# IMPORTANCE OF FAILURE MODES AND EFFECT ANALYSIS APPLICATION FOR RISK ANALYSIS IN BARAPUKURIA COAL MINE, BANGLADESH

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## ABSTRACT
Because of the complex working situations, mining is known for being one of the most hazardous industries in the world. The working activities in such risky conditions in the underground coal mine often leads to many types of accidents. The working condition of Barapukuria Coal Mine (BCM) which is a producing underground coal mine in the North-western part of Bangladesh, has become insecure due to the lack of practising appropriate plan and methodology for reducing risk.Therefore, this study aims to assess the potential hazards by failure modes and effect analysis (FMEA) method in BCM. FMEA is a quality management tool often used to identify possible failure mode by calculating a risk priority number (RPN) from severity, occurrence, and detection scores. A noteworthy aspect in FMEA is the estimation of RPN to prioritize failure modes. In this phase, a quality point scale (1-10) is typically used to measure the three facets of a failure mode's risks, and it indicates that the higher the score, the greater the chance of accidents. We have studied some accidents data in BCM it indicates that roof fall is more hazardous compared to other accidents. With the help of FMEA method, we have assessed causes and effects of accidents and finally recommended actions to reduce hazards. Therefore, an integrated approach is a burning necessity that can predict the risk before the actual mishaps and the FMEA can be a handy solution in this case as it is a robust tool for identifying multi-horizon risks and mitigating threats that can be strengthened further.

**Keywords:** Accidents, BCM, FMEA, Mitigating threats, RPN, Bangladesh.

## INTRODUCTION
In northwest Bangladesh, the Barapukuria coal mine (BCM) is the first developed ongoing coal mine in the country which is located at the stable platform of Bengal Basin and having the largest reserved bituminous coal layer covering an area of 6.68 $km^2$ (BCMCL, 2012). From a gross stockpile of about 390 million tons of coal, nearly 64 million tons are extractable, which is categorized as seams Ⅰ to Ⅵ and the thickest one is seam Ⅵ (nearly 36m) which contains 90% of total coal reserved (Wardell, 1991; Imam, 2013). With technical and financial assistance from China, the BCM began production of underground coal in 2005, following an agreement with China National Machinery Import and Export Corporation (CMC) to produce 1 million tons/year over a 25-year mine life in 1994 (Kibria et al., 2012).
However, during the production time, several failures and issues occurred in BCM, including the release of toxic gases such as carbon monoxide (CO) reaching up to 6000 ppm during the development of the 1110 longwall face, as well as various underground and surface mishaps that led to injuries and death of many mine workers, employees and land subsidence of surrounding areas (BCMCL, 2011; Hoshour, 2011). Additionally, the Barapukuria coalpit is impacted by a dynamic relationship of convergence-related tectonic processes between the continental Indian plate and the continental Eurasian plate since it is a strongly deformed basin (Islam and Hayashi, 2008; Islam et al., 2009). It was reported that underground coal mining is one of the most unsafe practices on the earth and is prone to miscellaneous accidents (Javadi et al., 2017).

The risks of accidents are analyzed using the severity of mine accidents. Despite the great variability and complexity, many scientists around the world have studied accidents in coal mines around the world using a variety of techniques, including failure mode and effects analysis (FMEA), the bayesian network-based model (BN), multi-criteria decision-making (MCDM), multi-dimensional statistical analysis and others. Subsidence risk and tunnel stability analysis were predicted by using FMEA with an artificial neural network and fuzzy inference system (Rafie et al., 2015).

