resources: The lack of optimal use of knowledge and skills in the company.

3.1.4 DMAIC application

To complete the cycle of continuous improvement with DMAIC, we utilized FMEA to identify and classify potential risks and wastes, as illustrated in Figure 1.1. Based on the findings from FMEA, the next step is to organize the DMAIC steps, as depicted in Figure 3.4.

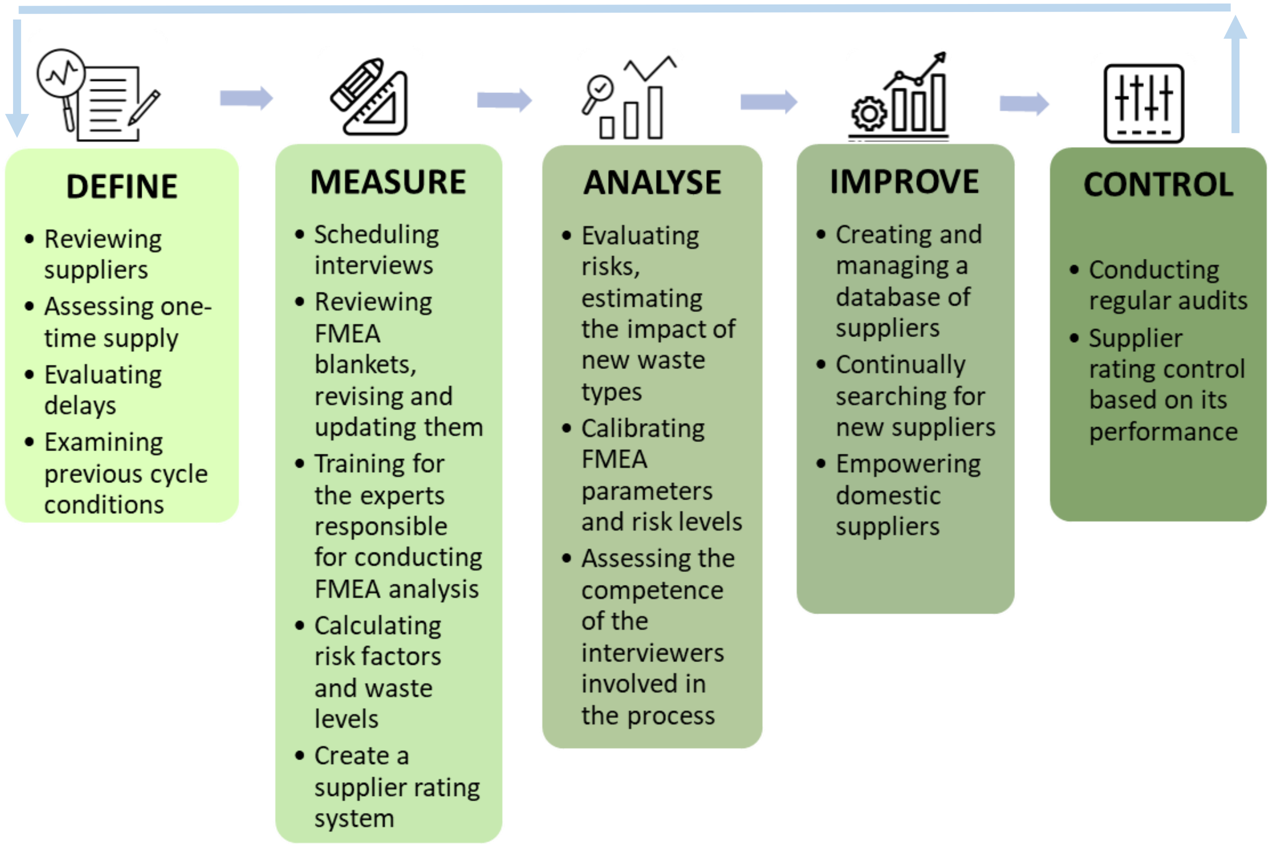

Figure 3.4 Organizing DMAIC steps

3.1.5. Results

Managers acknowledged during the interviews that without a systematic and thorough technique for risk assessment, many problems may occur in supply chain risk management (for example, unexpected costs, increased waiting time, poor quality of parts, etc.). Managers of Iran Khodro Company believe that the analysis of risks related to SCM is a relatively new issue in the Iranian automotive industry, and the lack of a systematic risk assessment framework to help managers in this process is evident, and the results of using two methods, DMIC and FMEA, can greatly help They are slow. Therefore, most of the managers believed that the results of combining these two methods can effectively help in the analysis of supply chain risks in the company.

