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Risk Assessment and Management in Supply Chain

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Abstract- Supply chains have expanded rapidly over the decades, with the aim to increase productivity, lower costs and fulfil demands in emerging markets. The increasing complexity in a supply chain hinders visibility and consequently reduces one's control over the process. Cases of disruption such as the ones faced by Ericsson have shown that a risk event occurring at one point of the supply chain can greatly affect other members, when the disruption is not properly controlled. Complexity and disintegration are emerging as major challenges in supply-chain risk management. It has become more difficult to identify risks as supply-chain operations have fallen into the hands of outside service providers, and are therefore less visible. The risks, their identification and impact depend on the position of the companies in the chain, and on the level of analysis they can carry out. . Supply chain management thus faces a pressing need to maintain the expected yields of the system in risk situations. This work provides a review of definitions and classifications of types of risk; a holistic view of risk assessment and management is taken here. This project aims to analyse how supply chain risks could be effectively managed. This is done firstly by positioning the research agenda in Supply chain Risk Management (SCRM).Then, methods for effective management of supply chain risk are identified and analysed.

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I. Introduction

Supply Chain Management (SCM) is a principle emphasizing the utilization of an efficient integrated system of suppliers, producers, warehouses, retailers and customers, so that items can be produced and distributed system-wide at the right quantities, locations, and time to minimize costs and maximize services. A supply chain is the linkage of series of organizations with facilities, functions, processes, and logistics activities that are involved in producing and delivering a product or service. In the past, when firms manufactured in-house, sourced locally and sold direct to the customer, 'risk' was less diffused and easier to manage. With the advent of increased product/service complexity, and outsourcing of supply networks across international borders, risk is increasing and the location of risk has shifted through complex changing supply networks. Managing risk in supply chains is an important topic in supply chain management. The topic's importance is due to several industry trends currently in place: increase in strategic outsourcing by firms, globalizations of markets, increasing reliance on suppliers for specialized capabilities and innovation, reliance on supply networks for competitive advantage, and emergence of information technologies that make it possible to control and coordinate extended supply chains. These trends have manifested themselves in an increase in outsourcing and off-shoring of manufacturing and R&D activities, low cost country (LCC) sourcing, and collaboration with international supplier partners. While these increase the strategic options for firms, they also increase the probability of experiencing adverse events in supply chains that significantly threaten normal business operations of firms in the supply chains. Along with the increase in these initiatives, there has been an increase in the potential and magnitude of supply chain risks. Many industrial cases have shown different outcomes after risk events due to diverse actions (or lack of action) taken in facing supply chain disturbances and disruptions. One typical example is Ericsson's crisis in 2004. Since Ericsson used a single-sourcing policy, a fire accident in its chips' supplier immediately disrupted the material supply. Ericsson's loss was estimated to reach USD 400 million for its T28 model.

a) Risk

Risk can be broadly defined as a chance of danger, damage, loss, injury or any other undesired consequences. A more scientific definition of risk was provided by the Royal Society (1992): ''the probability that a particular adverse event occurs during a stated period of time, or results from a particular challenge".

i. *Sources of Risk*

a. Supply Risk

Supply risk relates to potential or actual disturbances to the flow of product or information emanating within the network, upstream of the focal company. Therefore, it is risk associated with a company's suppliers, or supplier's suppliers being unable to deliver the materials the company needs to effectively meet its production requirements/demand forecasts. It adversely affects inward flow of any type of resource to enable operations to take place; also termed as 'input risk'. It includes.

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- Dependency on key suppliers
- Consolidation in supply markets
- Quality and management issues arising from off-shore sourcing
- Potential disruption at 2nd tier level
- Length and variability of replenishment lead-times

b. Demand Risk

Demand risk relates to potential or actual disturbances to flow of product, information, and cash, emanating from within the network, between the focal company and the market. This demand risk can be a failure on either the high or low side to accurately accommodate the level of demand. It encompasses uncertainties in both product volume and mix which includes.

- Loss of major accounts
- Volatility of demand
- Concentration of customer base
- Innovative competitors

c. Process Risk

Processes are the sequences of value-adding and managerial activities undertaken by the company. Process risk relates to disruptions to these processes. It affects a firm's internal ability to produce and supply goods/services, which results from the consequences of a breakdown in a core operating, manufacturing or processing capability. It includes.

- Manufacturing yield variability
- Lengthy set-up times and inflexible processes
- Equipment reliability
- Limited capacity/bottlenecks
- Outsourcing key business processes

d. Control Risk

Controls are the assumptions, rules, systems and procedures that govern how an organization exerts control over the processes. In terms of the supply chain they may be order quantities, batch sizes, safety stock policies etc. Control risk is therefore the risk arising from the application or misapplication of these rules. It includes.