In addition, after scrutinizing 10 years of accident data by multi-dimensional statistical analysis, it was found that human factors contributed the majority (about 94.09%) to the mine accidents (Chen et al., 2012). Moreover, roof falls were found to be the most critical accidents in mines, obtained by analyzing them using a Bayesian network-based model (BN) and a fuzzy TOPSIS model for risk ranking in the Tabas coal mine, Iran (Javadi et al., 2017). Furthermore, (Ahamed et al., 2016) evaluated the continuous combustion risk by proximate analyses of inherent and total moisture contents in BCM. Boundary element method (BEM) numerical modelling was adopted to evaluate mining-induced fault reactivation associated with the main roadway of the Barapukuria coal mine (Islam and Shinjo, 2009). By developing profile functions and influence functions, the pattern and depth of subsidence in BCM was investigated (Howladar and Hasan, 2014).

However, to our best knowledge, none of the studies utilized the FMEA method for risk analysis in the BCM. The FMEA is an assorted risk analysis tools, which was formally introduced by the US armed forces in the late 1940s. It was used as a modelling tool for the aerospace industry in the 1960s, with its apparent durability and safety requirements (Sharma and Srivastava, 2018). FMEA is a pessimistic prevention approach that can be conveniently interfaced with several engineering and reliability approaches to assess risks in the decision-making process (Tay and Lim, 2006). In this method, each provider is assessed using a similar multi-criteria methodology, risks are viewed as potential variations from predicted results, and they are represented as failure modes in risk analysis (Li and Zeng, 2016). A noteworthy aspect in FMEA is the estimation of risk priority numbers (RPN) to prioritize failure modes. In this phase, a 10-point scale is typically used to assess three facets of a failure mode's risks, for example, probability, severity, and control and the higher the score, the greater the chance of accidents (Li and Zeng, 2016).

Cost reduction with decisive effects on the guarantee return, shortening of the time from the project phase to the market launch as well as improvement of the quality and reliability of the products, while increasing the operational safety is the supremacy of using the FMEA approach (Sharma and Srivastava, 2018).

Although the BCM is economically a huge potential for the country, it has been facing a declining production rate for quite a few years. Many scholars have been investigating the risk of numerous accidents, most of them being post-accident analysis. Therefore, an integrated approach is a burning necessity that can predict the risk before the actual mishaps and the FMEA can be a handy solution in this case as it is a robust tool for identifying multi-horizon risks and mitigating threats that can be strengthened further. Besides, the FMEA has been applied in diverse industrial sectors and the present study is the first approach to be implemented in BCM.

## ACCIDENTS OCCURR IN BCM

Unsafe conditions and poor mining practices occur in a slew of mishaps in underground coal mines resulting human deaths and injuries, property damages, production interruptions etc. The common causes of accidents in BCM are roof fall, subsidence, water inrush, mechanical, spontaneous combustion, electrical, poisonous gas emission, temperature & humidity, and so on. During production period, there have been happened various accidents and troubles within BCM shown in table 01. Some miners were seriously injured or died as a result of roof collapse, poisonous gas, and extremely high temperatures and humidity in the faces 1105 and 1108, respectively (Monir & Hossain, 2013). For example, In 2005, a severe water inrush in the BCM's central district caused coal production to halt for several days.

Table 01: Hazard occur in BCM and their consequences (Annual Report 2011-2012)

| **Year** | **Hazard** | **Consequence** |
|---|---|---|
| 2005 | Warer inrush, Poisonous gas emission, Temperature & humidity | Production shut down & equipment loss (1500 m$) |
| 2006 | Roof fall, Subsidence | One died |
| 2007 | Temperature & humidity, Water inrush | One died |
| 2008 | Mechanical, Electrical | One died |
| 2009 | Roof fall | One worker severely injured |
| 2010 | Roof fall and coal bump | One died & 18 workers injured |

## MATERIALS AND METHODOLOGY

This is a descriptive survey that was carried out in BCM. In this study, analyzed the risks that occurred in various areas of the mine using FMEA method. For analysis, using an example FMEA worksheets extracted from the reference. Thus, we are able to obtain failure modes with various components and failure effects in quantity using RPN equation. Finally, we discussed the system's benefits..

