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Supply Chain Risk Model for Cement Industry Based on Interpretive Structural Model Driven by FMEA

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Abstract:

Purpose: This paper aims to identify, analyze, model the risk elements in the supply chain and further set future trends to evaluate risks in other domains of cement manufacturing industry. Cement is the second most consumed material in the world, has a fast supply chain in the global market. This has driven the authors to study the supply chain risks for this sector.

Design/methodology/approach: Through a detailed literature review and interaction with industry experts, 19 risk elements have been identified that may disrupt the supply chain activities. Failure Mode and Effect Analysis (FMEA) is used to prioritize these risk elements based on the risk priority number (RPN). RPN is derived from the severity, occurrence, and detectability of these risk elements in various process functions of the supply chain. 10 risk elements are selected from this analysis that have higher priority number. Further, these elements have been fed to the Interpretive Structural Model (ISM) that derived the contextual interrelationship among these elements. Further MICMAC analysis has been implemented on the risk elements based on their driving and dependency power.

Findings: Unpredicted heavy rainfall and energy shortages have been identified as the root causes of other risk elements. Increasing turnaround time in logistics and fleet adjustment during heavy demand, having the highest dependence power, are considered as the most important risk elements in the cement industry supply chain.

Originality/value: This is the first study in the domain of supply chain risks which has analyzed and modelled risks for cement industry. This work would provide the decision-makers of cement industry to focus on the specific risk elements for reducing disruptions in the supply chain.

Keywords: supply chain risks, failure mode and effect analysis, interpretive structural modelling

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1. Introduction

Supply chain management is a set of processes that are used for the effective integration of suppliers, manufacturers, warehouses, and stores. With the help of this process, the products can be produced and distributed in the right quantities to the right locations at the right time by minimizing the overall costs. A basic supply chain consists of elements such as planning, purchasing, inventory, production, and transportation. In any company, supply chain management is associated with many new technological advancement tools such as ERPs, SAP, and Oracle. With the help of these technologies, all the businesses have an upper hand in global markets. The main advantage of using web-based software and internet communications is that there is instant communication with vendors and customers with timely updates of information. This helps in the effective management of the supply chain.

Now a day's supply chains belong directly or indirectly to all the aspects of the business. Current decade witnessed that supply chain has created a noticeable place in manufacturing and service sectors because of globalization. Success of supply chain management also invited various issues in its execution. As per the global survey, companies face various issues and problems in their supply chain activities which are political uncertainties, natural calamities, and economic issues (Khaskhelly, Bano & Soomro, 2019).

As the significance of supply chain is increasing in the global markets, companies are facing many challenges because of the complexity in the supply chain itself. This has rebelliously threatened the business and the new creations and new opportunities for the management (ZandHessami & Savoji, 2011). Supply chain risks are mostly associated with supply chain disruptions (Monroe, 2012). Supply chain disruptions can be defined as the major breakdowns in the method or the process of production or distribution networks. When there are any disturbances in the supply chain, a series of events in the supply chain are affected (NC State University, 2011).

Overall supply chain risks are divided into two parts that are internal risks and external risks. Further, the internal risks are divided as that are internal to the organization and external to organization but internal to the supply chain. The external risks are classified into the risks which are external to the supply chain. The risks associated which are internal to the organization are a supply-side risk, process side risks and demand-side risks. The risks associated with the external of the organization but internal to the supply chain includes logistics side risk, collaboration risk, financial risk. Overall external risk is associated with environmental risk (Khaskhelly et al., 2019).

Through the researches it is evident that risks occur because of lack of visibility, lack of ownership, self-imposed chaos, the erroneous effect of Just In Time practices and inappropriate forecasts (Monroe, 2012). According to (ZandHessami & Savoji, 2011) the supply chain risk includes risks such as financial risks, operational risks, strategic risks, human resources risks, technological risks, fame risks, and laws risks.

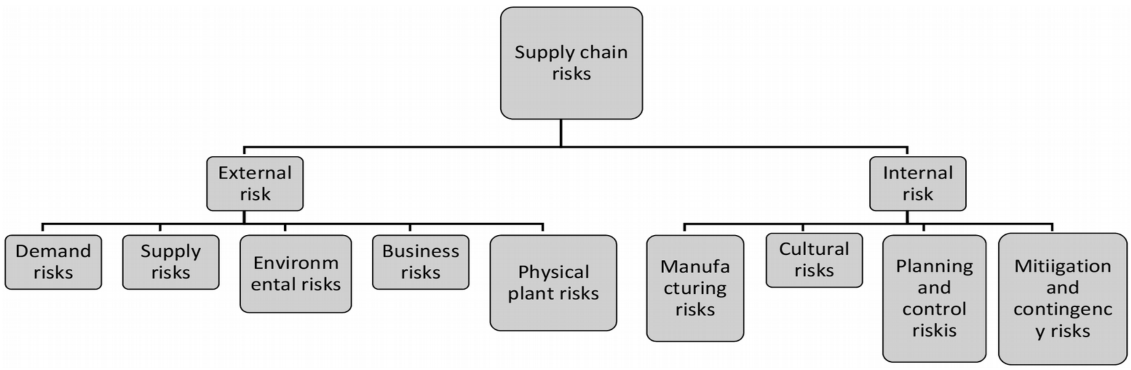

Figure 1. Supply Chain Risks derived from Literature review

As globalization and competitive environment are increasing day by day in the manufacturing industries, they are approaching to technological advancements to cater to the ever-changing environment. However, there is tremendous economic pressure to advance to technological inclusions. Continuous changes are seen in customer behavior and their needs or demands. With all these innovative changes there comes the need for good management which can handle the supply chain process effectively and efficiently to address the changing needs of the customers. In turn the organization faces many unwanted events and unavoidable circumstances that can be machine breakdowns, material shortages, accidents, absenteeism and many more (Islam & Tedford, 2012). This type of situation hampers the productivity and profitability of the organization.

1.1. Intension on the Selection of the Cement Industry for the Study of Supply Chain Risks

Cement is the second most consumed substance in the world and it is an irreplaceable ingredient for the daily utility (Noche & Elhasia, 2013). As cement is a highly used component in the world, it has a fast supply chain network all over the global markets. As the importance and need of the cement industries is increasing, the network of the supply chain also becomes very complex. This gives rise to many risks associated with the cement industry's supply chain. It starts from the procuring of raw material to the distribution of finished cement to the end customers. These risks range from disruptions in the distributions, risk of change or modification of any federal/state regulations, labor health or labor concerns, risk of competitors, risk of change in commodity and raw material prices, risk of economic conditions, cyber risks, currency risk (Hickey, 2017).