- Inappropriate rules that distort demand
- Poor visibility along the pipeline
- Lack of collaborative planning and forecasts
- Bullwhip effects due to multiple echelons

II. Environmental Risk

Environmental risk is the risk associated with external and, from the company's perspective; uncontrollable events. It consists of any uncertainties arising from the supply chain and environmental interactions. These may be the result of accidents, man-made or natural disasters. It includes.

- Natural disasters
- Terrorism and war
- Regulatory changes
- Strikes

Following figure shows some of the Risk sources and their characteristics.

Figure 1.1 : Risk sources and their characteristics

a) Risk Assessment

Risk assessment is used to analyze the degree of risk associated with each hazard. The goal of risk assessment is to indicate which areas and activities in the value chain are most susceptible to hazards. It balances the probability of demand, the likelihood of reliable supply, the most effective allocation of resources, and the probability of success of new product introductions, market conditions, and the opportunity costs of alternative decision paths.

b) Risk Management

It is a process of measuring or assessing risk and then developing strategies to manage the risk. Risk management is the broad activity of planning and decision making designed to deal with the occurrence of hazards or risks. Risks include both unlikely but high-impact disruption risks, as well as more common volatility in demand, internal processing, and supply.

Some of the factors impacting exposure to Risks are also given below:

i. Customers reactions.
ii. Competitor reactions.
iii. Supplier reactions.
iv. Government reactions.

III. Summary of Literature Review

Increasing product/service complexity, outsourcing and globalisation have led to complex and dynamic supply networks, there by increasing the factors impacting exposure to risks. The review shows various types of risks and there classifications based on different categories which affects the Supply chain operations. It also addresses the importance of Supply chain Risk Management (SCRM) to make decisions that

optimally align organizational processes and decisions to exploit opportunities while simultaneously minimizing risk. Understanding the types of risks and their probability of occurrence as well as the associated impacts is a starting point for companies to develop effective Risk Management strategies.

IV. Problem Description

To gain cost advantage and market share, many firms implemented various initiatives such as outsourced manufacturing and product variety. These initiatives are effective in a stable environment, but they could make a supply chain more vulnerable to various types of disruptions caused by uncertain economic cycles, consumer demands, and natural and manmade disasters. The objective of the problem is to maximize productivity by reducing Supply Chain Risks. In this work, an effective method for managing 'Supply chain Risk' in a manufacturing industry involving in Casting is proposed with aid of a flow chart and a strategy is developed for its Mitigation.

a) Identification of Problem

- Obtaining various sources of risk which impacts on Supply chain operations.
- Obtaining an effective method for managing Supply chain risk.
- To develop a Flow chart for Supply chain risk management.
- To develop a framework strategy for Supply chain Risk Mitigation.

i. *Definition*

a. Supply Chain Risk Management (SCRM)

SCRM is viewed as "the management of supply chain risk through coordination or collaboration among the supply chain partners so as to ensure profitability and continuity". Risk management is the process of measuring or assessing risk and then developing strategies to manage the risk. These strategies can involve the transference of risk to another party, risk avoidance or mitigation, and channel risk sharing. SCM risk assessments balance the probability of demand, the likelihood of reliable supply, the most effective allocation of resources, and the probability of success of new product introductions, market conditions, and the opportunity costs of alternative decision paths. A framework for Supply Chain Risk Management is shown below:

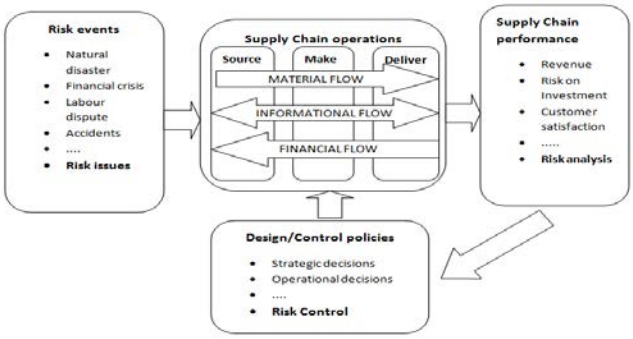

Figure 3.1 : Framework for Supply Chain Risk Management

This figure shows that the continuity of supply chain operations can be affected by various risk events. A solid risk analysis process could identify the impact of disruption on supply chains. This could be established by monitoring supply chain performance, for example the production or financial performances. With a proper implementation of risk control, for instance via risk mitigation strategies, the impact of disruption on flows could be diminished, or even avoided.

b) Objectives

The main objective is to analyse how supply chain risks can be effectively managed. Firstly, this is done by positioning the agenda in supply chain risk management (SCRM). Then, methods for effective management of supply chain risk are identified and analysed.

Based on the framework shown above, we can classify the objective into two sub-categories

Objective I: Identifying Supply Chain Risk Management Agenda.

It is important to identify the current agenda in this field. The exploration of various definitions, for both terminology and processes involved in this area, helps to clarify future scope. To achieve this objective, we hereby raise two questions as follows:

FQ1: What risk issues should be considered in supply chain operations?

