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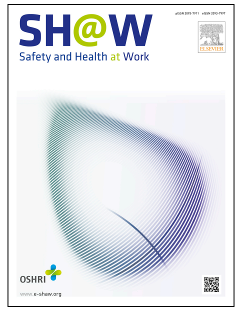

Safety of Workers in Indian Mines: Study, Analysis and Prediction

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Safety of Workers in Indian Mines: Study, Analysis and Prediction

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Abstract

Background: Mining industry is known worldwide for highly risky and hazardous working environment. Technological advancement in ore extraction techniques, for proliferation of production levels has further enhanced concern towards safety for this industry. Research so far in the area of safety has revealed that majority of incidence in hazardous industry takes place because of human error, which if can be controlled then safety levels in working sites can be enhanced to considerable extent.

Method: Present work focuses upon analysis of human factors like unsafe acts, preconditions for unsafe acts, unsafe leadership, organizational influences, adopting modified *Human Factor Analysis and Classification System (HFACS)* and an accident predictive Fuzzy Reasoning Approach (FRA) based system is developed which can predict chances for occurrence of accidents with analysis of factors like age, experience of worker, shift of work etc., for manganese mines in India.

Results: The outcome of analysis indicated that *skill based errors* are most critical and requires immediate attention for mitigation. FRA based accident prediction system developed gives outcome as indicative risk score associated with identified accident prone situation, based upon which a suitable plan for mitigation can be developed.

Conclusion: Unsafe acts of the worker are most critical human factor identified to be controlled on priority basis. Significant association of the factors namely age, experience of the worker and shift of work with unsafe acts performed by the operator is identified based upon which FRA based accident prediction model is proposed.