As the demand for infrastructure increases, for example, houses, dams, schools, sewers, the demand for cement also consistently increases. Therefore, the production of cement goes up, the reason being that cement is the main ingredient for concrete used in construction. It is estimated that by the year 2050, the cement production is going to increase multi-fold. But this can have adverse impact on the environment as well (Potgieter, 2012). Cement has made possible the construction and is also very affordable. Cement is so extensively used which makes its 30 times most produced industrial material with its closest rival being steel. The growth of construction industry is accompanied by an enormous amount of construction waste such as abandoned cement concrete, wood, metal and soil. Cement has a huge effect on the strength of lightweight mixtures. Cement waste has to be reduced as it has an adverse effect on the environment. The quick fixing property of cement makes it vulnerable to water and moisture if left abandoned. Better ways to manage waste have been evolving in the construction industry in order to take care of this problem (Lu, Wang & Zhang, 2020). Concretes are the most widely utilized development materials in the world, a huge range of concretes depend on a range of cements. Low costs, simplicity of use, and high compressive quality are the primary components to be thought of for a given application. Inorganic (mineral) concrete based on the Portland cement has inadequacies: poor flexural quality, low elasticity, high porosity, freeze defrost weakening, pulverization by destructive synthetics, thus forward (Bozkurt & İslamoğlu, 2013).

Thus in cement manufacturing, the availability of the raw material is specific to the geographic region and this material being bulky, risks associated with the logistics, further manufacturing and distribution can be forceful and critical. This urges the authors to select this sector of heavy industries for the study of supply chain risks.

2. Literature Review

Supply chain management helps to evaluate the process of planning, implementing, and controlling the transfer of raw materials and finished goods from manufacture to the end-user. The whole process of dealing with customers' orders starts from the supplier of the raw materials, then using the raw materials to produce a product, and distributing the finished product to the end customer with the help of distributors, retailers, and wholesalers. Manufacturing is a major part of supply chain management.

2.1. Some of the Top Risks Factors in Manufacturing Companies

Rapid increase in globalization, growing customer expectations and market volatility, environmental changes the supply chains are getting easily exposed to many risks. Every industry suffers from adequate amount of challenges which should be mitigated (Chen, Sohal & Prajogo, 2012). Risks in manufacturing like wasteful resource consumption, and scrap generation resulting from company supply chain operations including pollution and harmful emissions, as well as accidents caused by the firm's staff, operations, and machines (Baz, Cherrafi, Benabdellah, Zekhnini, Nguema & Derrouiche, 2023).

Vendor concerns: One of the most important aspects of the supply chain of the cement industry relies on the vendors or the suppliers of raw materials required for cement manufacturing. As cement is the second most important commodity, it is essential to manufacture cement of the highest quality. There might be several impurities within the raw materials that could take time to clean up for final manufacturing and this might become a risk for the manufacturer, along with this timely delivery of materials and proper packaging is also expected. Therefore, to get good quality raw material companies need to select suppliers that could provide good quality raw materials (Komsiyah, Wongso & Pratiwi, 2019).

Federal, state or local regulations: The main risks factors for any manufacturing company can be the rules and regulation which are they abide to follow. Any changes in the given rules and regulations due to any external political forces can create a hindrance in the way. The political risks, heavily impacts the business climate and lead to disturbance in the operations (Wei & Zhang, 2012). Political/legal risk affecting business are change of legislation/regulation, and loss of regulatory license to function (Suopajärvi, Lindah, Eerola & Poelzer, 2023).

Commodity/Raw material prices: As there are many fluctuations found in market for the demand and supply of the commodities, it as a market risks which are typically found in many manufacturing industries. This occurs due to the constant changes in demand and supply and price as a major driver. It is seen that the price changes in any phase of the supply chain and are not transmitted to the other stages. For better understanding, if any retailer sales the commodity for higher prices range as it is one of the market leader but the suppliers of that commodity do not receives any favors (Ali & Shukran, 2015).

Labor Concerns: Labors are an integral part of the manufacturing sector. They are also crucial to supply chain management. There are several risks associated with laborers which may act as a crisis in the whole manufacturing system. Some of the risks may be the handling of dangerous equipment, improper environmental factors, improper lighting conditions, exposure to hazardous chemicals, physical attributes, equipment complexity, air purity, etc. These risks also pertain to cement manufacturing as well, so handling and mitigating such risks become important as laborers work at the optional level of the business (Dumitrescu & Deselnicu, 2017).

Environmental Risks: As Cement manufacturing industries have the major sources of CO2 emissions from the fuel burning. The main challenge faced by Manufacturing industries are cement dust, Air pollution, water Pollution, solid waste pollution, noise pollution, ground vibration, resources depletion (Zainudeen & Jeyamathan, 2016) as manufacturing industries are energy extensive and a very crucial contributor to the climate change. These emissions of harmful air deteriorates the air quality and also impact the human health (Devi, Lakshmi & Alakanandana, 2017).

Technological risks: Technological risks are increasing as a lot of manufacturing systems are relying on technology to optimize their performance and increase productivity. With the recent introduction of concepts like industry 4.0, cloud manufacturing, etc. Cyber security risks have increased in the manufacturing sector. As these systems are not so resistant to attacks like the banking systems are, a lot of attackers have targeted such systems over the years and lot of data has been compromised. Although there have been several measures taken to enhance security systems, a lot of work is still left to be done (Zarreh, Wan & Lee, 2019).

Product quality or contamination issues: In any manufacturing industry, if the company does not adhere to the conformed product quality this leads to loss in customer satisfaction, increases the liability risks, customer loyalty decreases so quality risks can create a biggest blunder for the manufacturing industries. The supply chain risks include supply quality and supply commitment (Lavastre, Gunasekaran & Spalanzani, 2013).

2.1.1. Risks at Supplier's Side

In cement industries, the first and foremost activity is to procure the raw material from the supplier. For cement production limestone, basalt, sandstone, pumice, gypsum, are required. The process of manufacturing cement begins from the quarrying of these materials, so the process of extracting raw materials involves mining and removal of overburden, drilling, and blasting, loading, crushing, and site restoration so there are risks associated at every step of the manufacturing of cement from procuring of raw material to delivering it to its end customers (Moges, Abule & Endalamaw, 2023).