FQ2: How does a risk event affects supply chain operations?

Objective II: Identification of Effective Management of Supply Chain Risk.

The second objective focuses on finding how supply chain risk can be effectively managed. To achieve this objective, an investigation of selected approaches and methods will be conducted to analyse their competency and robustness in sustaining supply chain operations. Hence, to achieve the above objective, we raised three questions that focuses on risk analysis and risk control.

FQ3: How can we analyse supply chain performance from a risk management viewpoint?

FQ4: What kind of mitigation policies should be used for managing risk in supply chains?

FQ5: What modelling techniques and approaches are possible in this area?

V. Proposed Methodology

Supply chain Risk Management process can be mainly classified into two categories:

- Risk Analysis.
- Risk Control.

Risk Analysis deals with Identification, Estimation and Evaluation of risks, whereas Risk Control deals with Mitigation and Monitoring of risks. The Risk Management process can be developed with the aid of a flow chart which is shown below.

Review Process

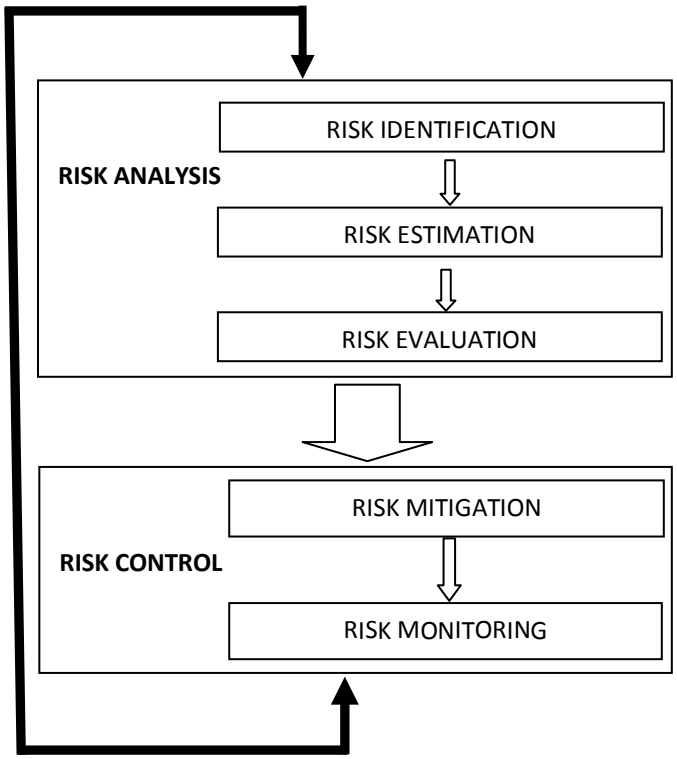

Figure 4.1 : Flow chart for Supply Chain Risk Management

Risk Management process which is constituted of two main elements; Supply chain Risk Analysis and Supply chain Risk Control, henceforth referred to risk analysis and risk control respectively. The term risk assessment is also interchangeably used in referring to risk analysis. The first process covers the identification, estimation and evaluation of risk. Proper implementation of all stages in this process will result in the recognition of potential risk events affecting supply chain. However, not all risk events fall under the category of disruption risk events, and therefore the potential impact caused by an individual risk event needs to be carefully estimated and evaluated according to the individual supply chain operation's definition.

a) Risk Identification

A key aspect of supply chain risk management is identification. Identification involves creating a list of potential events that could harm any aspect of the supply chain's performance. Risk identification allows an organization to take steps to create plans to manage risks before they occur. This is typically more cost effective then waiting to react to adverse events when they occur.

i. *Methods for Identifying Risk*

Geomapping/Supply chain mapping – Visual maps of supply chains reveal supply chain structures, dependencies, and handoffs that may contain risk. Supply Chain Operation Reference (SCOR) mapping and Value Stream Mapping are two types of supply chain mapping that can be used. Looking at historical problems – Historical problems may have a high chance of recurring. Those problems may have happened to the organization itself or to others. Researching industry trends – Other organizations and industry groups may have already researched risks that are applicable. Group of experts brainstorming – People with experience in different areas of your organization and supply chain have lots of knowledge of risks. Getting them together increases the knowledge sharing. (The Delphi method is one technique to conduct expert interviews.) Assessment surveys – Well designed surveys can be an effective way to quickly gather information on risks in your supply chain. Site visits – Site visits to supply chain partners allow you to collect detailed and less "filtered" information on risks. Information audits – Data system audits can reveal issues and trends from the past. It can show areas of the supply chain that have had poor performance in the past and are thus more likely to perform poorly in the future.