Key words: FRA, HFACS, mining safety, risk assessment

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1. Introduction

Mining industry exists with well recognized fact of having most arduous working environment where safety and health of the worker engaged is always a prime concern. Mining safety has always drawn attention of researchers working in the field of health and safety. The metal and mining industry of India has recorded a strong expansion in the recent past with expectation of India to become the second-largest steel producer later 2015. Production volumes have also grown steadily over the years - during the period 2007-2015 [1-8]. Therefore manganese mining and sudden enhancement in its production levels have germinated increased concern with safety scenarios in mines. Nevertheless, adverse working conditions and technological advancements cannot solely be blamed for incidences taking place in the working sites. Patterson [9] conducted study in Queensland, considering accident data for quarry, open cut coal mines, underground coal mines, open cut metal mines and underground metal mines and revealed that irrespective of the mine type skill based errors performed by the operators is the major cause of incidences took place between 2004 to 2008, indicating the need for analyzing the mining accident with human factors perspective in Indian environment also. The accident analysis in the present work is done by the adoption of the modified HFACS framework. HFACS is an adaptation of reasons' swiss cheese model of accident causation. The Human Factors Analysis and Classification System (HFACS) is a general human error framework originally developed and tested within the U.S. military as a tool for investigating and analyzing the human causes of aviation accidents [10]. One of the major lacuna in the model developed by Reason is less systematic categorization of the errors. HFACS addresses more systematic and detailed classification of human errors in four levels and many sub levels, as shown in figure 1 below. Original model developed by (Wiegmann and Shappell 2003) includes 19 causal categories of errors, but the framework modified by [9] for the Australian mining industry includes 21 causal categories, including outside factors triggering unsafe consequences. This framework is an investigation model which enables the identification of human factors involved in any occurring/recurring unfavorable incidence. It is believed that faulty management and work practices, faulty traits of the workers can be effectively controlled with an efficient safety management system. This can ultimately contribute towards a considerable reduction in incidences/accidents and aid in the development of safe working environment. Since 88% of the incidences takes place because of human error, 10% because of operating machine related issues and 2% because of an act of God [11]. HFACS has primarily adopted for aviation industry [10 12-21]. Slowly the importance of the framework catered and adopted in other fields like analysis of marine accidents [22 23], medical industry [24] etc., to identify the common human mistakes committed during any surgical process, the contribution of human errors towards any marine mishap etc. Application of this framework is not evident specifically in the area of manganese metal mines, although for the mining industry in Australia for coal and metals similar kind of framework was developed [9]. In year 2011 another research was carried out, utilizing the accident data related to underground and surface operations in mining in Australia, to understand the human factors involved in the accidents and to magnify the impact of ill decision, policies/regulations, leadership lacunas in the organization that eventually develops accident scenarios [25]. Since in first research [9] conducted with same database the prime focus was upon the level I and II of HFACS, means the factors related to sharp end in the industry, later [25] the focus was shifted upon the level III and IV, issues related to leadership practices, organizational factors, outside factors etc. Fuzzy based model is evident to be resolving issues related to data uncertainty, vagueness and impreciseness [26-29]. Application of Fuzzy based approach in the area of risk and safety has gained significant importance in the recent past since the data related to safety, accidents etc. is highly uncertain and vague in nature. Analysis of such data and obtaining a robust and reliable outcome for critical issue like safety has always been a challenge which is resolved evident in the number of cases adopting this approach [30-32]. [33] Proposed a hybrid FAHP approach for the assessment of risk level in Waterloo rail depot. The criteria considered to evaluate risk level using a fuzzy approach are *consequence, exposure frequency of occurrence*. [34] Has applied fuzzy TOPSIS for risk evaluation in the Italian sausage making industry. [35] Adopted fuzzy logic in tunneling construction site for assessment of risk. [36] Proposed Fuzzy FMEA approach for risk assessment, the outcome of which is a fuzzy risk priority number computed based upon criteria like occurrence (O), severity (S), detection (D). [37] Proposed a hybrid model of set pair analysis (SPA) and fuzzy logic theory for real time risk assessment for storing of flammable gas. As an outcome, deviations from the safety levels related to hazard factors like gas leakage, pressure of gas etc. can be timely assessed and accidents can be predicted and prevented.[38] Proposed fuzzy risk assessment model for the construction industry. The proposed model is a hybrid model with QFD, fuzzy ANP (for prioritization of hazards), and FMEA. Risk assessment in uncertain environments using triangular fuzzy numbers gives better and reliable results as the uncertainty and vagueness of the data can be managed with a fuzzy approach [39]. [40] Proposed a fuzzy based generalized risk assessment model that can be adopted irrespective of industry type. Input parameters considered in this model are expenses in the health care, expenses in the safety training, expenses in up-gradation of process related tools, expenses on safety equipment and tools. Output parameters are accident that does not cause any disability and does not involve any lost work days, an accident that caused lost work days etc. [41] proposed a Fuzzy AHP risk assessment model for assessment of risk in the industries where the environment is hot and humid. Factors that are considered for assessment of risk were working, worker and environment with ten sub factors to evaluate the level of risk adopting the trapezoidal fuzzy AHP technique and as an outcome safety index is evaluated. Risk and safety are assessed using this approach specifically in mining industry also and outcome obtained is considerable in deducing significant conclusions related to safety levels in mines. [42] Evaluated health and safety levels in underground mines in Kerman coal deposits in Iran, using fuzzy TOPSIS. Altogether 86 hazards with 8 hazard categories were identified. Hazard categories identified were *geo-mechanical, geo-chemical, electrical, mechanical, chemical, environmental, personal, and social, cultural and managerial risks*. [43] Proposed fuzzy based risk assessment approach in which combined output of FRA and FAHP is considered to evaluate the level of risk associated with hazard factors. Criteria for risk evaluation identified are *consequence of severity, level of exposure, frequency of occurrence* and hazard factors identified are *ground movement, winding in shaft, transportation by machinery, machinery other than transportation, explosives, electricity, dust/gas*. [44] Proposed FRA based risk assessment model for metal mines in India, for cause-wise and place-wise identified hazard factors. [45] proposed fuzzy based risk assessment model outcome of which is a risk score, for the assessment of worker safety. [46] proposed fuzzy based risk assessment approach outcome of which is validated with the outcome of conventional method of risk assessment i.e. rapid ranking method (RRM), adopted majorly in the Indian mining industry for broad brush risk assessment. RRM is not a robust tool for assessment of risk, since it is complex, always calculations needs to be started from scratch so time taking, continuous involvement of experts with immense experience and many more lacunas is identified by the author. But the proposed approach is found to be suitably working for the case of mining industry with robust applicability in other industries also. The existing literature related to the application of fuzzy based approaches is highly indicative towards suitable adoption of same for the proposed model. Present work focuses upon analysis of mining accidents with the perspective of involvement of human factors as a precursor to mishaps using modified HFACS framework. Accidents are coded as per the following categories, namely unsafe acts of operators, preconditions to unsafe act, unsafe leadership, organizational factors and outside factors, which are further classified into 21 categories for detailed assessments. Successively an accident prediction fuzzy based model is proposed to predict the possibility of occurrence of mishaps based upon factors, namely, age of the worker, experience of the worker, shift timings in which worker will be working. Since the research emphasizes upon human based factors leading to accidents; this indicates the need to understand the chance of mishap based upon factors like age, experience of worker etc., considering their possibility as underlying reasons inducing error making behavior of an operator.