The disruptions in the supply chain are very uncertain which can affect the performance of the company and the countermeasures are costly. The considerable risks in procuring the materials from suppliers are the coordination problems, demanding and the disruptions of mundane activities, the dependency on suppliers also increases this causes risks to supply chain network. The uncertainty and delays in the delivery of raw materials are risks (Handayani, 2018).

In the cement manufacturing industries, the supply chain activities include demand for concrete or cement bags. This is the first step towards the production of the cement. According to research, the risk identified in the procurement of the raw materials where there are a very limited source of raw materials, various conflicts, and money related issues are emerging between the supplier and customer, when the raw materials procured and that are damaged while shipping this lead to decrease in the production of finished goods, the arrival of raw materials very late due to the payment processing, the supplier is not able to complete the commitment regarding raw materials, the inappropriate forecast for sales. This all are the basic risks in procuring the raw materials (Hatmoko, Wibowo, Astuty, Arthaningtyas & Sholeh, 2019)

As cement manufacturing is a very costly affair and it is intensive energy consuming plant so the companies use coal and pet coke as the fuel in the production of energy in the year 2017 the rate of both principle fuels coal and pet coke were increased significantly so the raise or hike in fuel prices is the risks in the production of cement (ACC, 2017).

2.1.2. Risks at the Manufacturing Side

Cement is the basic material used for any construction process. Cement manufacturing generally involves various steps from loading the limestone, grinding, and then finally getting cement. The process of manufacturing of cement involves mining, crushing, stacking, reclaiming, grinding, calcination stage, cooling, storage, and transportation system; in each of these steps, numerous risks are involved which if not identified and dealt on time can lead to serious implications.

The various types of risk involved in cement manufacturing can be poor supervision of tasks going in the factory, electrical risks - power failure and inappropriate usage of cables during manufacturing, kiln thermal load risk - the inappropriate temperature in the kiln can affect the quality of cement, using equipment which is not in good condition, accidental fires can cause troubles during the transportation of material, failure of mechanical equipment is also a major risk (Mishra, 2019).

Another risk involved is issues related to fire and explosions. The raw material needs to be transferred from one place to another for this purpose rubber conveyor belts are used which are generally combustible so this poses a high risk of fire. Besides, there is a furnace required for heating which requires different fuels and natural gases, so if any mishap occurs it can lead to fire and explosions leading to severe damage. Besides, there are short circuit risks involved every time, which can also lead to a fire (Trust Re, 2018).

The cement manufacturing, involves various machinery, equipment, tools, raw materials, electric supply, and most important the workers. Employees are assets to the company and anything happening to the employees is considered a risk to the company. In the case of cement, manufacturing employees is the one, which is at high risk if anything happens to the employees it leads to disruption in the whole supply chain. Also, poor ergonomics of machines makes the workers job repetitive that can lead to muscle pain, strains, etc., workers working in a confined space can also affect their health (Occupational Safety and Health Administration, 2004).

Thus it is evident that there are several constraints related to overall business operations and supply chain monitoring, analyzing processes making risks evaluation a major challenge in the cement industry (Munir, Shakeel, Chatha & Farooq, 2020).

2.1.3. Other Risks Involved in Cement Industries

a) **Market demand risk:** The demand for cement keeps on changing globally sometimes the sales figures are high but sometimes they are very low, generally developing countries where new infrastructure has required the demand for cement is high whereas in developed countries the demand is not that much (McCaffrey, 2018). With the government boosting the infrastructural development, the demand for cement is expected to rise. This gave momentum to the company to increase its capacity. With increasing demand in future capacity, utilization is expected to happen. But currently, there is a mismatch between the demand and the supply (Aditya Birla Ultratech, 2014-2015).

b) **Political risks:** Political instability in the operating market may pretence a huge risk for cement manufacturers while setting up new plants and facilities in the areas of development (McCaffrey, 2018). As the global economy of the year, 2017-2018 was at 3.9% growth, the trade increased which made the international crude oil prices hike. There was uncertainty about the normalization of monetary policies. These factors gave rise to the geopolitical risks for the cement industry (Aditya Birla Ultratech, 2014-2015).

c) **Cyber-attacks:** With the increase in globalization, there is a boom in technological advancements all over. The integration of information technology with the supply chain is giving a pathway to increasing cyber risks (Ghadge, Weib, Caldwell & Wilding, 2019). There are many cybersecurity solutions established. But every developed solution has a bug inside and that bugs are identified and cyber-attacks are executed (Infosec, 2019). This thereby increases the risk of information disclosure and manipulation. Companies, whose core is information, may suffer irreparable losses due to loss of information.

d) **Pandemic risks:** As the supply chain is heavily dependent upon the transportation and logistics they are known to keep their customer's satisfaction at a high level but when epidemic situations arise, people who are working in the particular supply chains are at the high risks as they are vulnerable to fall ill. This leads to an unstable supply chain which hampers the whole supply chain directly (Larson, 2008). Global supply chain disruption caused by the COVID-19 pandemic is one example of disruption in the supply chain. The shortage of raw material, sub-assemblies, and finished products have disturbed the supply chain of many companies across China and other countries thereby impacting the global supply chain (Veeraraghavan, 2020).

3. Research Design

This research is based on the case of a major cement manufacturing firm. The researchers performed this study in two phases. The first phase was to identify and prioritize the risks using Failure Mode and Effect Analysis. The risks elements identified through the literature review were feed in the FMEA model. Table II shows the FMEA model comprising of the risk elements being quantified by the industry exerts from the field of cement industry. There were five experts from among the cement manufacturing firm holding managerial positions. All the five respondents agreed to fill the FMEA sheets. Based on the FMEA data sheets filled, the risk factors that hold top priority in the FMEA model were incorporated in the Interpretive Structural Model (ISM) to understand the structural relationship among the entities. This procedure of ISM was furthermore based on the same expert's inputs. The experts were given a week's duration time to understand the ISM model and derive the interrelations among the risk elements. Based on their inputs, Structural Self Interaction Matrix shown in Table III, that shows the interrelationship among the risk elements, was prepared. The researcher's perspectives that necessitated the use of FMEA and ISM model and their process of implementation is explained as under.

3.1. FMEA - Need and Process

Failure Mode Effect Analysis is a standardized, foresighted method for assessing the process to check for any failure that might occur in the future. It is used for improving the reliability of a system. Various causes of failures are listed down before the actual beginning of work, these risks are then worked upon to minimize their consequence or eliminate those risks or failure modes. For an FMEA to work certain parameters are needed to be calculated which are severity, occurrence, detectability and according to these there, risk priority number (RPN) is calculated (Rakesh, Jos & Mathew, 2013). When different risks are analyzed before starting work. It immediately helps in enhancing the process and reduces the likelihood of failure in the future. FMEA provides several failure modes and also identifies causes connected to it (Rana & Belokar, 2017).

