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Risk Management in Ready Mixed Concrete (RMC) Plant by Using FMEA and ANP

Krishna H. Gupta[1]* and Ajay K. Gaikwad[2]

[1]Student, ME (Construction Management), Pimpri Chinchwad College of Engineering, Pune, India
*Corresponding Author E-mail Id: kg1998604@gmail.com

[2]Associate Professor and Guide, Pimpri Chinchwad College of Engineering, Pune, India
E-mail Id: gaikwadajayk@gmail.com

Abstract: Due to technological development, gigantic skyscrapers and mega projects are possible resulting into increased demand of concrete for these projects. In municipal areas, site locations are in congested places where manual mixing is not possible. As Ready Mixed Concrete (RMC) is favoured more as it provides concrete of required quality and of required quantity. The success of RMC industry depends upon proper identification and assessment of risks or failure modes involved in various stages in concrete production. RMC industry is extremely complex in nature which contain many uncertainties resulting into complex risk management methodologies. The main aim of the research is to determine most critical risk that can occur at Ready Mix Concrete (RMC) plant and to provide suggestions to mitigate the most critical risk or failure modes. To achieve this aim, Failure Mode Effect Analysis (FMEA) is used combined with Analytical Network Process (ANP) to access and prioritize the risks involved at RMC plant as six risks resulted into same Risk Priority Number (RPN). Finally, it was concluded that injury at site is most critical risk involved at RMC plant. The research also provides suggestion to mitigate most critical risk.

Keywords: RMC plant, Risk of RMC, Risk management in concrete, Analytical Network Process in RMC, FMEA in RMC management, Critical risks in RMC plant.

I. INTRODUCTION

As per Indian Standard code of practice (IS 4926-2003) Ready Mixed Concrete plant (RMC) is defined as "concrete mixed in a stationary mixer in a central batching and mixing plant as shown in figure 1 or in a truck-mixer and supplied in the fresh condition to the purchaser either at the site or into the purchaser's vehicles" [1-16]. This results in more accurate concrete design of desired strength with proper quality. Due to eco-friendly nature and effective quality control of Ready Mixed Concrete (RMC), it is preferred more than in-situ concrete. The manufacturing of RMC concrete is less time consuming with high customer satisfaction rate as the concrete is produced with good quality and delivered in time. The used of RMC also benefits in reducing space required at site to produce in-situ concrete [15]. The popularity of RMC has increased due to benefits such as reliability, stability, lower cost and its ability of modify design of concrete as per its application in various structural elements.

ISO 31000-2009 defines risks as, "risk is the effect of uncertainty on objectives" [17]. The effect of these uncertainties can be at various aspects of the RMC plant such as financial, safety, health of employee, environmental safety, etc. Concrete is most used construction material in the world [14]. As India is a developing country, the demand of concrete is increasing day by day for infrastructure development. To fulfil the required demand, the popularity of RMC is ever increasing. To improve efficiency of RMC plant, a proper risk management system is essential, to eliminate the risk involved in various stage of RMC production process. The proper identification and assessment of the most critical risk is essential to improve the efficiency of RMC plant, resulting into success of RMC industry and projects. The analysis of the risks or uncertainties can be done qualitatively or quantitatively depending upon the data available and the extent of details available. Qualitative risk assessment process deals with prioritizing the risks and uncertainties according to their severity, occurrence and detection whereas, quantitative risk assessment deals with identifying the frequency of risk occurrence. Methods such as Failure Mode Effect Analysis (FMEA), Monte Carlo simulation (MCS), decision tree analysis, fault tree analysis (FTA), fuzzy logic, etc. can be used to identify and assess risk involved at RMC plants [5].

Figure 1. Ready Mix Concrete Plant

The paper presents use of Failure Mode Effect Analysis (FMEA) to identify and prioritize most critical risks or failure modes involved at RMC plant at also to suggest actions to mitigate those risks. In case of tie breaking situation to identify most critical risks, Analytical Network Process (ANP) is used to prioritize the risks with similar risk priority number. Failure Mode and Effects Analysis (FMEA) is a structured approach to determine potential failures mode that may occur within the design of a product or process [11]. The mode or way in which failure can occur is known as failure modes and effects are the outcome of those failure mode. The main step involved in performing FMEA are identification of risks, analysis of the risks to calculate Risk Priority Number (RPN) and finally to prioritize the risks to identify most critical risk is production process. FMEA should not be considered as replacement to good engineering, but it actually deals with application of knowledge and experiences to access the existing process or design and to improve the process for better efficiency by eliminating most critical risk. In case of tie breaking situations where RPN of more than one risks are equal, Analytical Network Process (ANP) the universal form of Analytical Hierarchy Process (AHP) is used as a multi criterial decision-making tool to prioritize the risks. AHP formulates a decision problem into a hierarchy with a goal, decision criteria, and alternatives, while ANP structure has a built-in feedback network [6]. A pair-wise comparison matrix is used to analyse the collected data by using super decision software to find weighted average of every risk to finally prioritize the risks involved at RMC plant.