ii. *Tools used in risk identification*

Risk checklists – a list of risks that are common for our environment. It may come from past experience or industry research. Cause-and-effect diagrams – a diagram that traces back the causes for events. Gantt charts – a bar chart showing the precedence and timing of activities. It can help identify the critical path, i.e. the most critical organizations and processes that would be bottlenecks if they experienced a disruption. (It can also be used later during Risk Assessment to determine the effect of disruptions at different points in a supply chain).

b) Risk Assessment and Evaluation

Supply Chain Risk assessment provides management with an understanding of where the greatest risks may exist in order to prioritize resources for risk mitigation and management. Performing such

assessments will involve clarifying the nature of the risk, understanding conditions that may lead to the event, knowing how frequently such events have happened or can be expected to happen, and the potential impact of such events. The team can then prioritize addressing the risks. Risk assessment is typically made up of two measures: Likelihood and Impact. Likelihood– measures the probability that the event will occur. The exact probability may be difficult to determine unless there is historical data that can be used to find the frequency of the event occurring. Alternatively an organization can use a subjective likelihood, or degree of belief, based on the opinions of experts. A time horizon is necessary to define the probability in a useful way (e.g., the likelihood that an event will occur in the next year or 50 years). Impact – measures the consequences on the organization if the event occurs. It can be measured directly, for example in terms of dollars. It can also be measured on a scale, for example from zero to one with zero being very little negative consequence and one being a very bad consequence. Methods for measuring impact include "what-if" simulations, financial models, and opinions of teams of experts. Impact may also be measured in terms of other SCOR metrics besides financials. Summary risk score – A summary risk score can be calculated for each risk by multiplying the Impact times the Probability to get an expected value of the risk. Then risks can be ranked by risk score. Also the risks can be shown on a map or graph. An example is shown below.

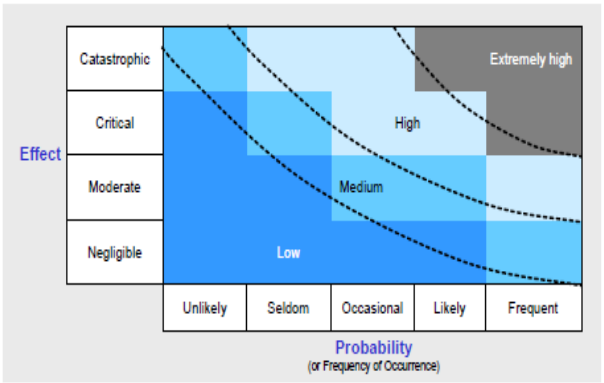

Figure 4.2 : Qualitative Risk assessment

i. *Tool used in Risk Assessment*

Failure Mode Effect Analysis (FMEA) – It is used to prioritize the risk using Risk Priority Number (RPN), which can be calculated from probability of occurrence, severity and detection of risk and also using Risk Score Values (RSV) in which Severity and Occurrence of risk is calculated.

Other methods for assessment include:

- Fault tree analysis – This is a graphical technique that provides a systematic description of the combinations of possible occurrences in a system, which can result in an undesirable outcome. This method can combine hardware failures and human failures. The most serious outcome is selected as the "Top Event". A fault tree is then constructed by relating the sequence of events, which individually or in combination, could lead to the top event. FTA is both a design and a diagnostic tool. As a design tool FTA is used to compare alternative design solutions and the resulting Top event probability. As a diagnostic tool FTA is used to investigate scenarios that may have led to the Top event.
- Event tree analysis – Event tree analysis (ETA) is an analysis technique for identifying and evaluating the sequence of events in a potential accident scenario following the occurrence of an initiating event. ETA utilizes a visual logic tree structure known as an Event Tree (ET). The objective of ETA is to determine whether the initiating event will develop into a serious mishap or if the event is sufficiently controlled by the safety systems and procedures implemented in the system design. An ETA can result in many different possible outcomes from a single initiating event, and it provides the capability to obtain a probability for each outcome.

c) Risk Monitoring and Mitigation

Once areas of risk have been identified, an organization needs to monitor their internal and external environment. This helps them to predict when risky events are becoming more likely. It also helps to identify new risks and is tightly linked to the best practice of Supply Chain Risk Identification. Supply Chain Operation References focus on supply chain metrics enables Supply Chain Risk monitoring. Real time metrics and periodic reports give decisions maker's knowledge upcoming risks. Statistical analysis of key metrics can reveal trends. Visibility into supplier and customer metrics increases the ability to monitor. Reports on risk monitoring can be combined with existing management reviews and meetings. Monitoring can also include monitoring qualitative sources of information such as news or weather reports to identify events that are precursors to risks. In the Plan step, an organization can plan methods for monitoring Source, Make, Deliver, and Return risks. These methods may include specific metrics to monitor and "watch-out" lists of precursor events. It may also include monitoring the environment external to the organization's supply chain.

- Deliver risk monitoring can be done with customer service metrics.
- Make risk monitoring can be done automatically through an organization's data systems such as an ERP system.
- Source risk monitoring is enhanced with visibility into suppliers' metrics.