A significant purpose of FMEA is to identify the failures which could arise within the system before it actually begins its operations (Sulaman, Beer, Felderer & Host, 2017). The RPN i.e. Risk Priority number not only supports quantitative analysis of risk events that may occur but also provides the highest risk present accurately. Results can be quickly fetched from the analysis and there is little to no concerns of losing of the data collected (Subriadi & Najwa, 2019).The failure modes (FM) if not found, can result in severe losses in terms of financial and operational stability. FMEA absolutely benefits in finding several risks attached to a supply chain (Kim, Miller, Siddiqui, Movsas & Glide-Hurst, 2018). The purpose of using FMEA has a varied range of advantages like the reduction of the costs that might occur in case of the failures, to make the system more secure and steady to overcome failures, to mitigate and identify a variety of risks and gradually work upon them, increases reliability on the system or process and increases the safety of the operations. The ultimate goal is to provide customer value and satisfaction (Sharna & Srivastava, 2018). The risks pertaining to supply chains can be greatly assessed using FMEA to good extent. As the cement industry sometimes requires multimodal mode of transportation of the finished goods from one place to another lot of challenges arise while in transit (Sommerfeld, Teucke & Freitage, 2018). FMEA has also been a proven method in identifying and analyzing such constraints in the supply chains (Kudláč, Štefancová & Majerčák, 2017).

FMEA includes the risk priority number (RPN). RPN is used to evaluate and assess the failure mode which occurs in the system, it is determined by the multiplication of S, O and D (Chen & Ko, 2007).

The technique of implementation of FMEA is as follows:

1. Industry experts from the cement manufacturing firm holding managerial positions, from manufacturing, logistics and supply chain department were contacted.
2. The scope of FMEA was identified for the manufacturing and supply chain.
3. Potential failure modes in the manufacturing and supply chain process were identified through literature review, validated by these industry experts.
4. For each failure mode, the effects of it on the system and their root causes were identified.
5. For each cause, probability of Occurrence (O) of failure was rated on a scale from 1 to 10, where 1 is extremely unlikely and 10 is inevitable.
6. For each cause, current process controls were identified, whose Detection rating (D) was rated on the scale of 1 to 10, where 1 meant the control was absolutely certain to detect the problem and 10 meant the control was uncertain to detect the problem
7. Further the severity (S) of each effect was rated on a scale from 1 to 10, where 1 is insignificant and 10 is catastrophic.
8. Finally, Risk Priority Number was calculated as follows:

<table>
<tr><th>Process Function</th><th>Potential failure mode</th><th>Potential Effect(s) of Failure</th><th>Severity Score</th><th>Potential Cause(s) of Failure</th><th>Occurrence Score</th><th>Detection Score</th><th>RPN</th><th>Recommended actions to avoid the risk</th></tr>
<tr><td rowspan="4">Logistics function</td><td>Long Route selection</td><td>Delay in product delivery to the client</td><td>2</td><td>Avoiding product damage during rains</td><td>2</td><td>1</td><td>4</td><td>Detouring or identifying shorter routes</td></tr>
<tr><td>Bulky Raw material handling risk</td><td>Increase in wastage, more energy consumption</td><td>2</td><td>Raw material too bulky for movement</td><td>1</td><td>1</td><td>2</td><td>Unitization of goods in small lots</td></tr>
<tr><td>Accidental risk in transportation</td><td rowspan="2">Delay in raw material delivery, delay in product delivery to the client</td><td>5</td><td rowspan="2">Transportati on vehicles not maintained or upgraded</td><td>2</td><td>10</td><td>100</td><td rowspan="2">Periodic maintenance to be given to the vehicles</td></tr>
<tr><td>Turnaround time in logistics</td><td>10</td><td>10</td><td>8</td><td>800</td></tr>
</table>

Process Function	Potential failure mode	Potential Effect(s) of Failure	Severity Score	Potential Cause(s) of Failure	Occurrence Score	Detection Score	RPN	Recommended actions to avoid the risk
	Fleet management during heavy demand		10	A limited number of transport vehicles	9	9	810	Engaging more vehicles during heavy demand
Manufacturing function	Failure of mechanical equipment/ machine breakdown	Production stoppage, mismatch in supply and demand	2	Improper or no maintenance to the equipment	7	8	112	Periodic/ predictive maintenance to be given to machines to avoid breakdown
	Power failure		2	Uneven supply of power	1	1	2	Backup power supply
	Health and safety risk	Increasing worker turnover	2	Unfavorable working conditions, lack of training to the workers	1	10	20	Proper training given to the workers
	Storage risk	More work in process inventory	1	Limited storage space for bulky material	1	1	1	Use of certain inventory analysis techniques to store material based on its type
Economic	Fuel price fluctuation	The rise in the product price	10	Production costs	10	1	100	Hedge pricing to offset the risks of fluctuating prices
	Energy shortages		3	Localized shortages, market manipulation	3	10	90	Looking for alternative fuels (renewable energy resources)
	Fluctuating market demand risk	Creation of bullwhip in the supply chain	7	Supply and demand mismatch	3	8	168	Using business analytics to get right predictions.
Suppliers	Coordination risk between buyer and seller	Delay in raw material delivery, quality problems in the material received	4	Improper vendor management	5	6	120	Proper vendor management by vendor training, establishing strategic relationship with the vendors
	Uncertainty in material availability	Production delays	4	Unavailabilit y of raw material with the suppliers, scarcity of material	2	10	80	Identifying alternate or backup suppliers