2. Method

2.1 Data

The accident data reports, summary sheets, narratives referred for analysis is gathered from one of the major manganese ore extraction central government undertaking company having 4 mining sites in Maharashtra and 6 mining sites in Madhya Pradesh in India. Accident data spanning 1985 to 2015 is referred to the analysis with a total of 119 case histories. Among these 17 cases were found partially documented so those were discarded and remaining 102 cases were finally considered. For the accidents leading to fatalities the reports were retrieved from Directorate General of Mining safety, since such reports were submitted to the central body in consideration of the severity of the outcome. The forms and reports referred were in standard format and uniform as required by DGMS. Considered data combines both underground and opencast mines.

2.2 Coding Process

One human factors specialist along with three seasoned experts having nearly forty years of experience in the industry analyzed, coded the cases and categorized human factors. Since there was one rater the consensus classification was deemed appropriate for the analysis and the concern regarding inter rater reliability was insignificant. Incidences were analyzed for each category of the HFACS framework for coding.

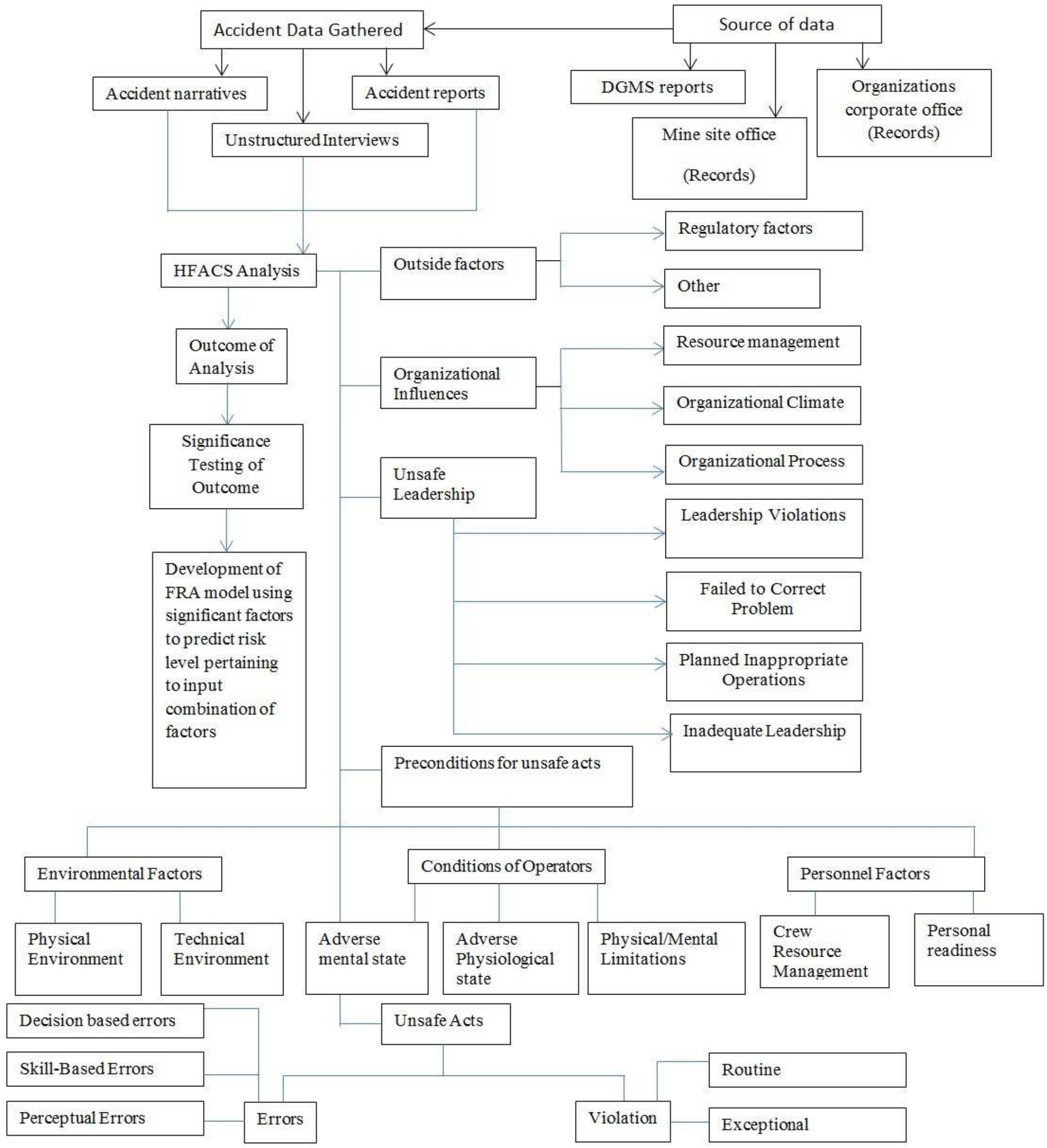

Figure1. Modified HFACS Framework

3. Outcome of HFACS analysis

Table 2 describes the details of causal factors. The frequency of the cases may add up to more than 100% since one incidence might be associated with more than one causal category. As expected, the maximum contribution to the unsafe incidence is witnessed due to unsafe acts of operator followed by preconditions for unsafe act and accordingly unsafe leadership and finally organizational influences. As far as outside factors are concerned, no case is being identified to be held because of outside factors, but this could be because of insufficiency in data compilation since it cannot be concluded that outside factors did not influence the safety conditions of the mining sites at all.

Table 2 Frequency of cases associated with causal code categories

HFACS Category		Frequency	N (102) (%)
	Outside Factors		
Regulatory Influences		0	0
Other Influences		0	0
	Organizational Influences		
Organizational Climate		4	3.9
Organizational Process		6	5.8
Resource Management		4	3.9
	Unsafe Leadership		
Inadequate supervision		23	22.5
Planned Inappropriate Operations		8	7.8
Failed to Correct Known Problems		3	2.9
Supervisory Violations		2	1.9
	Preconditions for Unsafe Acts		
Environmental Conditions			
Technical Environment		38	37.2
Physical Environment		22	21.56
Conditions of the Operator			

Adverse Mental State		4	3.9