FMEA and DMIAC are typical techniques used to analyze the risk management decisions for most companies. However, some of managers were concerned with the inconsistencies in the ranking of severity, occurrence, and detection and the inaccuracies that may delay effective FMEA implementation in a supply chain. Managers want guidelines for customers in correcting these problems in FMEA applications, so they can adopt and integrate their FMEA process into a supply chain environment. The case example provides direction for managers by emphasizing that supply chain FMEA cannot be viewed as purely an engineering exercise, and by ensuring that the terms and measures used in FMEA are driven by the key stakeholders. Most managers asserted that proactive risk mitigation efforts applied to the supply chain is not common practice, but is required for minimizing wastes and energy. There was a general impression that with FMEA and DMIAC based SCM risk assessment techniques; unforeseen problems that might have impacted the success of supply chain management efforts can be avoided. They also want to know the critical success factors to the implementation process of the FMEA and DMIAC.

The results of the evaluation of risks and wastes identified according to the FMEA method are presented in Table 3.6:

Table 3.6 Results of the FMEA method

No.	Risks and Wastes	Probability of Occurrence	Probability of Detection	severity	Ranking or Priority number
1	The risk of not providing imported parts on time	7	5	7	245
2	The risk of increasing the cost of imported parts	5	5	5	125
3	The risk of quality non-compliance of imported parts with the required specifications	5	3	7	105
4	The risk of physical non-compliance of imported parts with the required specifications	3	5	5	75

No.	Risks and Wastes	Probability of Occurrence	Probability of Detection	severity	Ranking or Priority number
5	The risk of not being able to supply imported items	7	5	5	175
6	Customs clearance risk	5	5	5	125
7	The risk of shortage of parts due to the instability of the supplier	7	5	5	175
8	Risk of logistics performance	7	7	5	245
9	The risk of not passing the warranty	5	5	7	175
10	Waste from excessive production	5	7	7	245
11	Waiting time	7	7	7	343
12	Inventory loss	3	3	3	27
13	Excessive processing waste	5	7	5	175
14	Waste in transportation	3	3	5	45
15	Waste in arrangement and delivery	3	5	5	75
16	Waste of defective parts	7	5	5	175
17	Waste of knowledge resources	5	7	3	105

According to table 3.6, “Waiting time” is major issue among the all risks and wastes in supply chain. The highest score is 343 and the lowest is 27 which is belonging to “Inventory loss”.

After calculating the risk priority numbers (RPN), the prioritization of risks is presented as a pareto chart in figure 3.5:

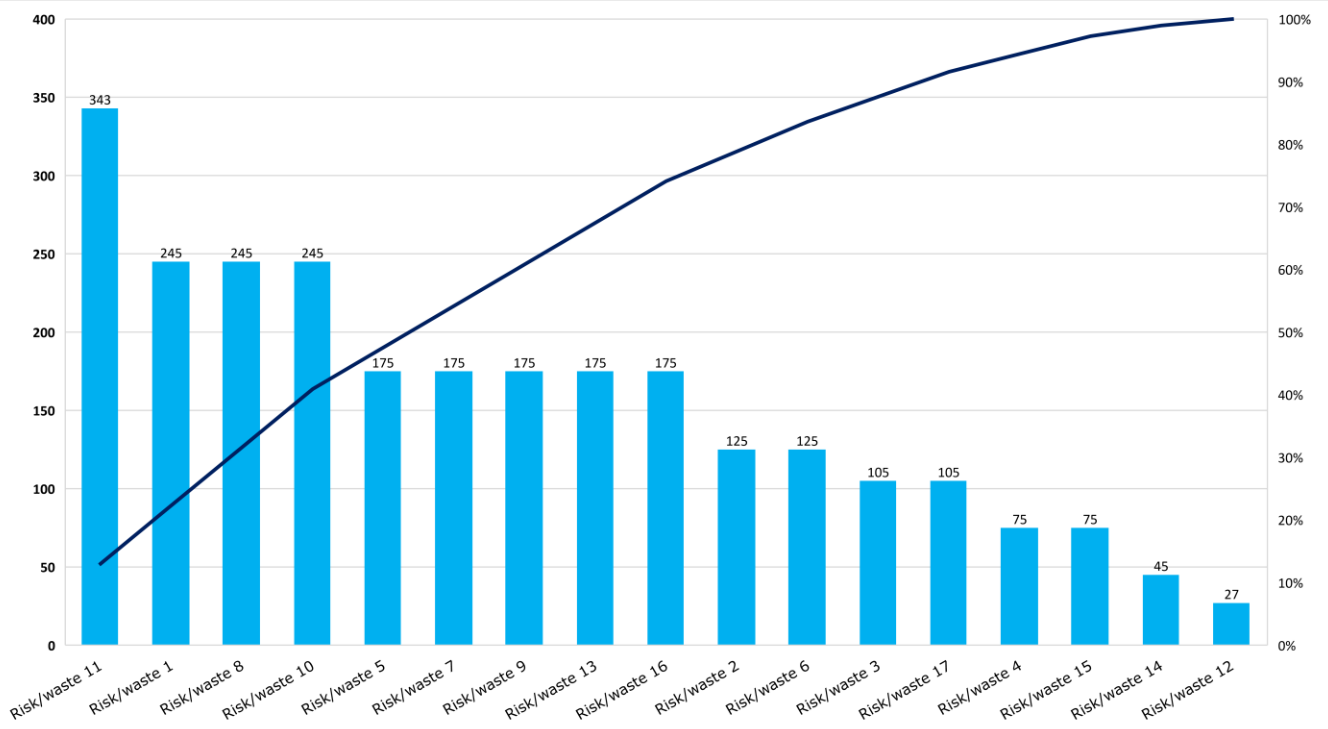

Figure 3.5 Order of prioritization of risks and wastes based on RPN: The numbering of risks/wastes in the pareto chart are based on the order of their placement in Table 3.6

The order of prioritization of risks and wastes based on Ranking or Priority number are as follows:

1) Waiting time (343)

2) The risk of not providing imported parts on time (245)

3) Risk of logistics performance (245)

4) Waste from excessive production (245)

5) The risk of not being able to supply imported items (175)

6) The risk of shortage of parts due to the instability of the supplier (175)

7) The risk of not passing the warranty (175)

8) Excessive processing waste (175)

9) Waste of defective parts (175)

10) The risk of increasing the cost of imported parts (125)

11) Customs clearance risk (125)

12) The risk of quality non-compliance of imported parts with the required specifications (105)

13) Waste of knowledge resources (105)

14) The risk of physical non-compliance of imported parts with the required specifications (75)

15) Waste in arrangement and delivery (75)

16) Waste in transportation (45)

17) Inventory loss (27).

Table 3.7 showed the result of FMEA and DMIAC Analysis of types of Risk/Waste in automotive industry.

Table 3.7 FMEA and DMIAC Analysis of Types of Risk/Waste in automotive industry

No.	Risk / Waste	Type of Risk / Waste	Failure	Potential Failure Effects	Potential Causes	Recommendation
1	The risk of not providing imported parts on time	Procurement	Production line failure	Production failure	Failure to provide the required financial resources, Disturbance in the transfer of financial funds, Failure to receive relevant permits at the right time, Failure to adhere to time commitments by the supplier	Proper planning for the duration of supply, providing required financial resources, facilitating international transactions, Empowering domestic suppliers
2	The risk of increasing the cost of imported parts	Procurement	Production line failure	Short-term interruptions in the production line	Increase in the price of currency, especially dollar, as well as fluctuations in the exchange rate	Government support, solving political obstacles, Use of alternative suppliers in emergency situations.
3	The risk of quality non-compliance of imported parts with the required specifications	Procurement	Procurement failure	Short-term interruptions in the production line	Political situation, The lack of attention of some Chinese suppliers to the quality of parts	Replacing Chinese suppliers, Not receiving low-quality parts and returning them to the supplier
4	The risk of physical non-compliance of imported parts	Procurement	Procurement failure	Short-term interruptions in the	The lack of attention of some Chinese suppliers to the quality of parts	Replacing Chinese suppliers, Not receiving low-quality parts and

No.	Risk / Waste	Type of Risk / Waste	Failure	Potential Failure Effects	Potential Causes	Recommendation
	with the required specifications			production line		returning them to the supplier
5	The risk of not being able to supply imported items	Procurement	Production line failure	Production failure	Failure to provide the required financial resources, Failure to adhere to time commitments by the supplier	Government support, solving political obstacles, Use of alternative suppliers in emergency situations.
6	Customs clearance risk	Overproducti on	Production line failure	Cost increase, Short-term interruptio ns in the production line	Customs regulations, Lack of providing technical specifications on products or defects in documents	Obtaining relevant permits at the right time
7	The risk of shortage of parts due to the instability of the supplier	Procurement	Production line failure	Production failure	Failure to provide the required financial resources, Failure to adhere to time commitments by the supplier	Use of alternative suppliers in emergency situations.
8	Risk of logistics performance	Inventory	Quality defect	Delivery failure	Damage to automobiles during transportation, Lack of integrity of product information	Enhancing the logistics management, Monitoring the delivery of products with defined quality