<table>
<tr><th>Process Function</th><th>Potential failure mode</th><th>Potential Effect(s) of Failure</th><th>Severity Score</th><th>Potential Cause(s) of Failure</th><th>Occurrence Score</th><th>Detection Score</th><th>RPN</th><th>Recommended actions to avoid the risk</th></tr>
<tr><td></td><td>Procurement lead time risk</td><td></td><td>2</td><td>Delays in payments unavailability of raw material with the suppliers</td><td>1</td><td>2</td><td>4</td><td>Using procurement soft wares to track requirements and make purchase orders on time</td></tr>
<tr><td>Environment function</td><td>Unpredicted/ Heavy rainfall</td><td>Customer dissatisfaction, decreasing demand</td><td>10</td><td>Product damage during transportatio n in the rainy season, the formation of lumps in cement</td><td>3</td><td>8</td><td>240</td><td>Increasing product packaging to reduce product pilferage</td></tr>
<tr><td rowspan="3">Other external functions</td><td>Political risk</td><td>Supply chain disruption</td><td>1</td><td rowspan="3">Uncontrollab le extrinsic factors</td><td>1</td><td>7</td><td>7</td><td rowspan="3">The decision of establishing the plant in the given region is strategic and requires deep investigation of political situations, natural calamities and cyber-attacks in the region.</td></tr>
<tr><td>Cyber-attack risk</td><td>Loss of confidential information of the company</td><td>1</td><td>1</td><td>8</td><td>8</td></tr>
<tr><td>Epidemic risk</td><td>Workforce unavailability</td><td>1</td><td>1</td><td>9</td><td>9</td></tr>
</table>

RPN = Severity * Occurrence * Detectability

Table 1. FMEA model for cement manufacturing plant supply chain risks

3.2. ISM - Need and Process

Interpretive structural modeling (ISM) is used to identify the relationship between different criteria involved in a complex situation. In this method, the elements which are directly or indirectly linked to a system are organized systematically. The ISM approach begins with the finding of elements that are associated with the situation. A self-interaction matrix is developed which represents the relationship between these elements. Then this matrix is converted into a reliability matrix. The reliability matrix is then used to produce the ISM in which nodes are replaced with statements (Kulkarni, Ravi & Patil, 2018).

The research study on developing the framework for the implementation of lean construction strategies used the interpretive structural modelling (ISM) technique to study the Saudi construction industry. This study employed the (ISM) technique for data collection and analysis. This helped in specifying the hierarchical relationships between the different elements that contributed to the successful implementation of lean construction. The validation of the ISM model was further carried out by the experts (Sarhan, Xia, Fawzia, Karim, Olanipekun & Coffey, 2019).

Based on the risk priority number, there are 10 risk variables identified that hold triviality in the system. They are Increasing turnaround time in logistics (800), Fleet adjustment during heavy demand (810), Fuel price fluctuation (100), Energy shortages (90), Fluctuating market demand risk (168), Coordination risk between buyer and seller (120), Uncertainty in material availability (80), Unpredicted/ Heavy rainfall (240), Accidental risk in transportation (100), Failure of mechanical equipment/ machine breakdown (112).

These risk elements are feed to the self-interaction matrix. Further steps of developing an ISM matrix is explained as under:

Step 1: Construction of Structural Self-Interaction Matrix and Initial Reachability Matrix

A structural self-interaction matrix is a matrix that shows the relationship between any two random elements of the matrix. The following symbols are used to represent the relationship between the elements.

If i influence j: V

If j influences i: A

If i and j influence each other: X

No relation between i and j: O

Structural Self-Interaction Matrix

Sr. No.	Structural self-interaction matrix	10	9	8	7	6	5	4	3	2	1
1	Increasing turnaround time in logistics	A	A	A	O	A	O	A	A	A	X
2	Fleet adjustment during heavy demand	O	A	A	A	O	A	A	A	X	
3	Fuel price fluctuation	O	O	O	O	O	O	X	X		
4	Energy shortages	V	V	A	O	O	O	X			
5	Fluctuating market demand risk	O	O	A	O	V	X				
6	Coordination risk between buyer and seller	O	O	O	O	X					
7	Uncertainty in material availability	O	O	A	X						
8	Unpredicted/ Heavy rainfall	V	V	X							
9	Accidental risk in transportation	O	X								
10	Failure of mechanical equipment/ machine breakdown	X									

Table 2. Structural self-interaction matrix

For the 10 major risk factors identified using FMEA, the contextual relationship was identified among these risk variables through academic experts.

According to the self-interaction matrix, it can be seen that failure of mechanical equipment's or machine breakdown, accidental risk in transportation, unpredicted/ heavy rainfall, coordination risk between buyer and seller, energy shortage like a limited supply of all types of natural gases for manufacturing as well as logistics, fleet adjustment during heavy demand leads to increasing turnaround time in logistics. Also, there is the relationship between accidental risk in transportation, uncertainty in climatic conditions, fluctuations in raw material availability and market demand, energy shortage, fuel price fluctuation and fleet adjustment during heavy demand. Along with this unpredicted/heavy rainfall leads to energy shortage by making the natural resource hard to acquire and utilize. Also, unpredicted/heavy rainfall affects the availability of materials.

There is no relation between increasing turnaround time and uncertainty in material availability; fluctuating market demand risk and increasing turnaround time in logistics. Also, there is no relation between fleet adjustment during heavy demand and increasing turnaround time; coordination risk between buyers and sellers and fleet adjustment during heavy demand. And fuel price fluctuations are not at all related to the failure of mechanical equipment/ machine breakdown, accidental risk in transport, unpredicted/heavy rainfall, uncertainty in material availability, coordination risk between buyers and sellers, fluctuating market demand risks. Also, energy shortages are not linked to uncertainty in material availability, coordination risk between buyers and sellers, fluctuating market demand risks. Along with this, there is no link between fluctuating market demand risks and failure of mechanical equipment, accidental risks in transportation, uncertainty in material availability. Along with this coordination risks between buyers and sellers are not related to the failure of mechanical equipment, accidental risks in transportation, unpredicted/ heavy rainfall, uncertainty in material availability. In addition to this uncertainty in material, availability is not concerned with the failure of mechanical equipment and accidental risks in transportation. Accidental risk in transportation is not linked to failure in mechanical parts.

According to the self-interaction matrix, that energy shortages can lead to failure of mechanical equipment and accidental risks in transportation. Along with this, fluctuating market demand risks can result in coordination risks between buyers and sellers. In addition to this unpredicted heavy rainfall leads to failure of mechanical equipment/machine breakdown and increases accidental risks during transportation.

Step 2: Construction of the Initial Reachability Matrix

Initial Reachability Matrix (IRM):

IRM is a binary matrix that uses the following method for the construction of the matrix.

In the (i,j) entry in the self-interaction matrix is V, then it becomes 1 in the reachability matrix and (j,i) entry becomes 0.

If the (i,j)entry in the self-interaction matrix is A, then I represent 0 in reachability matrix and for (j,i) entry shows 1.

If the (i,j)entry in the self-interaction matrix is X, then I represent 1 in reachability matrix and for (j,i) entry shows 1.