It is important to monitor indicators that would appear early in a risk event or, better, even before it occurs by indicating an increasing likelihood. If

monitoring only reveals a risk well after its first occurrence, it will likely be too late to adequately respond to it. Monitoring can also be used to test the effectiveness of risk controls. If a plan to mitigate or prevent a risk has been implemented, monitoring can check to see if the corresponding metrics show no signs of the risk occurring. Five operational strategies for managing disruption risks are given below:

Table 4.1 : Operational strategy for managing disruption risk

Operational Strategy	Description
Stockpile Inventory	Hold inventory that can be used to fill customer demand even if supply is interrupted.
Diversify Supply	Source product from multiple vendors/facilities so that a problem at one vendor/facility does not affect the entire Supply.
Backup Supply	Have an emergency supplier (or logistics provider) that is not normally used but that can be activated in the event of a Supply problem.
Manage Demand	Influence demand to better match the actual supply by, for example, adjusting prices or offering incentives to encourage Customers to purchase products that are less supply-constrained.
Strengthen Supply Chain	Work with suppliers to reduce the frequency and/or severity of supply problems.

i. *Risk Mitigation Strategies*

- Multiple sources of supply: - having multiple sources of supply for a raw material reduces the impact of one source failing to deliver materials.
- Strategic agreements or partnerships with suppliers: - strategic agreements with suppliers can lead to continued service in the event of capacity constraints.
- Collaborative Planning Forecasting and Replenishment (CPFR): - by sharing demand and fulfilment data with supply chain partners, there is a reduced risk of unforeseen demand swings or supply shortages.
- Joint product design and delivery: - designing products with suppliers reduces the risk of material non-performance or material shortages.

d) Supply Chain Operation Reference (Scor) Model

Supply Chain Operations Reference (SCOR) model provides a unique framework that links performance metrics, processes, best practices, and people into a unified structure. The framework supports communication between supply chain partners and enhances the effectiveness of supply chain management, technology, and related supply chain improvement activities. It features an intentionally broad scope and definitions that can be adapted to the specific supply chain requirements of any industry or application.

SCOR is based on Five Core management process:

Table 4.2 : SCOR process

SCOR PROCESS	DEFINITIONS
PLAN	Processes that balance aggregate demand and supply to develop a course of action which best meets sourcing, production and delivery requirements
SOURCE	Processes that procure goods and services to meet planned or actual demand.
MAKE	Processes that transform product to a finished state to meet planned or actual demand.
DELIVER	Processes that provide finished goods and services to meet planned or actual demand, typically including order management, transportation management and distribution management.
RETURN	Processes associated with returning or receiving returned products for any reason.

i. *SCOR Performance*

The performance section of SCOR consists of two types of elements: Performance Attributes and Metrics.

a. Performance Attributes

A performance attribute is a group of metrics used to express a strategy. An attribute itself cannot be measured; it is used to set strategic direction. SCOR identifies five core supply chain performance attributes: Reliability, Responsiveness, Agility, Costs, and Asset Management. Consideration of these attributes makes it possible to compare an organization that strategically chooses to be the low-cost provider against an organization that chooses to compete on reliability and performance.

b. Metrics

A metric is a standard for measurement of the performance of a process. SCOR metrics are diagnostic metrics. SCOR recognizes three levels of predefined metrics:

- Level 1 metrics are diagnostics for the overall health of the supply chain. These metrics are also known as strategic metrics and key performance indicators

(KPIs). Benchmarking level 1 metrics helps establish realistic targets that support strategic objectives.

- Level 2 metrics serve as diagnostics for the level 1 metrics. The diagnostic relationship helps to identify the root cause or causes of a performance gap for a level 1 metric.
- Level 3 metrics serve as diagnostics for level 2 metrics.

Table 4.3 : SCOR Level 1 metrics

Perspectives	Metrics	Measure
Supply chain reliability	On-time delivery Order fulfillment lead time Fill rate Perfect order fulfillment	Percentage Days Percentage Percentage
Flexibility and responsiveness	Supply chain response time Upside production flexibility	Days Days
Expenses	Supply chain management cost Warranty cost as percentage of revenue Value added per employee	Percentage Percentage Dollars
Assets/utilization	Total inventory days of supply Cash-to-cash cycle time Net asset turns	Days Days Turns

ii. *Benefits of adopting the SCOR model*

- Rapid assessment of supply chain performance
- Clear identification of performance gaps
- Efficient supply chain network redesign and optimization
- Enhanced operational control from standard core processes
- Streamlined management reporting and organizational structure
- Alignment of supply chain team skills with strategic objectives
- A detailed game plan for launching new businesses and products
- Systematic supply chain mergers that capture projected savings

In this work, a Case study is taken up to develop an effective method for managing 'Supply chain Risk' in a manufacturing industry involving in Casting, by collecting the sample data and a strategy is developed for its Mitigation. AutoKast Ltd, a Casting industry undertaking by Government of Kerala is taken here as the case study. The industry is fully equipped to manufacture all kinds of Ferrous Castings weighing from 20 kg to 8000 kg single piece. The present annual production capacity is 6000 Metric Tons. AutoKast produces and markets different grades of Grey Iron and SG Iron Castings for the domestic and international markets.