No.	Risk / Waste	Type of Risk / Waste	Failure	Potential Failure Effects	Potential Causes	Recommendation
9	The risk of not passing the warranty	Quality control	Quality defect	Fast depreciation	failure in maintenance, Failure to comply with the standard in the manufacture or assembly of car parts	Enhancing maintenance process, Adherence to standards in the manufacture or assembly of machine parts
10	Waste from excessive production	Waste management	Waste increase	Cost increase	Lack of proper planning in production, Lack of strict supervision of production, Relying on wrong information	Improve production planning, Close monitoring of the production line
11	Waiting time	Process	Longer production time	Cost increase, energy consumption	workers' time waiting for the production line to start, Inventory failure	Improve production planning, more efficient HRM
12	Inventory loss	Inventory	Quality defect	Quality failure	due to the accumulation of inventory, damage to the final product or the raw materials in the warehouses	Preventing the accumulation of inventory, preventing damage to the final product, preventing damage to raw materials in warehouses
13	Excessive processing waste	Waste management	Waste increase	Cost increase	Lack of proper planning in production, Lack of	Improve production planning, Close

No.	Risk / Waste	Type of Risk / Waste	Failure	Potential Failure Effects	Potential Causes	Recommendation
					strict supervision of production	monitoring of the production line
14	Waste in transportation	Inventory	Quality defect	Delivery failure	Damage to automobiles during transportation	Enhancing the logistics management, safe transportation
15	Waste in arrangement and delivery	Inventory	Quality defect	Delivery failure	Damage to automobiles during transportation, Lack of integrity of product information	Enhancing the logistics management, Monitoring the delivery of products with defined quality
16	Waste of defective parts	Process	Longer production time	Cost increase, energy consumption	workers' time waiting for the production line to start, Inventory failure	Improve production planning, Quality control
17	Waste of knowledge resources	Overproduction	Waste increase	Cost increase	Lack of proper planning in production	Improve production planning

As it can be seen in 3.7, for all identified risks and wastes, case solutions were presented using the DMIAC method, and the types and processes related to which risks were investigated. Also, with the help of Figure 3.6, it is possible to understand the effect of implementing changes with the help of DMAIC in the supply chain process.