The aim of the present work is to identify, analyse and prioritize risks involved in RMC plant in Pune region. The objective are as follows:

1. To identify risks involved in RMC plant.
2. To analyze the risk involved in RMC plant by using Failure Mode Effect Analysis (FMEA).
3. To prioritize the risk involved at RMC plant by using multi criteria decision making tool.
4. To suggest remedial measures for most critical risk.

II. LITERATURE REVIEW

Agnieszka et al. (2015) presented three different methodology of risk analysis. They explained their advantages, dis-advantages and area of application. The 3 methods of which can be used for risk analysis are: 1) multi-criteria decision-making methods, 2) Statistical methods, 3) Sensitivity analysis method [5].

Mohamed et al. (2021) explained than Failure Mode Effect Analysis is a systematic method which can be used for risk identification along with the impact of those risks. The method also provides corrective actions to eliminate those risks. The paper presents application of FMEA methodology for risk assessment and management in construction industry. Fuzzy logic and fuzzy analytical hierarchy process are used to eliminate the limitations of traditional FMEA [1].

Prabhakaran et al. (2016) presented that there is huge awareness in European countries about importance of risk management system. The paper presented a survey data revelling that Indian RMC industry lacks practical risks management methodology. It was also presented that RMC industry in India will not gain creditability unless a proper risk management methodology is adopted which will increase the confidence of customer and improve efficiency of RMC plant [6].

Baheti et al. (2017) applied Failure Mode Effect Analysis (FMEA) to enlist various risk involved at RMC plant Statistical Quality Control also known as SQC charts are used to monitor the quality on concrete produced [7].

Augustine et al. (2019) published a paper. In this paper, major risk factors affecting Ready mix production were assessed and prioritized using Failure Mode Effect Criticality Analysis (FMECA). The most critical risk associated with the RMC was found to be the reduction in compressive strength due to delay in the delivery of concrete [12].

More et al. (2017) presented a research on risk management system by using Failure Mode Effect Analysis (FMEA) methodology to determine most critical risk. It was also stated that, six risks resulted into similar RPN of 48. Finally, some remedial measures have been suggested for the most critical risks in that RMC plant [8].

Zunzunwala et al. (2018) used Fuzzy Logic in MATLAB for effectively managing risks to improve overall process of RMC plant. In this study, a successful attempt is made to merge qualitative analysis of risk and the fuzzy logic tools to identify the risk factors that arise in RMC plants and to prioritize the identified risks [10].

Marcelo et al. (2014) explained the application of discrete event simulation combined with Failure Mode Effect Criticality Analysis (FMECA) to assess risks involved in supply chain of RMC plant. The effect of those risks on was also studies and remedial measure for those risks was presented to reduce the interruptions that occurs due to the risks [4].

Walke et al. (2010) proposed a paper presenting application of Expected Monetary Value (EMV) for risk assessment at RMC plant in India. It is an easy but effective approach for quantification of failure modes and it shall help to achieve the objectives of RMC business in terms of cost of production and supply of RMC [2].

Chen and Luo (2019) studied the application of ANP with other methods for risk prioritization and the ability of ANP to present relation between risks involved. Analytic Network Process (ANP) method is used in the third stage to assess the relative importance of the risk factors to define risk priorities in project [13].

Najwa and Subriadi (2018) presented that lack of information and survey data can provide inconsistent results in FMEA methodology. Limitation of FMEA arises due to lack of sufficient data of product or part, potential failure mode, potential impacts of failure, the potential causes failure, and the design of control. So that, this has led to a misconception, confusion or uncertainty in risk identification [11].

Khan et al. (2017) described use of soft computing such as FMECA hybridized with discrete event simulation to assess risk involved in transportation of concrete from plant to site using transit mixture. The research also said that FMECA provides better result than FMEA as it reduced the limitation of FMEA method. Different mitigation strategies were found based on our findings [9].

Walke et al. (2012) proposed a paper presenting an approach for qualitative analysis of both internal and external risks is RMC plants at various locations in India. Total 133 risks were listed in this paper. An acceptance and rejection criteria are suggested to bifurcate the risks having significant impact on the objectives of companies running RMC plants [3].

Figure 2 shows the evolution of research work since 2010 till 2019. In 2010 researchers wore using Fuzzy AHP and Fuzzy FMEA to analyse the risks in construction project. In 2012 research have been done to find 133 risks involved in RMC plant. In 2017 Statistical Quality control (SQC) with FMEA was used to manage risks in RMC plant. Further in 2017 FMEA and in 2019 FMECA was used to access the risks involved in RMC plant.