If the (i,j)entry in the self-interaction matrix is O, then I represent 0 in reachability matrix and for (j,i) entry shows 0.

Sr. No.	Structural self-interaction matrix	10	9	8	7	6	5	4	3	2	1
1	Increasing turnaround time in logistics	0	0	0	0	0	0	0	0	0	1
2	Fleet adjustment during heavy demand	0	0	0	0	0	0	0	0	1	1
3	Fuel price fluctuation	0	0	0	0	0	0	1	1	1	1
4	Energy shortages	1	1	0	0	0	0	1	1	1	1
5	Fluctuating market demand risk	0	0	0	0	1	1	0	0	1	0
6	Coordination risk between buyer and seller	0	0	0	0	1	0	0	0	0	1
7	Uncertainty in material availability	0	0	0	1	0	0	0	0	1	0
8	Unpredicted/ Heavy rainfall	1	1	1	1	0	1	1	0	1	1
9	Accidental risk in transportation	0	1	0	0	0	0	0	0	1	1
10	Failure of mechanical equipment/ machine breakdown	1	0	0	0	0	0	0	0	0	1

Table 3. Initial Reachability Matrix

Sr. No.	Structural self-interaction matrix	1	2	3	4	5	6	7	8	9	10
1	Increasing turnaround time in logistics	1	0	0	0	0	0	0	0	0	0
2	Fleet adjustment during heavy demand	1	1	0	0	0	0	0	0	0	0
3	Fuel price fluctuation	1	1	1	1	0	0	0	0	0	0
4	Energy shortages	1	1	1	1	0	0	0	0	1	1
5	Fluctuating market demand risk	0	1	0	0	1	1	0	0	0	0
6	Coordination risk between buyer and seller	1	0	0	0	0	1	0	0	0	0
7	Uncertainty in material availability	0	1	0	0	0	0	1	0	0	0
8	Unpredicted/ Heavy rainfall	1	1	0	1	1	0	1	1	1	1
9	Accidental risk in transportation	1	1	0	0	0	0	0	0	1	0
10	Failure of mechanical equipment/ machine breakdown	1	0	0	0	0	0	0	0	0	1

Table 4. Final Reachability Matrix

In the final reachability matrix, the relation between different factors using binary denomination is done and it provides a better idea about the relationship between different factors. The rows and columns are arranged in a fashion that gives a clear idea about the relations among these factors.

The final reachability matrix is carried forward which specifies the relation between different factors involved and their dependence or driving power. Which means which factors are prone to happen is calculated. The driving power represents the total number of factors it may help achieve while the dependence power represents the total number of factors it may help achieving it. Based on driving power and dependency the above-listed factors will be grouped into four groups which are autonomous, dependent, linkage and independent factors.

Sr. No.	Structural self-interaction matrix	1	2	3	4	5	6	7	8	9	10	Driving power
1	Increasing turnaround time in logistics	1	0	0	0	0	0	0	0	0	0	1
2	Fleet adjustment during heavy demand	1	1	0	0	0	0	0	0	0	0	2
3	Fuel price fluctuation	1	1	1	1	0	0	0	0	0	0	4
4	Energy shortages	1	1	1	1	0	0	0	0	1	1	6
5	Fluctuating market demand risk	0	1	0	0	1	1	0	0	0	0	3
6	Coordination risk between buyer and seller	1	0	0	0	0	1	0	0	0	0	2
7	Uncertainty in material availability	0	1	0	0	0	0	1	0	0	0	2
8	Unpredicted/ Heavy rainfall	1	1	0	1	1	0	1	1	1	1	8
9	Accidental risk in transportation	1	1	0	0	0	0	0	0	1	0	3
10	Failure of mechanical equipment/ machine breakdown	1	0	0	0	0	0	0	0	0	1	2
	Dependence power	8	7	2	3	2	2	2	1	3	3	33/33

Table 5. Final Reachability Matrix with driving and dependence power

Step 3: Table 6 Partition of Reachability Matrix Into Different Levels

Sr. No.	Structural self-interaction matrix	1	2	3	4	5	6	7	8	9	10	Driving power
1	Increasing turnaround time in logistics	1	0	0	0	0	0	0	0	0	0	1
2	Fleet adjustment during heavy demand	1	1	0	0	0	0	0	0	0	0	2
3	Fuel price fluctuation	1	1	1	1	0	0	0	0	0	0	4
4	Energy shortages	1	1	1	1	0	0	0	0	1	1	6
5	Fluctuating market demand risk	0	1	0	0	1	1	0	0	0	0	3
6	Coordination risk between buyer and seller	1	0	0	0	0	1	0	0	0	0	2
7	Uncertainty in material availability	0	1	0	0	0	0	1	0	0	0	2
8	Unpredicted/ Heavy rainfall	1	1	0	1	1	0	1	1	1	1	8
9	Accidental risk in transportation	1	1	0	0	0	0	0	0	1	0	3
10	Failure of mechanical equipment/ machine breakdown	1	0	0	0	0	0	0	0	0	1	2
	Dependence power	8	7	2	3	2	2	2	1	3	3	33/33

Table 6 Partition of Reachability Matrix Into Different Levels

Step 4: Level Partitioning

Level partitioning is prepared with the support of the reachability set, antecedent set and intersection sets that are generated for each risk factor. The reachability set is a combination of the risk variable i and the other risk variables which are affected by it. Similarly, the antecedent set is the combination of the risk variable j and the other variables which are affected by it. The intersection set contains of those variables which are common to reachability set and antecedent set. A risk factor's level is identified by checking those risks having the same set of reachability and intersection. Table VII shows the first iteration of level partitioning.