## SYSTEM AND PROCESS DESCRIPTION

Risks associated with activities is analyzed in depth after collecting and analyzing different hazard data in BCM as well as likelihood, severity, and occurrence were quantitatively observed. Moreover, the risk associated with each operation is determined, as well as the control steps. At the end of this study, we will display tables major hazards identified in BCM with risk probability, risk severity, frequency of exposure and control measures.

The following is a summary (Oraee, 2011) of the standard FMEA process:

1) Establish severity, occurrence, and detect table scale,
2) Observes the purpose, intention, aim, and objective process,
3) Define potential failures of the process,
4) Assess failures to other components, processes, personnel and government regulations,
5) Find out potential main cause of potential failures,
6) Method/procedure at the first stage for detecting process failures,
7) Severity rating: assign a severity level to the impact of the potential failures,
8) Occurrence rating: assessment of failure frequency for a possible reason,
9) Detect rating: Process control's probability of detecting a particular root problem of a failure,

10) RPN estimation: severity, occurrence, detect, and product of the three inputs rating,
11) Correction,
12) Finish.

| System Name:<br>Problem/Subsystem:<br>Core Team:<br>Prepared by: | | | | | | | FMEA No:<br>FMEA Date: | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Process Function or Step | Potential Failure Mode | Potential Failure Effects | SEVERITY | OCCURRENCE | DETECTION | RPN | Action Recommended | Taken Actions | SEVERITY | OCCURRENCE | DETECTION | RPN |
| | | | | | | | | | | | | |
| | | | | | | | | | | | | |

Figure 1: Example of FMEA worksheet framework for BCM

## POTENTIAL FAILURE MODE

It's known as a component, subsystem, or system that could potentially fail to meet the design purpose being investigated. It can either be the reason of a potential failure mode in a higher level subsystem, or system, or result of one lower level element (Kumar, 2012). Failure mechanism defects in requirements, design, process, quality control, handling or part application which are the underlying causes of initiative process that leads to a failure mode over a certain time. Each possible failure mode for the item and its work should be recorded.

## POTENTIAL FAILURE EFFECTS OR CONSEQUENCES

It is described as the effects of the failure mode on functions, and it should be based on evaluations or analysis of the system's responses after failure (Kumar, 2012). In addition, Failure effects have immediate consequences of a failure on operation that should be interacted by the system but now is not, or not entirely, fulfilled. It is actually applied to the next higher total system .

## SEVERITY

Severity is a scale that measures how much impact on seriousness of a potential failure mode. Severity or seriousness is only depending on the effects of event and the risk severity can likely be mitigated by changing method and the manner conducting actions (Ebrahemzadih et al., 2014). Severity ranking is measured the impact of the effect caused by the failure mode is shown in Table 1.

Table 02: Severity criteria for FMEA (Oraee, 2011)

| Severity of failure | | |
|---|---|---|
| **Rating** | **Effect** | **Severity of effect** |
| 10 | Hazardous without warning | Very high severity ranking when a potential failure mode effects safe system operation without warning |
| 9 | Hazardous with warning | Very high severity ranking when a potential failure mode effects safe system operation with warning |
| 8 | Very high | System unworkable with destroying failure without compromising safety |
| 7 | High | System inoperable with equipment damage |
| 6 | Moderate | System unusable with minor damage |
| 5 | Low | System inoperable without damage |
| 4 | Very low | System operable with significant degradation of performance |
| 3 | Minor | System operable with some decrease of performance |
| 2 | Very minor | System operable with minimal interference |
| 1 | None | No effect |

## OCCURRENCE

Occurrence estimates the frequency in which possible risks will occur in a particular situation or process. The probability of failure is used to prioritize the occurrence which reflects the expected number of failures over the life of the operation (Kumar, 2012). Probability score is compared to possibility that the result occurred by failure mode is presented in Table 2.