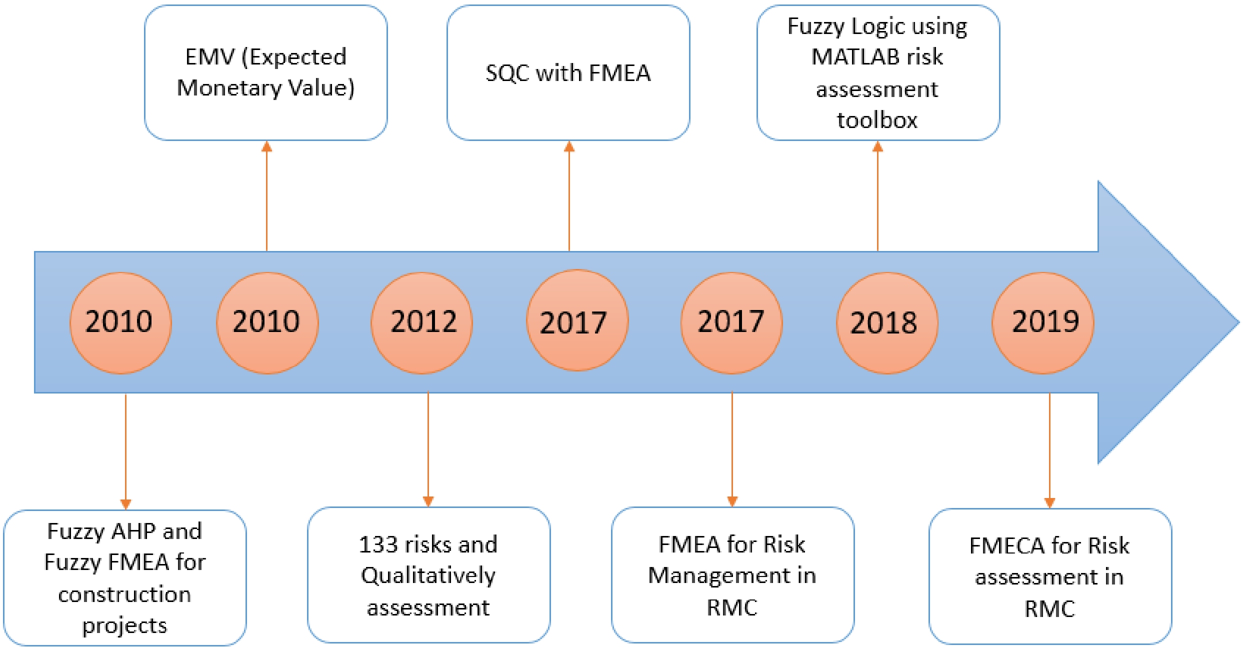

Figure 2. Evolution of research work

III. FAILURE MODE EFFECT ANALYSIS (FMEA)

Failure Mode and Effects Analysis (FMEA) is defined as, "a systematic process for identifying probable design and process failures before they can occur, with the intension to eradicate them or minimize the risk associated with them" [7]. FMEA is a qualitative risk assessment methodology which have a systematic approach to determine risks or failure modes in design stage of process or product. The mode or way in which failure can occur is known as failure modes and effects are the outcome of those failure mode. The main aim of FMEA methodology is identification and assessment of risks before it can occur in any process or production stage. It might also prioritize each failure according to the criticality of a failure effect and its probability of taking [10]. The risk analysis method in FMEA methodology is based on determining risk priority number (RPN) for every failure mode by collecting survey data. The failure mode with high RPN is a high priority risk and by elimination this risk, the efficiency can be improved drastically. There is no threshold value for Risk Priority Number (RPN). The rating factor of RPN mostly consists of severity, occurrence and detection rankings.

The severity, occurrence and detection ranking for calculation of Risk Priority Number (RPN) can be obtained by surveying and primary data sources. The failure mode with high RPN represents most critical risk and failure mode with least RPN represents least critical risks. The major emphasis should be given to eliminate failure modes with most critical risks. The formula to calculate RPN is given below,

$$RPN = Severity*Occurrence*Detection = S*O*D \text{ [4].}$$

Steps to perform Failure Mode Effect Analysis (FMEA)

Figure 3 show a flow chart of steps to perform FMEA:

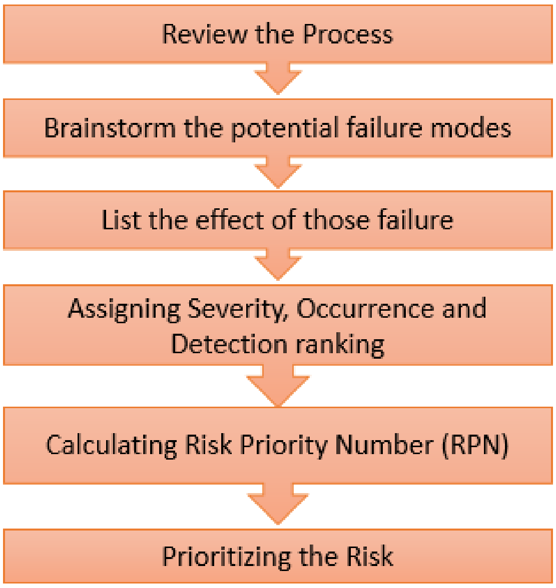

Figure 3. Steps to perform FMEA.

