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INTEGRATED SAFETY ANALYSIS OF COAL MINE ACCIDENTS USING FMEA AND FTA APPROACHES (2016–2022)

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ABSTRACT
Coal mining remains one of the most hazardous industries globally. This paper aims to analyze fatal and serious accidents in Indian coal mines from 2016 to 2022 using Failure Mode and Effects Analysis (FMEA) and Fault Tree Analysis (FTA). Drawing on the Directorate General of Mines Safety's (DGMS) "SANKET" dataset, we identify key failure modes, assess risks using FMEA, and construct fault trees for selected high-risk accident categories to understand root causes. The study concludes with actionable recommendations to enhance mine safety systems through targeted interventions.

Keywords: FMEA, FTA, COAL, MINE

I. Introduction
The coal mining sector in India, while essential to energy needs, poses substantial occupational hazards. Despite regulatory mechanisms by the DGMS, accidents—especially fatal and serious—continue to occur. Applying structured safety analysis techniques such as FMEA and FTA enables proactive identification of risks and causal chains, thereby offering pathways for mitigation.

2. Methodology
Two complementary safety analysis tools were used:

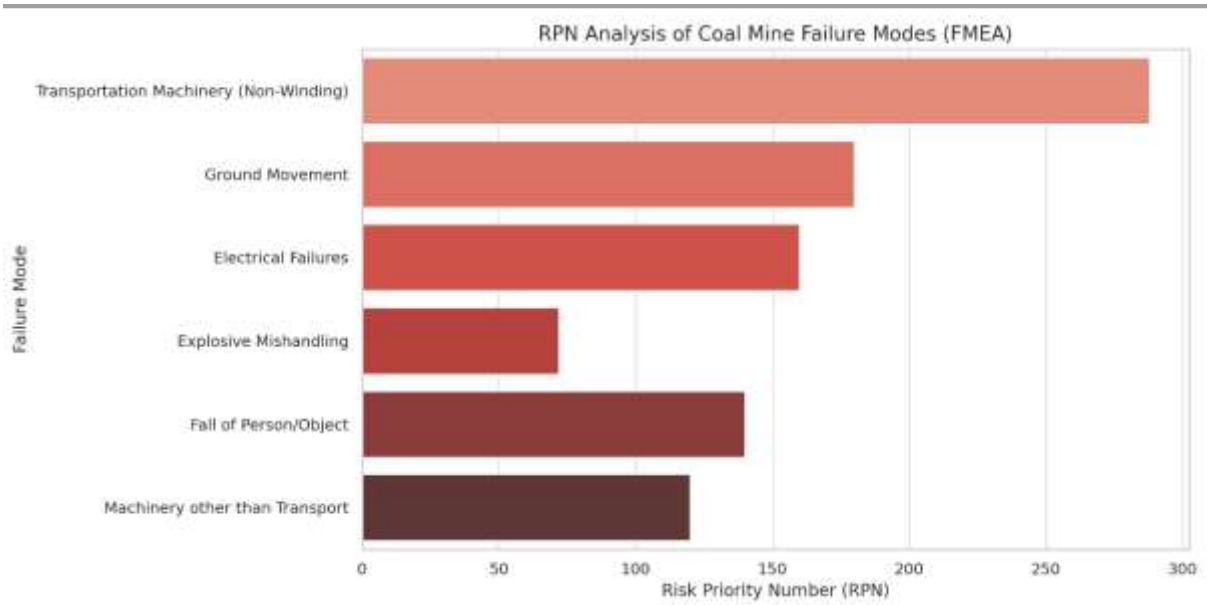
- **FMEA** was applied to categorize failure modes, determine risk priority numbers (RPN), and suggest control measures.
- **FTA** was used to trace root causes of high-severity accidents through logical backward analysis.