Table 2: Occurrence measure for FMEA (Kumar, 2012)

| Occurrence of a Failure | | |
|---|---|---|
| **Probability of Occurrence** | **Failure** | **Rating** |
| **Very High:** Almost impossible to avoid failure | >1 in 2 | 10 |
| | 1 in 3 | 9 |
| **High:** Repeated Failures, Process that have frequently failed | 1 in 8 | 8 |
| | 1 in 20 | 7 |
| **Moderate:** Occasional Failures, but not in significant amounts | 1 in 80 | 6 |
| | 1 in 400 | 5 |
| | 1 in 2,000 | 4 |
| **Low:** Relatively few Failures, Isolated failures linked to the same processes | 1 in 15,000 | 3 |
| | 1 in 150,000 | 2 |
| **Remote:** Failure is improbable. | <1 in 1,500,000 | 1 |

## DETECTION

Detection possibility is a evaluation which has ability to determine the causes of risk occurrence. Before the probability of the failure, it has an effect on the process or system being evaluated (Ebrahemzadih et al., 2014). The detectability score is compared to the ability of control the failure mode's impact is displayed in Table 3

Table 3: Detectability standard for FMEA(Oraee, 2011)

| Detection of failure | | |
|---|---|---|
| **Rating** | **Detection** | **Likelihood of detection** |
| 10 | Absolute uncertainty | Undetected, cannot detect potential cause and subsequent failure mode |
| 9 | Very remote | Very remote chance to detect potential cause and subsequent failure mode |
| 8 | Remote | Remote chance to detect potential cause and subsequent failure mode |
| 7 | Very low | Very low chance to detect potential cause and subsequent failure mode |
| 6 | Low | Low chance the design control will detect potential cause and subsequentfailure mode |
| 5 | Moderate | Moderate chance to detect potential cause and subsequent failure mode |
| 4 | Moderately high | Moderately high chance to detect potential cause and subsequent failure mode |
| 3 | High | High chance to detect potential cause and subsequent failure mode |
| 2 | Very high | Very high chance to detect potential cause and subsequent failure mode |
| 1 | Almost certain | Certainly, detect potential cause and subsequent failure mode |

## RISK PRIORITY NUMBER (RPN) METHODOLOGY

In decision making processes, RPN methodology is used both RPN scoring and crisis level. The RPN is a mathematical equation that combines severity, frequency and detection. The number is used to identify the most serious failure mode, which leads to remedial action. RPN rating system focused that the higher risk priority number, the more attention on risk. RPN is obtained by multiplying three factors, which are the severity of the failure(S), the probability of occurrence(O), and the probability of detection(D) (Ebrahemzadih et al., 2014). It is calculated using Equation (1).

$$RPN = \text{Severity (S)} \times \text{Occurrence (O)} \times \text{Detection (D)} \quad \textbf{(1)}$$

RPN is used to assess the level of risk associated with a component or procedure. It is also used to measure risk in order to identify failure modes. RPN offers guidance for ranking potential failures and what steps can be taken to reduce severity or occurrence by changing design or procedure (Kumar, 2012).

## ADVANTAGES OF FMEA

FMEA is a systematic method, which is applied (Ebrahemzadih et al., 2014; Kumar, 2012) because of the following reasons

- To recognize and prioritize possible failure modes in a system, product, process, or service;
- Identifying and implementing steps to eliminate or minimize the incidences of possible failure modes;
- To keep analysis results in order to provide a comprehensive guide for solving future issues and problems.
- Accept a high level of complication;
- Danger can be quantified in a consistent manner;
- Results can be correlated directly with actual risks;
- Impact of various risk mitigation/detection approaches can be easily modeled;
- Provides a well-documented record of changes made as a result of corrective steps taken;
- Provides knowledge that can be used to establish test programs and standards for in-line control;
- Provides historical data useful in analyzing potential product failures during the manufacturing; process
- Provides new suggestions for how to change existing designs or procedures

## RESULTS AND DISCUSSION

Analysis of different accidents according to their causes, effects and controls which have been occurred in BCM production periods. This is usually achieved by geologist or geotechnical engineer's critical study in the area of mine. The major hazards in BCM that can be identified during different mining operations and their Failures and controls are depicted in Table 4.