1. Review the process

All RMC plants have similar process, the difference is in capacity of production and type of machinery used. Risk at RMC plant may be found only if we know the actual process at RMC plant. In every step, we may find some risk involved.

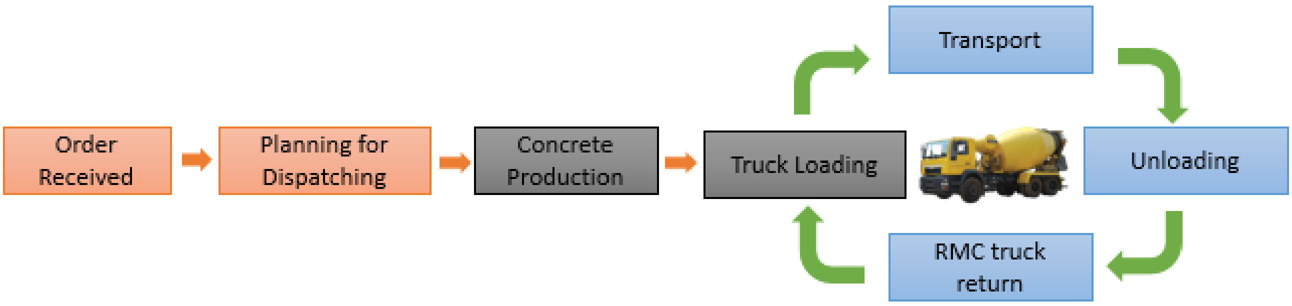

Figure 4. Process involved at RMC plant.

Process at RMC plant may be classified in 3 steps as shown in figure 4:

Step 1: Initially the order is received from the site. Depending on the requirement of each site dispatching schedule is prepared for the next day.

Step 2: As per the planned dispatching schedule, concrete is produced and loaded on transit mixtures.

Step 3: After concrete is loaded, the truck is transported on site. Truck is then unloaded on site and returns on RMC plant. This process continuous.

2. Brainstorming the potential failure modes

The mode by which process, or product can fail is known as failure mode. Risks or failure modes at RMC plant may be classified in 2 types:

A) Internal Risks: Risks occurring within organization and can be controlled by modifying process is known as internal risks.

B) External risks: Risks occurring outside the organization, and which cannot be controlled by any modification is known as external risks. Hence, only internal risks are considered in this research work.

Internal risks arising at RMC plant is further classified into 4 types:

A) Operational Failure
B) Poor Quality of concrete
C) Safety risks
D) Transportation risk

3. Listing effects of those failures:

Figure 5 represents a cause-and-effect diagram to list causes of the internal risk at RMC plant. Cause and effect diagram also known as fish bone diagram is a graphical tool used to represent causes of different failure modes with their effects.