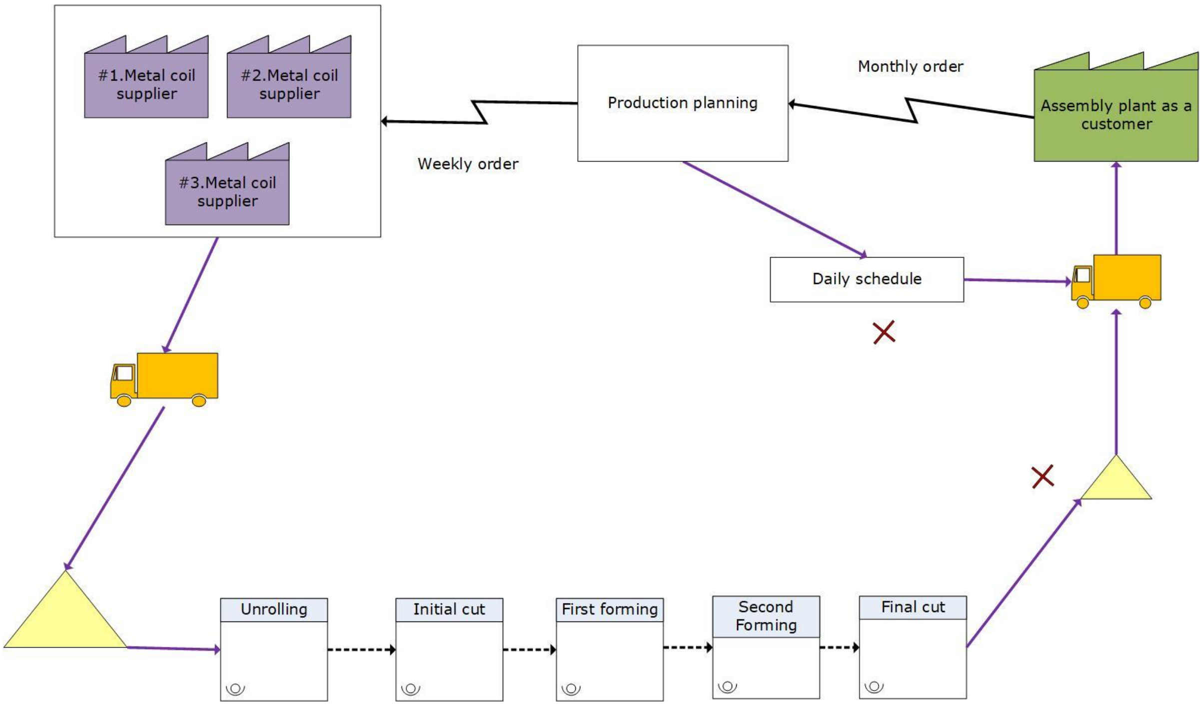

Figure 3.6 Car fender fabrication VSM after DMAIC implementation

4. Conclusion

Risk assessment is one of the pillars of risk management in the supply chain, and its purpose is to measure risks based on various indicators such as the degree of impact and the probability of occurrence, and the more accurate the results of this step, it can be said that the risk management process is carried out with a higher degree of confidence. On the other hand, one of the key issues in supply chain management is the formation of the supply chain and effective coordination between its components with the aim of customer satisfaction. Carrying out this coordination requires a complex flow of information, raw materials and capital at different levels of the process between different companies in the supply chain. To achieve this goal, different methods of evaluating and analyzing supply chain risks must be identified so that they can be managed. Supply chain risk management (SCRM) is a significant factor for both supply success and firm success as well, and it can be mitigated to a great extent by the selection of the appropriate supplier.

Goals

The research aims to achieve two objectives. Firstly, the Failure Modes and Effects Analysis (FMEA) method will be used to analyze the waste and risk factors in the supply chain management process, from the initial stage to the final stage. Secondly, the Six Sigma DMAIC (Define, Measure, Analyze, Improve, Control) methodology will be utilized to identify control measures and standardization techniques that can enhance the system output, based on the results obtained from the FMEA analysis.

Results

The research utilized interviews and the Failure Modes and Effects Analysis (FMEA) to investigate potential waste and risk factors in the supply chain management (SCM) process. Based on the findings, the most significant issues were selected to be addressed using the Six Sigma DMAIC methodology.

To improve the SCM system output, a control system was developed, which included standardization measures such as planning documents, measuring procedures, and analysis tools. The system also incorporated procedures for improvement and control, utilizing various techniques.

In this research an integrated DMAIC and FMEA approach was offered for SCM improvement. The research results have shown that the sources of risk may be environmental, organizational or caused by the supply chain itself, as a result, it is very difficult to predict their effects with certainty. Since the sources of chain risks are very numerous and diverse, it is impossible to completely eliminate them, and there are also various internal and external factors and conditions that greatly affect their intensity and weakness. Therefore, it is necessary to conduct researches that investigate and analyze this phenomenon and techniques that used to analyzing Supply chain risk management. The results of the research conducted in the field of supply chain risk management showed that in most of the research, single approach like FMEA has been used and the result compared with the previous results obtained in the background studies.

According to the research results, 17 risks and wastes were identified. Then to find control ways and standardization in supply chain management, we applied Six Sigma DMAIC methods to analyze the FMEA results. Therefore, for all 17 identified risks and wastes, case solutions were presented using the DMIAC method, and the types and processes related to which risks were investigated. According to the research results, the order of prioritization of risks and wastes based on Ranking or Priority number 4 major risk and waste calculated as follows:

1) Waiting time (343)
2) The risk of not providing imported parts on time (245)
3) Risk of logistics performance (245)
4) Waste from excessive production (245)

Based on the results obtained from the research, the following practical solutions can be suggested to managers to improve supply chain risk management in the automotive industry:

- Proper planning for the duration of supply,
- Providing required financial resources,
- Facilitating international transactions
- Trying to get government support,
- Solving political obstacles,
- Use of alternative suppliers in emergency situations or empowering domestic suppliers
- Returning low-quality parts to the supplier,

- Obtaining relevant permits at the right time
- Enhancing the logistics management,
- Monitoring the delivery of products with defined quality
- Enhancing maintenance process,
- Adherence to standards in the manufacture or assembly of machine parts
- Close monitoring of the production line
- Preventing the accumulation of inventory,
- Preventing damage to the final product,
- Preventing damage to raw materials in warehouses.