Adverse Physiological State		4	3.9
Physical/Mental Limitations		2	1.9
Personnel Factors			
Coordination and Communication		18	17.6
Fitness for Duty		10	9.8
	Unsafe Acts of the Operator		
Routine Disruption Errors		66	64.7
Decision Errors		52	50.9
Perceptual Errors		4	3.9
Violations		6	5.8

3.1. Unsafe Acts of operators

This category is realized to be one of the major contributors in mishaps, since in 66 cases routine disruption errors, 52 cases decision errors, 4 cases perceptual errors and in 6 cases violations are found responsible. For comprehensive and systematic classification, each of the subcategories of unsafe acts is further categorized. Attention failure, postural errors, electrical errors etc. included under skill based errors similarly information processing, risk assessment and situational assessment is included under decision errors; violation of usage of personal protective equipment (PPE), procedural violation included under violation nanocodes and finally mis-judgement, visual and auditory errors were included under perceptual error nanocodes. The most prevailing acts of the operator identified is the attention failure (23.53%), followed by procedural (decision) errors (14.71%), technique errors (12.75%), situational assessment (10.78%) and risk assessment (9.8%). Since from the outcome of the HFACs analysis, it is realized that unsafe acts of operator have gained maximum importance, therefore unsafe acts were studied in detail in order to understand whether unsafe acts performed by the operator gets influenced by factors like age of the operator, experience of the operator time of shift in which the operator is working, place where operator is working and category of work assigned to the operator. The results for the same are given in table [3-7] below. It is noticed that in the underground mining category, out of 66 incidences 35 incidences are found to be occurring because of skill based errors; in the same category 13 incidences out of 52 incidences have occurred because of decision errors; out of 4, 2 incidences are found to be occurred due to perceptual errors, finally out of 6 incidences 2 were found to be occurred due to violations performed by the operator. In similar way other tables can be interpreted. It can be noticed from the detailed analysis that skill based errors is on top priority, followed by decision errors, leaving dominant impact upon all the factors considered below. In any of the categories of working skill based errors and decision errors are on top priority similarly in any of the shift timing, with any age and experience of the worker most common unsafe act performed leading to any incidence is skill based error and decision based error.