Sr. No.	Structural self-interaction matrix	Reachability set	Antecedent set	Intersection set	Level
1	Increasing turnaround time in logistics	1	1,2,3,4,6,8,9,10	1	1
2	Fleet adjustment during heavy demand	1, 2	2, 3, 4, 5, 7, 8, 9	2	
3	Fuel price fluctuation	1, 2, 3, 4	3, 4	3, 4	
4	Energy shortages	1, 2, 3, 4, 9, 10	3, 4, 8	3, 4	
5	Fluctuating market demand risk	2, 5, 6	5, 8	5	
6	Coordination risk between buyer and seller	1, 6	5, 6	6	
7	Uncertainty in material availability	2, 7	7, 8	7	
8	Unpredicted/ Heavy rainfall	1, 2, 4, 5, 7, 8, 9,10	8	8	
9	Accidental risk in transportation	1, 2, 9	4, 8, 9	9	
10	Failure of mechanical equipment/ machine breakdown	1, 10	4, 8, 10	10	

Table 7. Level partitioning based on reachability and antecedent set-Iteration 1

Sr. No.	Structural self-interaction matrix	Reachability set	Antecedent set	Intersection set	Level
2	Fleet adjustment during heavy demand	2	2, 3, 4, 5, 7, 8, 9	2	2
3	Fuel price fluctuation	2, 3, 4	3, 4	3, 4	
4	Energy shortages	2, 3, 4, 9, 10	3, 4, 8	3, 4	
5	Fluctuating market demand risk	2, 5, 6	5, 8	5	
6	Coordination risk between buyer and seller	6	5, 6	6	2
7	Uncertainty in material availability	2, 7	7, 8	7	
8	Unpredicted/ Heavy rainfall	2, 4, 5, 7, 8, 9,10	8	8	
9	Accidental risk in transportation	2, 9	4, 8, 9	9	
10	Failure of mechanical equipment/ machine breakdown	10	4, 8, 10	10	2

Table 8. Iteration 2

Sr. No.	Structural self-interaction matrix	Reachability set	Antecedent set	Intersection set	Level
3	Fuel price fluctuation	3, 4	3, 4	3, 4	
4	Energy shortages	3, 4, 9,	3, 4, 8	3, 4	
5	Fluctuating market demand risk	5	5, 8	5	3
7	Uncertainty in material availability	7	7, 8	7	3
8	Unpredicted/ Heavy rainfall	4, 5, 7, 8, 9	8	8	
9	Accidental risk in transportation	9	4, 8, 9	9	3

Table 9. Iteration 3

Sr. No.	Structural self-interaction matrix	Reachability set	Antecedent set	Intersection set	Level
3	Fuel price fluctuation	3, 4	3, 4	3, 4	4
4	Energy shortages	3, 4	3, 4, 8	3, 4	4
8	Unpredicted/ Heavy rainfall	4, 5, 8	8	8	5

Table 10. Iteration 4

4. Findings and Discussion

Step 4: Developing the diagraph: Based on the levels of the risk elements identified, a diagraph is developed as shown in Figure 2.

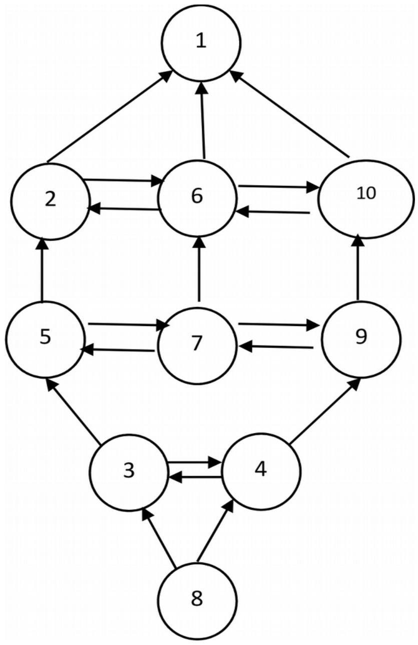

Figure 2. Levels of Cement Manufacturing supply chain risk

Step 5: Developing the ISM model: Finally, the ISM model based on the diagraph is constructed. This is done by replacing the numbers in the diagraph with the risk elements corresponding to that number as shown in Figure 3.

Figure 3 shows the ISM model developed for the supply chain of cement manufacturing firm. It shows that increasing turnaround time is the top level risk in the supply chain of cement. The turnaround time in logistics activities is said to be the most important risk factor that the firm needs to focus upon and try to reduce its impact on the efficiency of the firms supply chain. This turnaround time, that is the time taken by the transport vehicles to transport the finished products to various destination and further to keep ready for the next cycle, is primarily affected by fleet adjustment during heavy demand, coordination risk between buyer and seller and failure of mechanical equipment. During heavy demand, the number of vehicles catering to the customer's requirement is not maintained due to improper fleets adjustments. Further the lack of coordination amongst the buyer and the seller, resulting in the disruption in the supply chain of the cement is seen to increase the turnaround time. The heavy industry like cement manufacturing, where the raw material and the finished products are quite bulky and voluminous, require mechanical equipment for movement and handling. Failure of such mechanical equipment also has shown increase in the turnaround time.

MICMAC analysis helped us understand the driving and dependence power of all variables. So here it was observed that unpredicted heavy rainfall and energy shortage are the major risk in the supply chain of the cement industry. These factors are affecting market demand, uncertainty in material availability, accidents during transportation and fuel price fluctuations. These variables show a high driving power. Increasing turnaround time in logistics has high dependency power so it can be said that this can be a major risk and dependent on other risks.