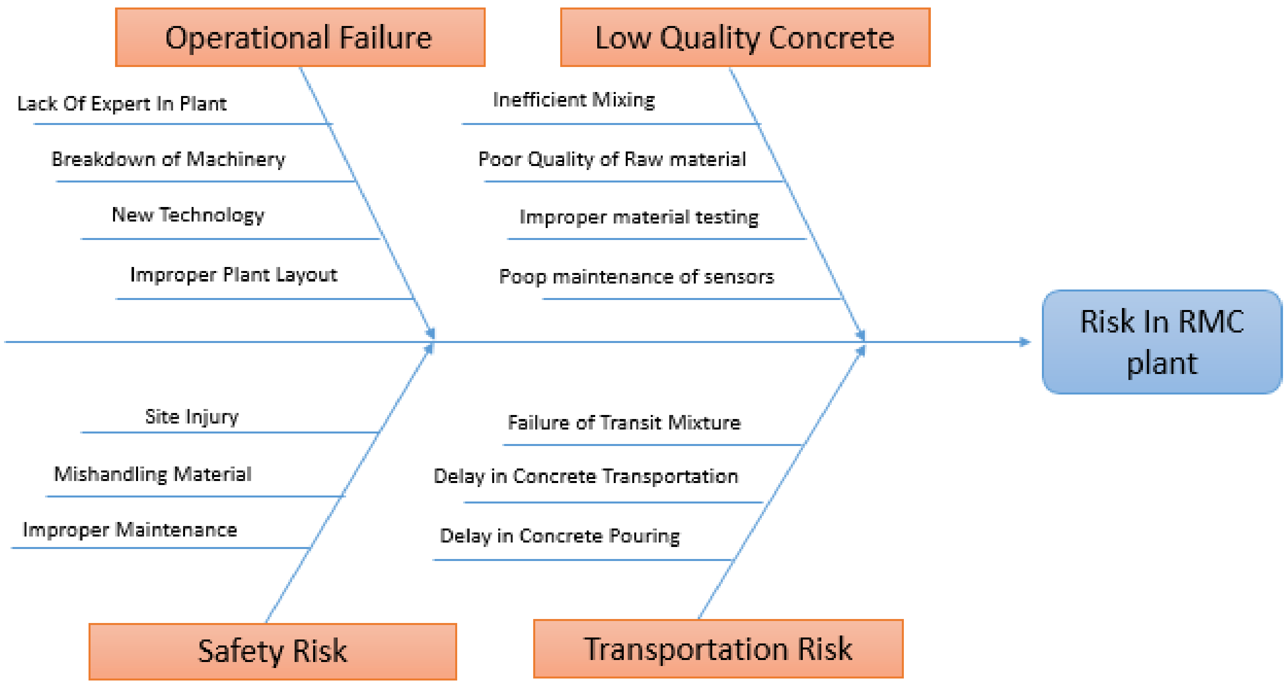

Figure 5. Cause and effect diagram of risk involve at RMC plant.

4. Assigning of severity, occurrence, and detection ranking

After surveying 10 RMC and interviewing the plant engineers, the data of severity, occurrence and detection was collected. FMEA methods gives a scale to give the following rankings. The average of collected data is shown below in Table 1:

Table 1. Average data collected for FMEA.

Sr. No.	Major Failure	Failure Modes	S	O	D
1	Operational Failures	Lack of expert at plant	4	3	4
		Breakdown of machinery	4	3	2
		New innovative technology	3	2	3
		Improper layout of plant	3	2	2
2	Poor Quality of concrete	Ineffective mixing	4	4	2
		Poor raw material	4	2	3
		Improper testing of material	3	3	2
		Inefficient maintenance of sensors	4	2	4
3	Safety risk	Injury at site	4	3	4
		Improper handling of material	2	2	2
		Improper maintenance of plant	4	4	3
4	Transportation Risk	Failure of TM	4	3	4
		Delay in transportation	3	2	4
		Concrete pouring delay	3	3	4

5. Calculation of Risk Priority Number (RPN)

The severity, occurrence and detection ranking for calculation of Risk Priority Number (RPN) can be obtained by surveying and primary data sources. The failure mode with high RPN represents most critical risk and failure mode with least RPN represents least critical risks. The major emphasis should be given to eliminate failure modes with most critical risks. The formula to calculate RPN is given below,

RPN= Severity*Occurrence*Detection = S*O*D [4].

The RPN for risks in RMC plant are shown below in table 2:

Table 2. Risk priority number

Sr. No.	Major Failure	Failure Mode	S	O	D	RPN
1	Operational Failure	Lack of expert at plant	4	3	4	48
		Breakdown of machinery	4	3	2	24
		New innovative technology	3	2	3	18
		Improper layout of plant	3	2	2	12
2	Poor Quality of concrete	Ineffective mixing	4	4	2	32
		Poor raw material	4	2	3	24
		Improper testing of material	3	3	2	18
		Inefficient maintenance of sensors	4	2	4	32
3	Safety risk	Injury at site	4	3	4	48
		Mishandling of material	2	2	2	8
		Improper maintenance of plant	4	4	3	48
4	Transportation Risk	Failure of TM	4	3	4	48
		Delay in transportation	3	2	4	24
		Concrete pouring delay	3	3	4	36

6. Prioritization of risks

After finding of RPN, all the risks are arranged in descending order. Here, there are 4 risks with 48 RPN. So, we cannot prioritize and find the most critical risk.

Table 3. Prioritized risk using FMEA

Sr. No.	Risks	RPN
1	Lack of expert at plant	48
2	Improper maintenance of plant	48
3	Failure of TM	48
4	Injury at site	48
5	Concrete pouring delay	36
6	Ineffective mixing	32
7	Inefficient maintenance of sensors	32
8	Breakdown of machinery	24
9	Poor raw material	24
10	Delay in transportation	24
11	Improper testing of material	18
12	New innovative technology	18
13	Improper layout of plant	12
14	Mishandling of material	8

Table 3 gives Risk priority number of various risks. The risks have been prioritize based on RPN. More the RPN more critical will be the risks.