Further, an attempt is being made to understand if there is any significant association between two top priority unsafe acts with below to discuss the factors, since perceptions and violations have not shown considerable contribution towards mishaps.

Table 3 Unsafe Acts (Category of working)

Category of working	Skill based errors	Decision errors	Perceptual errors	Violati ons
Underground mining	35	13	2	2
Underground filling	4	8	0	1
Opencast mining	2	6	0	1
Opencast transportation	3	4	0	1
Opencast mechanical/electrical	13	11	1	0
Ore cleaning floor	0	0	0	0
Surface working	0	0	0	0
Worker others (field man)	9	10	1	1

Table 4 Unsafe Acts (Shift of working)

Shift of working	Skill based errors	Decision errors	Perceptual errors	Violation s
General	22	16	2	2
I shift	28	19	2	4
II shift	11	13	0	0
III shift	5	4	0	0

Table 5 Unsafe Acts (Place of accidents)

Place of Accidents	Skill based errors	Decision errors	Perceptual errors	Violations
Stopping Area	32	23	0	2
Tramming Road	3	13	0	0
Benches	2	0	0	2
Ore Cleaning Floor	4	12	0	0
Other Transportation Road	21	0	4	0
Workshop	0	2	0	0

Stores	1	0	0	0
Above Ground	3	2	0	2

Table 6 Unsafe Acts (Age of worker)

Age of Worker	Skill based errors	Decision errors	Perceptual errors	Violations
18-32	15	13	2	0
33-47	36	26	1	3
48-60	15	13	1	3

Table 7 Unsafe Acts (Experience of worker)

Experience of Worker	Skill based errors	Decision errors	Perceptual errors	Violations
1 month-1year	7	13	0	3
1 year-5 year	14	11	1	0
6 year-10year	17	11	2	3
11 year -20 year	19	9	1	0
Above 20 years	9	8	0	0

To develop a fuzzy based predictive system for accidents, preliminary step is to identify input variables. These variables are identified based upon the outcome of the significance testing performed to identify the significant association between the factors age, experience of worker, shift of work, category of working, place of work and unsafe act performed by the worker. So that the predictive model to analyze the factors having dominant association with unsafe acts and robust outcome related to risk level can be obtained and considered for the developing intervention strategies. The association between *category of working* and *unsafe acts performed by the operator* is found to be *insignificant [P_{Test} = 0.027 (P_{Test}< P_{α}) ns]*. Followed by testing for significant association between *shift of working* and *unsafe acts performed by the operator*, outcome is significant,[$\mathcal{X}^2_{critical} = 7.815$ *and* $\mathcal{X}^2_{Test} = 1.306$, $P_{Test} > P_{\alpha}$ *i.e* P_{α} *= 0.727]*. Thereafter, other factors like place of working, age of worker and experience of workers are tested to identify existence of significant association with unsafe acts. The outcome obtained respectively is, *place of work* is insignificantly*[P_{Test} < .001i.e P_{Test} < P_{α}]* associated with unsafe acts of worker;age of the worker is found to be significantly*[$\mathcal{X}^2_{critical} = 5.991$ and $\mathcal{X}^2_{Test} =$ 0.241 and P_{Test}=0.886 > P_{α}]* associated with *unsafe acts performed by the operator*, lastly experience of the worker is found to be significantly *[$\mathcal{X}^2_{critical} = 9.488$ and $\mathcal{X}^2_{actual} =$ 4.776 and P_{Test}=0.311 > P_{α}]* associated *unsafe acts performed by the operator*.Since unsafe acts of the operator is found to be having significant association with shift of working, age of worker, experience of worker, therefore FRA based accident prediction model is devloped considering these as input factors.