Table 4: Major hazards identified in BCM with Failures and Controls(Monir & Hossain, 2013; PWC, 2013)

| Hazards | Potential causes | Potential consequences | Action Recommended |
|---|---|---|---|
| Roof fall | Geological setting and geotechnical status, Inadequate support system, Collapse of pillar. | Collapsed roadway, Damage machineries and personnel's, Death workers. | Proper supporting systems, Monitoring strata pressure regularly through EED, systematic support rule (SSR) formulated and imposed. |
| Subsidence | Underlying goaf and barriers, Longwall mining method, Working depth in mine, Nature of roof. | Goaf area originated, Collapse of mine, Disrupt ground water table, Damage agricultural land, houses and factories. | Improving mine design using long-wall retreating mining method, Applying Hydraulic Sand Stowing (HSS) filling method, Regular subsidence monitoring and treatment. |
| Water inrush | Adjacent UDT aquifer sources,Water seepage into mine, Faults in the mining area. | Shutdown of production, Water seeping into mine workings, Loss of men and equipment | Controlled by regular pumping, Monitoring fissures and faults, Timely reporting by hydrogeology section, Water volume monitors using preset alarm. |
| Mechanical | Installed heavy equipment, Brakes fail, Unawareness driving, Defective equipment. | Increased temperature in mine, Equipment jams, Collapse roadway. | Equipment and brake maintenance, Aware of the mine working, Regular maintenance. |
| Spontaneous combustion | Intrinsic and Extrinsic properties of coal. | Production operations sealed off, Endangering lives and properties, Polluted mine environment. | Worked out panels sealed properly, R&D efforts initiated in the mine level, Storage height not more than 7m, Avoiding fire occurrence using pro-active inertization. |
| Electrical | Wet working conditions, Defective equipment, Earthing system damaged. | Electric shock and/or burn, Fire arising from electric defects, Ignition of firedamp or coal dust. | Inspect equipment regularly, Checking earthing point regularly, Use of Personal Protective Equipment. |
| Poisonous gas emission | Spontaneous combustion, Poorly controlled Ventilation system, Mine fires. | Failing of cooling system, Oxygen deficiency, CO and $CH_4$ emissions. | Sealed goaf area, Heat control procedure, Airborne respirable dust (ARD) monitoring, Developing borehole gas survey. |
| Temperature & humidity | Geothermic gradient, Mining equipment, Auto-oxidation of coal and carbonaceous matter, Mine water thermal influx, High temperature of surface air. | Heat stroke, Ventilation system damaged, shut down production. | Heat Reduction, Allowing optimum quantity of air in longwall panels, Channelized water percolated intake airways, Air cooling system installed in the panels. |

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## CONCLUSION

Systematic safety management is first and foremost to avoid potential accidents and progress safety in industrial processes. Proper safety managements save miners as well as increase production, paying attention is for maintaining friendly working environment in mine. FMEA is a methodology for identifying and eliminating known or possible failures in complex systems to improve their reliability and safety. It is also designed to give guidance for risk management decisions. The RPN results will provide guidelines for ranking possible failures, and it is simple to recognize or suggest the appropriate steps for design or process to reduce severity or occurrence. In addition, conducting regular inspections and preventive measures can help reduce the chances of BCM accidents and their effects. Moreover, accidents analysis in BCM shows that roof fall accident more hazardous than others which have been occurred several times in mine. By using FMEA method, we can evaluate causes and effects of accidents as well as useful recommendations to reduce hazards in the mine. Thus, present findings showed that FMEA help prioritize and facilitate the performance of risk-reduction strategies, as well as identify and manage possible workplace hazards, when compared to other risk assessment approaches.

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