However, the FMEA and DMAIC proved to be effective, they haven't developed to Iran Khodro Company as something that is required to become part of the standard tool set, so for the short term, there seems will be limited use of supply chain FMEA and DMAIC. However, there is some consideration that FMEA and DMAIC will be updated as supply becomes more involved in new product development processes and to support the company's strategic objectives of moving into new markets.

4.1 Limitations and future research

For the future research we suggest to evaluate the model presented in the current study based on quantitative data to analyze the accuracy of its results. Moreover, future research can rank the criteria identified in this study and the relevant components using various multi-objective decision-making methods, including AHP and ANP, or a combination of various methods (e.g., combining ANP and DEMATEL). Also, in this research, it was not possible to investigate the impact of the implementation of the suggested solutions on the performance of the supply chain, so in future researches, the impact of the implementation of the suggested solutions on the performance of the supply chain can be investigated. Another limitation in the study was that participants generally agreed to and understood the meaning of the research scales, but there was often disagreement regarding actual assignment of a number to a risk issue. The probability ranking was the most challenging because the ranges are more difficult to interpret and agree upon. In future studies, by removing this limitation, the obtained results can be compared with the results of the current research.

SUMMARY

Supply chain risk management (SCRM) is a critical factor in ensuring the efficiency, effectiveness, and profitability of modern businesses. Over the last decade, there has been a significant increase in supply chain risks, particularly due to the outbreak of the COVID-19 pandemic. Against this backdrop, this study aims to investigate supply chain risk management techniques and identify potential improvements. To achieve this goal, the research applies two techniques: the Failure Mode Effect Analysis (FMEA) method and the DMAIC (Define, Measure, Analyze, Improve, Control) methodology from the Six Sigma Quality control technique. The FMEA method was applied to assess the reliability of the system, while the DMAIC technique is used to establish a sustainable routine system for continuous improvement of supply chain management (SCM) in the company. The research findings offer valuable practical solutions for applying the FMEA and DMAIC methods in SCM risk management evaluations. The study's results can help improve SCM in organizations, and the theoretical contributions of the research can enrich the literature on supply chain risk management. In addition, the research provides a comprehensive model for evaluating risks and wastes in the automotive industry. Furthermore, the study performed a qualitative and quantitative evaluation of the risks and wastes in the automotive industry. The results provide researchers and the scientific community with a comprehensive model and suitable results and clues. The research findings contribute to the theoretical foundation of SCRM by providing suitable techniques for evaluating risks and wastes.

KOKKUVÕTE

Tarneahela riskide juhtimine (SCRM) on kriitiline tegur, mis tagab kaasaegsete ettevõtete tõhususe, efektiivsuse ja kasumlikkuse. Viimase kümnendi jooksul on tarneahela riskide arv märkimisväärselt suurenenud, eriti tänu COVID-19 pandeemia puhkemisele. Selle taustal on selle uuringu eesmärk uurida tarneahela riskide juhtimise tehnikaid ja tuvastada võimalikud parendused. Selle eesmärgi saavutamiseks kasutatakse kahte meetodit: tõrgete mõju analüüsi (FMEA) meetodit ja DMAIC (Probleemi määratleda, mõõtmine, analüüsida, parendamine, Ohje) meetodit Six Sigma kvaliteedikontrolli tehnikast. FMEA meetodit kasutati süsteemi usaldusväärsuse hindamiseks, samal ajal kui DMAIC tehnikat kasutatakse jätkusuutliku rutiinse süsteemi loomiseks tarneahela juhtimise (SCM) pidevaks parendamiseks ettevõttes. Uuringu tulemused pakuvad väärtuslikke praktilisi lahendusi FMEA ja DMAIC meetodite rakendamiseks SCM riskide juhtimise hindamisel. Uuringu tulemused võivad aidata organisatsioonidel SCM-i parendada ning uuringu teoreetilised panused võivad rikastada tarneahela riskijuhtimise kirjandust. Lisaks pakub uuring põhjalikku mudelit riskide ja raiskamiste hindamiseks autotööstuses. Lisaks hindas uuring kvalitatiivselt ja kvantitatiivselt riske ja raiskamisi autotööstuses. Tulemused annavad teadlastele ja teaduslikule kogukonnale põhjaliku mudeli ja sobivad tulemused ja viited. Uuringu tulemused aitavad kaasa SCRM-i teoreetilisele alusele, pakkudes sobivaid tehnikaid riskide ja raiskamiste hindamiseks.

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