3.2 Preconditions for unsafe acts

Preconditions for unsafe acts is further classified into environmental (physical and technical envionment), operators condition and personnel factors. Mining industry since ages is known for its dynamic and difficult to work in, environmental conditions. Issues concerning with illumination, ventilation etc. has been a hurdle in maintaining safety at the worksite. Technical environment factor is found responsible in 38 cases. Conditions, maintenance and operations related to tools and equipment (36.85%) is identified as mostly responsible for mishaps and standard operating procedures and risk assessment (10.5%), since the mines are semi mechanized so issues related to not complying or violating SOP's are very less in number and mostly risk associated with faulty machines are assessed timely and handled cautiously. Under physical environment, weather is also an important factor, but it has not contributed to a greater extent in leading mishaps. Since, rainy season is most bothering environmental condition for mining industry and specifically for open cast mines. During this season mining site gets drowned which obstructs working. Interaction of such hazardous site and workers is made limited that helps in prohibiting accidents, using pumps water is removed from the site till then sites are not accessible for working.

The physical environment is found responsible in 22 cases. Surface/road conditions (27.27%) followed by visibility (18.18%) as expected is found to be dominant. The insignificant contribution of ergonomics is also identified since the mines are semi mechanized so uncomfortable, unsuitable man machine interacting workplace or faulty workplace design is not noticed.

Condition of the operator is found responsible in 10 cases. Still, it is a very important factor to be considered, since an operator with poor mental health will definitely underperform the task which might lead to unsafe consequences and also poor productivity. Physical/mental limitations and adverse physiological state (40.02%) was noticed to be on the priority as a causal factor for accidents under this category. Under the category of physical/mental limitations the learning ability limitations found to be responsible to greater extent followed by condition based respiratory issues, rest of the factors were not considerably noticed, since height, weight, hearing capability, vision tests are done prior to joining of the worker which they have to clear mandatorily. If the worker eventually develops during his work any limitation, then the worker is assigned light duty for example, medical attendant on site, peon in office, store etc.

With analysis, personnel factor is found responsible in 28 cases. It was found that the contribution of communication and coordination (64.29%) is on topmost priority, followed by fitness for duty (35.70%).

3.3 Unsafe leadership

The role of the leader is to provide adequate training and guidance to the team members to perform any task/operation efficiently, safely. In absence of adequate leadership or leadership violations etc. unwanted consequence can come into existence. This category is further categorized into inadequate leadership (22.55%) major causal factor in the incidences followed by planned inappropriate operations (7.84%), failure to correct known problems (8.21%) and leadership violations (5.38%). As expected leadership violations are noticed with a minimum contribution of. Under the category of inadequate leadership, training (39.13%) related issues have shown major contribution. At times it happens that less than adequate training is given to the worker to perform the task, there are a variety of trainings mandatory to work on mining site like when any SOP changes training is required, refresher training etc. or vice versa the worker does not have competency to learn, this can also create problems related to unsafe working environment. Safety oversight (30.4%) having second highest contribution in mishaps. It is identified from the analysis that safety regulatory requirements were still not set, still the operator was permitted to continue with working, which lead to mishap. The timber that is used to provide roof support in underground mines has certain specification which has to be followed, the material winding in any situation should not be used for movement of the man as well as material together, no matter how heavy cap-lamp batteries are, it has to be carried in underground. If any kind of deviation is noticed in following such practices, an efficient leader should take immediate action to avoid any mishap. This in some of the cases is noticed to be missing, leading to issues related to safety oversight.

It is noticed in emergency circumstances, certain decisions are taken which are unconventional during normal situations/operations. To execute such decision if the plan formulation is poor it will never be executed in intend manner, which is also realized from the analysis. Major causal factor under planned inappropriate operation (PIO) is improper task or work plan (50.28%) followed by the work assignment (25.14%) nanocode. If blaster is not available and there is an emergency then any worker who has not done blasting before might have assisted in blasting cannot be assigned with the task of blasting or any driver who has never operated or drove heavy earth moving machinery before, but has been driving jeeps/ambulances on site should not be allowed to drive loaders, dumpers,tippers under emergency conditions. Anyone who is in job rotation and has handled such machinery can be assigned tasks during emergency situation to avoid accidents. If an improper work assignment is made then that might lead to unfavorable events. Leadership violation is found negligibly responsible. Another inference can be drawn from this is, leadership violation might have been responsible, but not documented or reported to overcome with drastic after effects upon the employment factor of the personnel responsible or vigilance inquiry issues.