IV. ANALYTICAL NETWORK PROCESS (ANP)

FMEA results into four failure modes or risks with same RPN of 48 which cannot be used to determine most critical risk at RMC plant. Decision making is an essential part of risk management. In order to make a correct decision, it is necessary to study all the factors affecting the decision-making from all aspects of the problem, whether the factors are political, social, environmental, cultural or psychological [6]. Many values of RPN are same for different risks, which results into difficulty in ranking risks by FMEA methodology. Hence, FMEA is integrated with ANP to find more accurate results and to find the most critical risks. Analytical Network Process (ANP) the universal form of Analytical Hierarchy Process (AHP) which is used as a multi criterial decision-making tool to prioritize the risks. AHP formulates a decision problem into a hierarchy with a goal, decision criteria, and alternatives, while ANP structure has a built-in feedback network [6]. A pair-wise comparison matrix is used to analyze the collected data by using super decision software to find weighted average of every risk to finally prioritize the risks involved at RMC plant.

Steps to perform ANP:

Flowchart in figure 6 shows the step involved in risk prioritization using super decision software. Figure 7 shows the hierarchy framework of the problem statement. After conversion of the results obtained from super decision software in percentage, we get importance factor for each risk. This importance factor can be used to prioritize the risks.

Table 4 shows the importance factor obtained from super decision software. This importance factor is used to rank the risks. Higher the importance factor, more critical the risk will be. Here, we can see that Injury at site is the most critical risk and Improper maintenance of plant is the least critical risk.

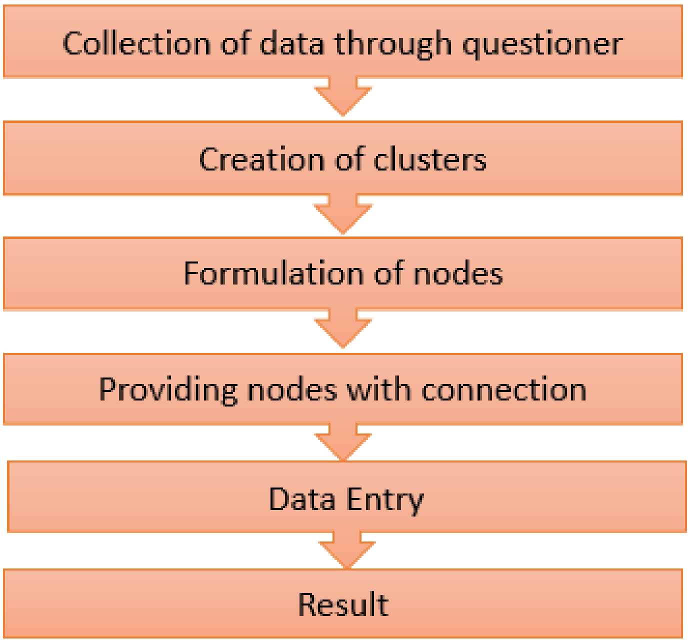

Figure 6. Steps to perform ANP.

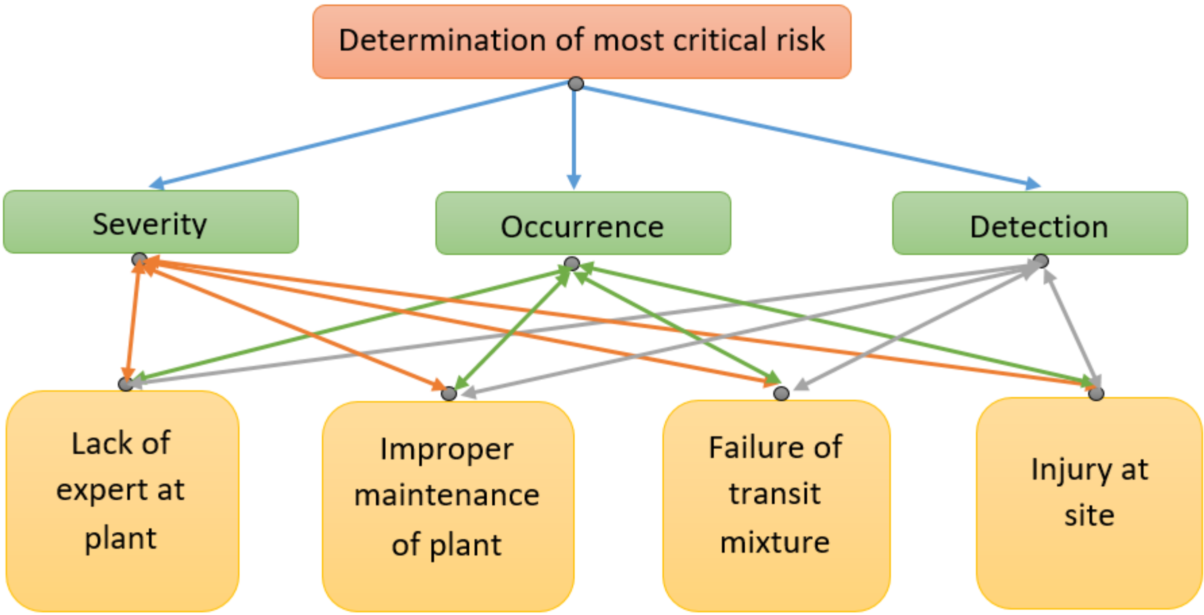

Figure 7. Hierarchy framework

Table 4. Importance factor of most critical risk

Sr. No	Risks	Importance Factor
1	Failure of transit mixture	21.5913
2	Improper maintenance of plant	4.2255
3	Injury at site	64.0583
4	Lack of expert at plant	10.1249