VI. Case Study: Risk Assessment and Management in Casting Industry

a) Risk Identification

Sources of risk

i. *Demand Risk*

It is the occurrence of an undesired event, which is mostly caused by fluctuation in customer demand. Forecast becomes more inaccurate if the fluctuation is really high, and the further result from forecast inaccuracy is the bullwhip effect as the most undesired outcome from this risk.

ii. *Supply Risk*

It refers to the increments of purchasing cost that is caused by price increase from suppliers, delivery delay from suppliers that can increase production cost, quality cost because of the low quality of inbound materials or even defects.

iii. *Operational Risk*

It is being the risk that has an effect on a company's internal ability to produce goods or services.

iv. *Environmental Risk*

Here several factors which were taken into consideration are technological, social, political and economic circumstances. However, natural phenomena, such as geological, metrological, disease and any other uncontrollable events have to be taken into consideration too.

b) Risk Assessment

To develop the risk mitigation strategies, the risk that constitutes the supply chain operations has to be identified using an effective tool. The method of assessment follows Failure Mode Effect Analysis (FMEA) guidelines. The concept of assessing the risk basically uses the score for the probability of the risk occurrence, the impact from the risk, and the identification method that the firm has to reduce the impact of the risk. All the values are calculated to obtain the risk priority number (RPN) and risk score value (RSV) by using the formula below.

RPN = Occurrence score * Severity score * Detection score

RSV = Occurrence score * Severity score

c) FMEA Analysis

Failure mode effect analysis is used to prioritize the risk using Risk Priority Number (RPN), which can be calculated from probability of occurrence, severity and detection of risk and also using Risk Score Values (RSV) in which Severity and Occurrence of risk is calculated.

i. *Occurrence Rating Scale*

Estimation of likelihood that a failure will occur.

Table 5.1 : Occurrence rating scale

Rating	Description	Potential Risk Rate
10	Certain probability	Risk occurs at least once a day or risk occurs almost every time
9	Risk is almost inevitable	Risk occurs predictably or risk occurs every 3 or 4 days
8 7	Very high probability	Risk occurs frequently; or risk occurs about once per week
6 5	Moderately high probability	Risk occurs about once per month
4 3	Moderate probability	Risk occurs occasionally or risk occurs once every 3 months
2	Low probability	Risk occurs rarely or Risk occurs about once per year
1	Remote probability	Risk almost never occurs no one remembers last risk occurrence.

ii. *Severity Rating Scale*

Table 5.2 : Severity rating scale

Rating	Description	Definition
10	Certain probability	Risk could cause loss of client
9	Risk is almost inevitable	Risk could cause major or permanent delay
8 7	Very high probability	Risk causes minor to moderate delay with a high degree of client dissatisfaction
6 5	Moderately high probability	Risk causes minor delay with some client dissatisfaction
4 3	Moderate probability	Risk causes very minor or no delay but annoys client
2	Low probability	Risk causes no delay and client is unaware
1	Remote probability	Risk causes no delay and has no impact on system

iii. *Detection Rating Scale*

How likely will the failure be detected?

Table 5.3 : Detection rating scale

Rating	Description	Definition
10	No chance of detection	There is no known mechanism for detecting the risk
9 8	Very Remote/Unreliable	The risk can be detected only with thorough inspection and this is not feasible or cannot be readily done
7 6	Remote	The risk can be detected with manual inspection but no process is in place so that detection is left to chance
5	Moderate chance of detection	There is a process for double-checks or inspection but it is not automated and/or is applied only to a sample and/or relies on vigilance
4 3	High	There is 100% inspection or review of the process but it is not automated
2	Very High	There is 100% inspection of the process and it is automated
1	Almost certain	There are automatic "shut-offs" or constraints that prevent risk

d) Sample Data Collection

Risk has to be prioritized before adopting effective mitigation strategies. All the inherent risks have been identified and the next stage is to assess each risk by using the FMEA method. Every risk is assessed by its likelihood value, impact value and detection method value. Determining those values is based on the secondary data and interviews with the experts. By having Chief Operating Officer, Procurement Manager and Distribution Manager as the key informants, the quality of the data and analysis is highly enhanced. All the informants enter values for the probability, impact and detection methods for each risk, and then they are adjusted by using past historical data (sales, volume of productions, suppliers performance and the occurrence of risks). All the values which informants have given in the interviews are shown below:

i. *Tabulated Risk Score Values*

Table 5.4 : Risk Score Values

RISKS	OCCURENCE			SEVERITY			DETECTION		
	COO	PRCMGR	DISTMGR	COO	PRCMGR	DISTMGR	COO	PRCMGR	DISTMGR
Demand Risks									
Demand fluctuation	8	8	6	7	7	5	5	5	6
Economic condition	6	6	3	4	3	4	5	5	6
Supply Risks									
Product arrival variability (delays)	6	6	7	6	7	7	6	5	6
Wooden pattern life cycle risk	6	6	6	6	6	5	6	5	5
Uncertainty in pattern availability	7	7	6	4	5	5	5	5	5
Bottlenecks in transportation routes	7	7	8	5	5	5	7	7	7
Operation Risks									
Lack of skilled workers	5	4	4	9	8	8	7	6	7
Breakdown of Fractioning machine	3	4	4	6	5	5	6	7	6
Breakdown of Refining machine	3	4	4	6	5	5	5	6	6
The condition of cargo-handling equipment	3	4	3	6	5	5	6	7	6
Carelessness and lack of motivation among the workforce	3	4	3	6	5	5	6	7	6
Environmental Risks	5	4	5	9	8	8	5	4	5

(Source: Interviews)

ii. Validated Risks Score and Calculated RPN & RSV

Table 5.5 : RPN and RSV calculation

RISKS	Occurrence (o)	Severity (s)	Detection (d)	RPN (o*s*d)	RSV (o*s)
Demand Risks					
Demand fluctuation	8	5	6	240	40
Economic condition	6	5	3	90	30
Supply Risks					
Inbound product Quality	6	6	6	216	36
Product arrival variability(delays)	6	6	5	180	36
Wooden pattern life cycle risk	7	5	5	245	35
Uncertainty in pattern availability	7	5	7	245	35
Bottlenecks in transportation routes	6	5	7	210	30

Operation Risks					
Lack of skilled workers	4	8	7	224	32
Fractioning machine breakdown	4	5	6	120	20
Refining machine breakdown	4	5	6	120	20
The condition of cargo-handling equipment	3	5	6	90	15
Carelessness and a lack of motivation among the workforce	3	5	6	90	15
Environmental Risks	5	8	5	200	40

e) Pareto Analysis

The 80:20 rules says that 20% of the work can gain 80% of all the benefits that can be obtained.

i. *Risk Priority Number's Pareto Chart*

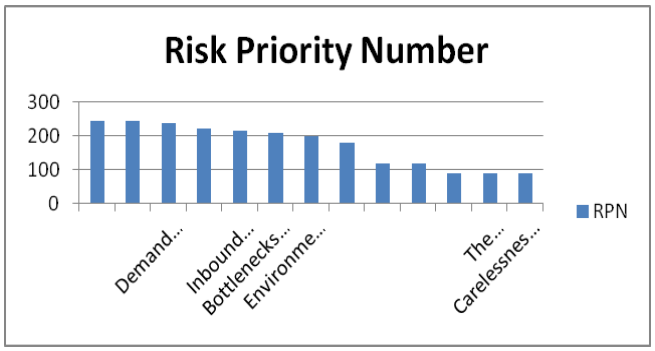

Figure 5.1 : Risk Priority Number's Pareto chart

ii. *Risk Score Value's Pareto Chart*

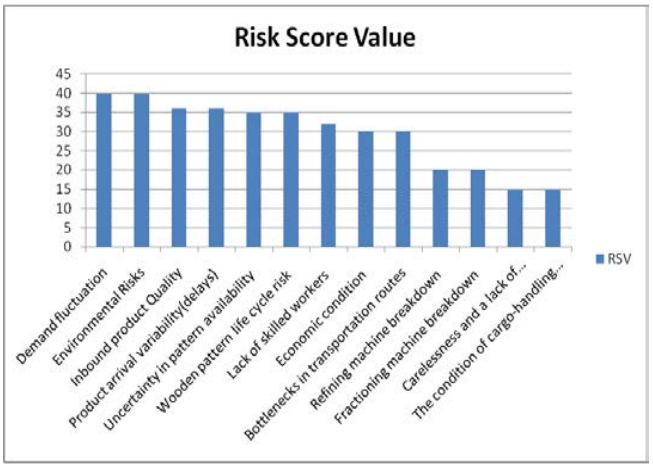

Figure 5.2 : Risk Score Value's Pareto chart

iii. *RPN versus Risk Score Scatter Diagram*

The two Pareto charts determines the critical RPN values for Risk scores. These charts are made simply to give guidance for prioritising risk response planning. Selecting critical values really depends on the nature of the business or project, for this reason the critical value for this project is based on the Pareto chart. From the charts, also the Pareto rule, the critical value for RPN is 200 and for risk the score is 35. A scatter diagram for the RPN is plotted against the risk score values. The aim of doing this is to find the intersection of those two critical values to reveal the set of risks that have high risk scores which need to be responded to and managed first. Identifying the process with high risk score helps the management in finding a way for its effective mitigation. The scatter diagram is shown on the graph below:

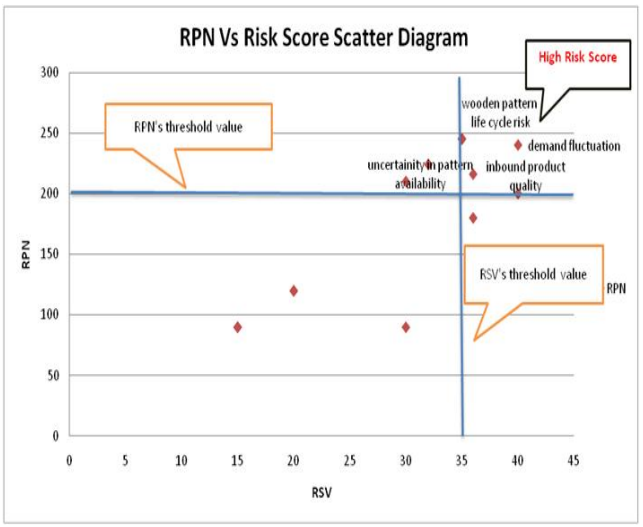

Figure 5.3 : RPN versus Risk Score Scatter Diagram

f) Risk Mitigation

Once the supply chain risk has been identified and assessed, information about the level of urgency of the risk can be obtained. Since the level of risk has been revealed, those high scored risks have to be mitigated by using specific supply chain strategies.

i. *Risk Mitigation Strategies framework for company's Casting Supply chain*

The Scatter diagram shows a cluster of risks above a particular threshold level that widely affects

Supply chain operations in a Casting industry. It shows three out of the four highest risks are of the supply type; inbound product quality, wooden pattern life cycle risk and uncertainty in pattern availability. The other risk is categorised as demand risk. The risks which categorised under the supply are mostly caused by the supplier. The impact of the low quality of the inbound products affects the quality of Castings. The key tool for mitigating this risk is by making good relationship with the supplier. Implementing collaborative relationships with the suppliers are extremely desirable to reduce or to prevent the occurrence and impact of the risk such as uncertainty in pattern availability. It supports the improvement of flexibility and ability of firm, thereby reducing the risk. Mitigation of supply risk can also be done by redundant suppliers (reconfiguring supply base). This strategy increases supply flexibility for the firms due to having more suppliers, and it automatically increases the buyer's bargaining power. The choice of which strategy is the most suitable for the casting supply chain entirely depends on the nature of the firm and its external parties.The fluctuations in demand are inherent in many Supply chain operations. The effect of these risks is decreased forecast accuracy, thus it might increase the cost of inventory or stock. In order to mitigate these risks, the firm can use pool or aggregate demand, which is termed as "Risk pooling". The impact of fluctuations in demand can be also be reduced by using postponement strategy in which the process starts by making a generic or family product that is later differentiated into specific end-product. A framework of Risk Mitigation Strategies for company's Casting Supply chain is shown below:

Table 5.6 : Risk Mitigation Strategies for company's Casting Supply chain

Category of Risk	Risk	Level of Risk	Mitigation Strategies
Demand Risk	Fluctuating demand	High	Collaborative forecast planning. Product postponement.
	Economic condition	Low	
Supply Risks	Inbound product Quality	High	Reconfiguring supply base (add more suppliers). Increase of patterns level (safety stock level).
	Product arrival variability(delays)	Low	
	Wooden pattern life cycle risk	High	
	Uncertainty in pattern availability	High	
	Bottlenecks in transportation routes	Low	
Operation Risk	Lack of skilled workers	Low	Implementing training and skill development programmes. Implementing Quality Management. Implementing Human safety Management.
	Breakdown of Fractioning machine	Low	
	Breakdown of Refining machine	Low	
	The condition of cargo-handling equipment.	Low	
	Carelessness and lack of motivation among the workforce.	Low	
Environmental Risk	Natural/Man-made disasters.	Low	Implementing Optimum Inventory level. Decentralized Inventory resources.

VII. Conclusion

The idea behind working on this project was to make aware the industries that neglecting the risks involved behind the supply chain increase their losses. Impacts of these risks and their occurrences can be minimized or even nullified. The SCOR model can play a substantial role in pursuing the overall objective of a real collaborative process within and between companies, aiming at maximizing the overall performances of the supply chain with reduced risk.

Here the given sample data gives the company's exposure to risk for the daily production process. So an effective Supply Chain Risk Management (SCRM) needs to be implemented in procurement and production process.

a) Future Work

The Future work of the thesis includes developing Risk Mitigation strategies that suits to the Industry scenario and also Cost benefit analysis is to be carried out by collecting real time data.

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