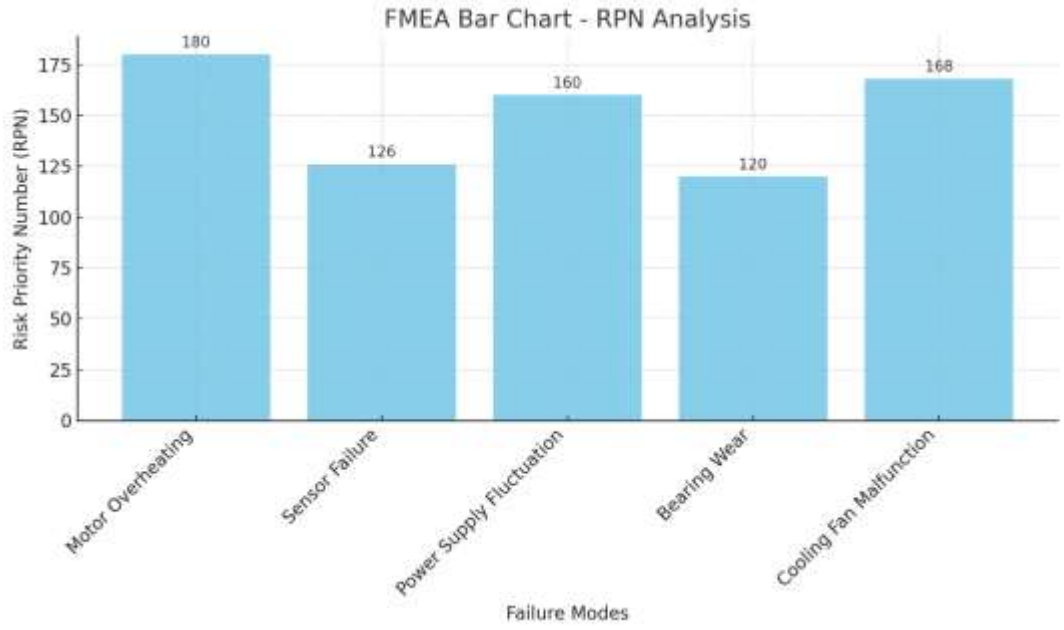
3. FMEA of Coal Mine Accidents (2016–2022)

Failure Mode	Effects	Severity (S)	Occurrence (O)	Detection (D)	RPN (S×O×D)	Suggested Action
Failure of Transportation Machinery (Non-Winding)	Fatality due to collision or overturn	9	8	4	288	Install advanced telemetry, periodic training
Ground Movement	Crushed workers	10	6	3	180	Improved support

Failure Mode	Effects	Severity (S)	Occurrence (O)	Detection (D)	RPN (S×O×D)	Suggested Action
(Fall of Roof/Sides)						systems, seismic monitoring
Electrical Failures	Fire, electrocution	8	4	5	160	Circuit protection, PPE, maintenance
Explosive Mishandling	Blast injuries	9	2	4	72	Strict SOPs, licensed handlers only
Fall of Person/Object	Head/spine injuries	7	5	4	140	PPE, better workplace layout
Machinery other than Transport	Limb injuries, entrapment	8	5	3	120	Safety interlocks, guards

Top RPN Identified: Transportation Machinery (Non-Winding) due to both severity and frequency.





4. FTA: Case Study on "Transportation Machinery (Non-Winding)" Accidents

Top Event: Fatality in Opencast Mine due to vehicle collision

Fault Tree Breakdown:

- **Top Event:** Worker Fatality
  - →**Event A:** Vehicle collision
    - → A1: Brake failure
    - → A2: Operator fatigue
    - → A3: Inadequate signaling
  - →**Event B:** Worker not in designated zone
    - → B1: Poor signage
    - → B2: Lack of training
  - →**Event C:** Absence of proximity sensors
    - → C1: Cost-saving measure
    - → C2: Unavailability of technology

Root Causes Identified:

- Poor equipment maintenance
- Inadequate operational protocols
- Training gaps
- Systemic safety culture weakness

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5. Discussion

- **Trend Insights from SANKET:** Opencast mines report the majority of accidents (~50%), with "Transportation Machinery" and "Ground Movement" leading causes.
- **FMEA Results:** Confirmed high RPN in transportation and fall-based incidents.
- **FTA Results:** Provided deep insight into organizational and technical root causes behind specific fatal events.

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6. Recommendations

1. **Technical Interventions**
   - Introduce fail-safe braking systems and fatigue monitoring in heavy machinery.
   - Digitally monitor worker presence in danger zones.
2. **Training and Culture**
   - Comprehensive operator training and recurring drills.
   - Embed safety awareness into work culture using behavior-based safety models.
3. **Policy Measures**
   - Mandatory FMEA reviews for all new equipment.
   - FTA as a legal requirement post-fatality analysis.

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7. Conclusion

Applying FMEA and FTA to coal mine safety data reveals critical gaps in operational safety and system-level vulnerabilities. Structured analysis tools like these not only quantify risk but guide systemic safety improvements. Adoption of these methods across DGMS protocols can significantly contribute to the vision of "Zero Harm" in mining.

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