V. RESULTS

Survey was carried in Pune region with 10 RMC plants as sample. In the survey different types of RMC plant was taken as sample. It contained CP 30, CP45, CP 60, H1.25 and CP 90 plants.

Two methods were used for risk assessment and analysis of risks in RMC plant. After calculation, the results were used to prioritize all the risks and find the most critical risk. The result of both the methods are shown below:

Failure Mode Effect Analysis (FMEA)

Table 5 represents the Risk priority number (RPN) obtained after data collection and analysis using FMEA. From figure 8, it can be clearly seen than there are four risks with RPN equals to 48. Hence, we are not able to prioritize the most critical risk involved in RMC plant. So, to solve this problem, ANP is used to prioritize those four risks.

Table 5. Prioritized risk using FMEA

Sr. No.	Risks	RPN
1	Lack of expert at plant	48
2	Improper maintenance of plant	48
3	Failure of TM	48
4	Injury at site	48
5	Concrete pouring delay	36
6	Ineffective mixing	32
7	Inefficient maintenance of sensors	32
8	Breakdown of machinery	24
9	Poor raw material	24
10	Delay in transportation	24
11	Improper testing of material	18
12	New innovative technology	18
13	Improper layout of plant	12
14	Mishandling of material	8

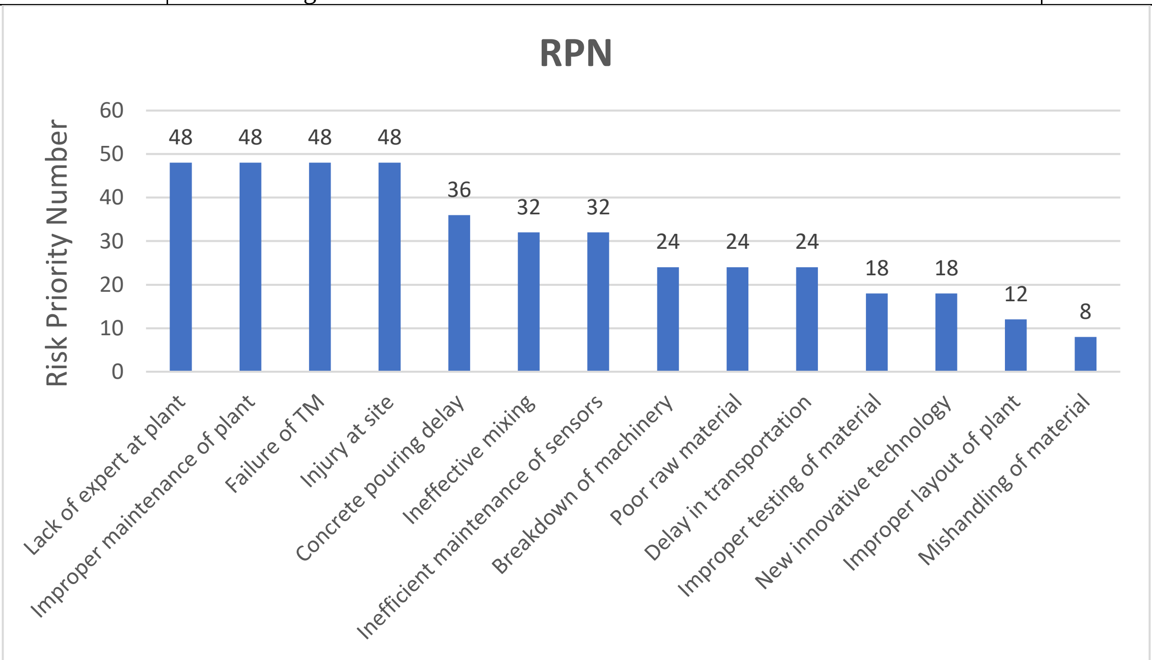

Figure 8. Graph representing RPN.

Analytical Network Process (ANP)

As RPN obtained after performing FMEA did not give a clear picture about most critical risk, ANP was used to prioritize the risks. As seen in the figure 9 we can conclude that the data can be easily prioritized. Here, we can see that injury at site is the most critical risk out of the four most critical risks. Table 6 shows the importance factor obtained from super decision software after performing ANP.