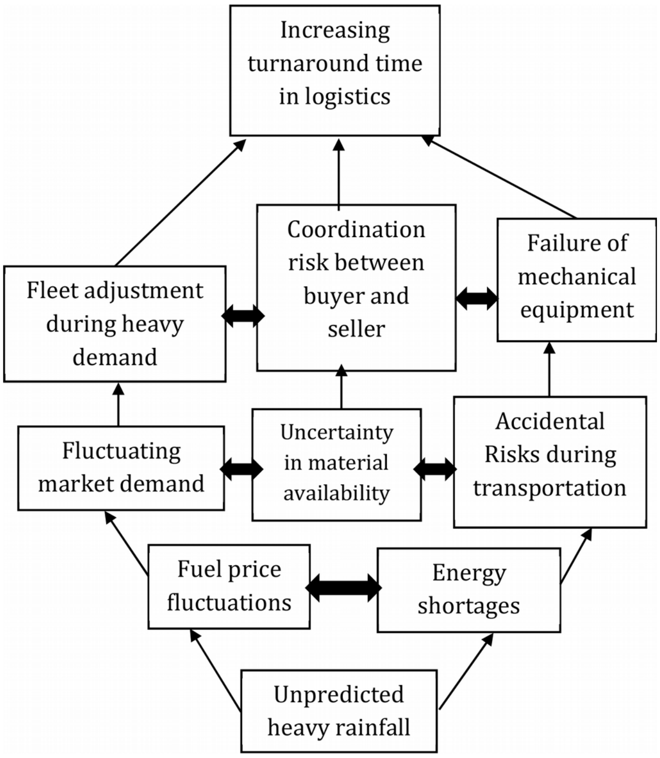

Figure 3. ISM based Supply Chain Model

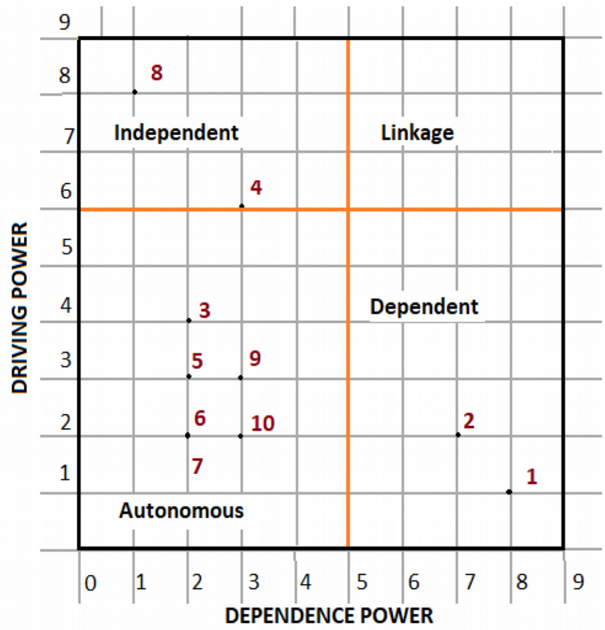

Figure 4. MICMAC analysis for the enablers of Supply Chain risks

Figure 4 shows driver power-dependency power of the risk elements.

- Cluster 1 represents autonomous driver. Autonomous drivers are those enablers that have weak driving and dependence power. They are "fuel price fluctuations", "fluctuating market demand risks", "coordination risk between buyer and sellers", "uncertainty in material availability", "accidental risk in transportation", "failure of mechanical equipment/machine breakdown". These enablers are disconnected and they remain extraneous.

- Cluster 2 represents dependent enablers. These enablers these enablers have weak driving but strong dependence power and are highly related to other enablers and if any action is taken on the influential enablers it will affect these too. they are "fleet adjustment during heavy demand", "Increasing turnaround time in logistics"
- Cluster 3 represents the linkage factors. They have strong driving power and strong dependence power. No factor falls in this category.
- Cluster 4 represents independent enablers that have a strong driving but weak dependence power. Any action taken on these enablers will show the effect on those risk elements which are dependent upon them. They are "unpredicted/ heavy rainfall", "energy shortages".

5. Conclusion

This paper is an attempt to identify various risks in the supply chain of heavy industry, specifically cement manufacturing. This study could support the supply chain decision-makers identify, analyze and access the risks in the system and further identify measures to reduce or mitigate them. The authors identified 19 risks through literature review and industry expert's interaction. FMEA analysis helped the authors to prioritize the risks based on the RPN. 10 major risks were identified which were further put in ISM to identify the interrelationships among these risk variables. MICMAC analysis derived the dependent and independent variables. In consequence, through the application of these well-established methodologies, root causes of the risk factors were identified.

Unpredicted heavy rainfall and energy shortages have been identified as the root causes of other risk elements. Cement, being a heavy load product with low value-to-weight ratio, transportation of the product by trucks over longer distances may not be feasible due to transportation costs or product damage due to water during rainy season. Cement hardens with water which creates a challenge in transportation. Thus, supply chain managers need to identify ways to decrease the impact of rainfall on the cement supply chain. Furthermore, Cement manufacturing is an energy intensive industry. One ton of cement produced involves 60 to 130 kilogram of Heavy fuel or its equal, depending on the variety of cement and the process used for its production. It uses about 105 KWh of electricity. The shortage of energy at global level has further resulted in the fluctuations in the fuel prices. This causes unsynchronized way of machine fuel usage resulting in the gradual increase of WIP and decrease in the efficiency of machines and further machine failure. Increasing turnaround time in logistics and fleet adjustment during heavy demand, having the highest dependence power, are considered as the most important risk elements in the cement industry supply chain. During the peak demand period, increasing turnaround time in logistics may interrupt the infrastructural development activities. Proper fleet management may help the carriers to maximize productivity in the supply chain. Heavy distribution of cement involves a devoted and expensive fleets and dedicated equipment for unloading. Failure of the equipment may further increase the turnaround time.

Thus the prime focus of this study is to develop a framework that reflects the enablers of the supply chain of cement manufacturing through identification of risks and its root causes. The raw material, composition, manufacturing processes, packing and packaging, material handling equipment and other supply chain elements for cement manufacturing and distribution are nearly similar throughout the cement industry. Hence this model can best fit to other cement manufacturing firms equally. Therefore, the supply chain professionals and the strategic players of this industry can rely upon this framework while designing their supply chain models.

There are some limitations in this study. The model developed in the study was an ISM model with only 10 risk elements identified that impacted the supply chain of the cement manufacturing firm. Since the ISM technique cannot accommodate too many variables, only those prioritized by the FMEA technique were used for detailed analysis and other risk elements were omitted. In addition, validation of the ISM model is based on the opinions of the experts selected for the survey. This may create some level of bias and may not reflect the complete scenario of the cement industry supply chain practices. The ISM model suggested the root causes for the probable occurrence of the major risk elements in cement supply chain. This technique does not provide insights into how these root causes be eliminated. This provide scope for further researches to be done to identify techniques to eliminate the impact of the root causes. Packaging solutions for cement transportation can be further studies that can reduce the impact of rainfall on the transportation of cement.

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Appendix A

Suggested FMEA scores criteria

Occurrence	
Score	**Meaning**
1 to 2	Occurrence of the cause of failure is extremely unlikely
3 to 4	Remote (relatively few failures)
5 to 6	Occasional (occasional failures)
7 to 8	Reasonably possible (repeated failures)
9 to 10	Frequent (failure is almost inevitable)
Severity	
Score	**Meaning**
1 to 2	No relevant effect on reliability or safety
3 to 4	Very minor, no damage, no injuries, only results in a maintenance action
5 to 6	Minor, low damage, light injuries (affects very little of the system, noticed by average customer)
7 to 8	Critical (causes a loss of primary function; loss of all safety margins, 1 failure away from a catastrophe, severe damage, severe injuries, max 1 possible death)
9 to 10	Catastrophic (product becomes inoperative; the failure may result in complete unsafe operation and possible multiple deaths)
Detectability	
Score	**Meaning**
1 to 2	Certain – fault will be caught on inspection
3 to 4	Almost certain detection of the cause or the effect
5 to 6	High detection of the cause or the effect
7 to 8	Moderate detection of the cause or the effect
9 to 10	Low detection of the cause or the effect

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