Table 6. Importance factor of risk

Sr. No	**Risks**	**Importance Factor**
1	Failure of transit mixture	21.5913
2	Improper maintenance of plant	4.2255
3	Injury at site	64.0583
4	Lack of expert at plant	10.1249

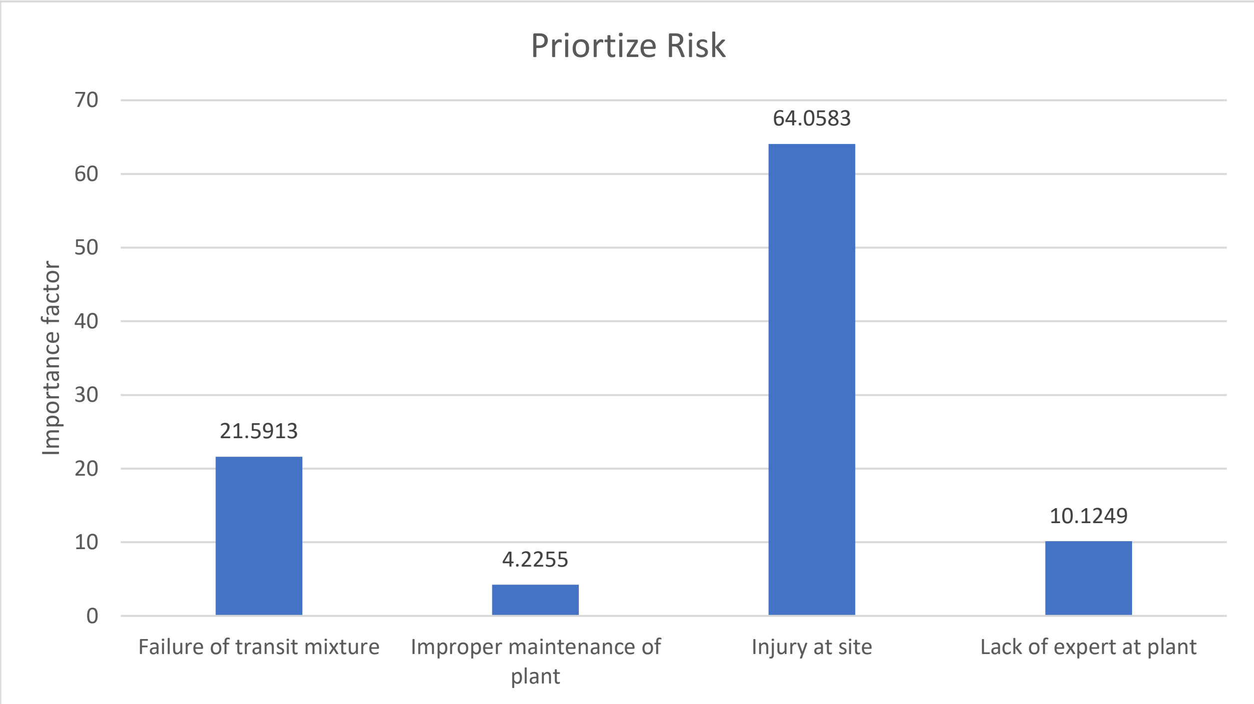

Figure 9. Graph of importance factor

VI. CONCLUSION

After doing rigorous study on risk management at 10 RMC plants in Pune region, we found that,

- There are four major failure modes found with fourteen risks.
- Analytical Network Process (ANP) found more effective than Failure Mode Effect Analysis (FMEA) for risk prioritization.
- Fourteen risks identified and prioritize based on data from table 5 and table 6 using FMEA and ANP shows effectiveness of ANP over FMEA. The list of prioritized risk at RMC plant are as follows:

  1. Injury at site
  2. Failure of TM

3. Lack of expert at plant
4. Improper maintenance of plant
5. Concrete pouring delay
6. Ineffective mixing
7. Inefficient maintenance of sensors
8. Breakdown of machinery
9. Poor raw material
10. Delay in transportation
11. Improper testing of material
12. New innovative technology
13. Improper layout of plant
14. Mishandling of material

- The most critical risk is “Injury at site” and the least critical risk is “Mishandling of material”.
- Suggestion for remedial measure of most critical risk are:

a) Provision of proper training of driving, first aid, firefighting, concrete pumping, material handling, etc. can reduce injury at site.
b) Provision of proper maintained and good quality of equipment’s to workers.
c) Use of proper engineering control over use of Personal Protective Equipment (PPEs) in RMC plant area.

VII. FUTURE SCOPE

Followings are the future scope of this project:

1. More sites can be surveyed to get more accurate results.
2. “Six Sigma” technique can be used to find remedial measure for the most critical risk.
3. Region wise the risks can change, so similar technique can be used to find Risks at RMC plant for other regions.

Conflict of interest: The authors declare that they have no conflict of interest.

Ethical statement: The authors declare that they have followed ethical responsibilities.

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