3.4 Organizational Influences

In total 14 cases, organizational factors were found responsible. Organizational process (42.64%) is identified as the dominant factor. Irregular reporting is found to be creating issues in the cases analyzed. Time pressure and short of staff are other identified important causal factors. As far as outside factors are concerned, these were not identified in analyzing cases. One of the reasons could be documentation provided for analysis didn't describe any outside factor responsible in mishaps.

4. Fuzzy reasoning approach (FRA)

As discussed in previous sections, if there exists any significant association between factors like age of the worker, place of working, shift of working, experience of the worker category of working, then an FRA model that can predict the level of risk associated with the given situation (combination of above mentioned factor for example prediction of risk level if "*a worker of age 27, with one year of experience, working in third shift i.e. night shift in underground*"). So that once the risk level can be predicted with a given situation and if considerable risk level is reflected than some changes like in a time of work or place of work or nature of work can be done and the level of risk can be rechecked and finally the allocation of work can be made. This can enhance preparedness against unsafe consequences and safe working environment can be developed and maintained in future. The outcome of the significance testing indicated towards a significant association between unsafe acts of the worker with the age of the worker, shift of the work and experience of the worker. Considering the same and with the help of three experts having 40 years of experience in this field a fuzzy rule base is prepared to develop in the inference engine so that risk level can be assessed.

Fuzzy set can be defined as: A fuzzy subset A of a universe of discourse U is characterized by a membership function μ: U→ (0, 1) which associates with each element u of U a number μ (u) in the interval (0, 1) which represents the grade of membership of u in A. The fuzzy set A of U = u1, u2 ..... u, will be denoted [26]

$$A = \sum_{i=1}^{n} \mu_{A\ (u_i)/u_i} = \sum_{t} \mu_{A\ (u_i)}$$

Where Σ stands for the union.

A fuzzy number can be demonstrated with an example of the triangular fuzzy number given as

$\tilde{n}_a\ (t^l_a\ t^m_a\ t^u_a)$ and can be interpreted as [43]

$$\mu_{\tilde{n}a}(x) = \begin{cases} 0, & x < t^{l}_{a} \\ \dfrac{x - t^{l}_{a}}{t^{m}_{a} - t^{l}_{a}} & t^{l}_{a} \leq x \leq t^{m}_{a} \\ \dfrac{t^{u}_{a} - x}{t^{u}_{a} - t^{m}_{a}} & t^{m}_{a} \leq x \leq t^{u}_{a} \\ 0, & x > t^{u}_{a} \end{cases}$$

The proposed FRA model is developed using MATLAB R2009a, Fuzzy Logic tool box. FRA model is used where only a small portion of the knowledge (information) for a typical problem might be regarded as certain or deterministic. FRA model is developed with the following steps:

4.1 Fuzzy Inputs

Fuzzy inputs need to be crisp numerical value limited to the universe of discourse of the input variable. The degree to which input belong to appropriate fuzzy sets is decided through a membership function which is one of the critical steps in deciding and defining inputs. The output is a fuzzy degree of membership between 0 and 1.

4.2 Application of fuzzy operator

Once the inputs are fuzzified, the degree to which each part of the antecedent is satisfied for each rule is identified. The output is always a single truth value, but if there is more than one part in the antecedent, the fuzzy operator is applied to get one number that representing the result of antecedent, of that rule which is applied to the output function.

4.3 Implication

To shape up the consequent implication method is applied. Implication occurs for each rule, the number given by the antecedent is the input for implication. Each rule has got a weight which is applied to the number given by the antecedent. Normally it takes 1 and it does not affect the implication process, this number may be varied time to time from 1 in order to weigh one rule relative to another.

4.4 Aggregation

All the fuzzy set representing the output of each rule is combined to single fuzzy set. Aggregation occurs once for each output variable. The input of the aggregation process is the list of truncated

Output functions returned by the implication process for each rule. The output of the aggregation process is one fuzzy set for each output variable.

4.5 Defuzzification

The input given to the fuzzy reasoning system is crisp, similarly the output is also expected in crisp form. The defuzzification process gives crisp form of output. The aggregate output fuzzy set is the input for this step and output is the crisp in nature.

5. Application of FRA model

For present case the FRA model is of three inputs and one output type [figure 2]. The inputs to the system are three, namely *age of the worker, experience of the worker, shift of work* and the output is *risk level.* Firstly the input parameters need to be defined with qualitative descriptors and membership functions. Below given are the yardsticks developed defining qualitative descriptors in detail [table 8].

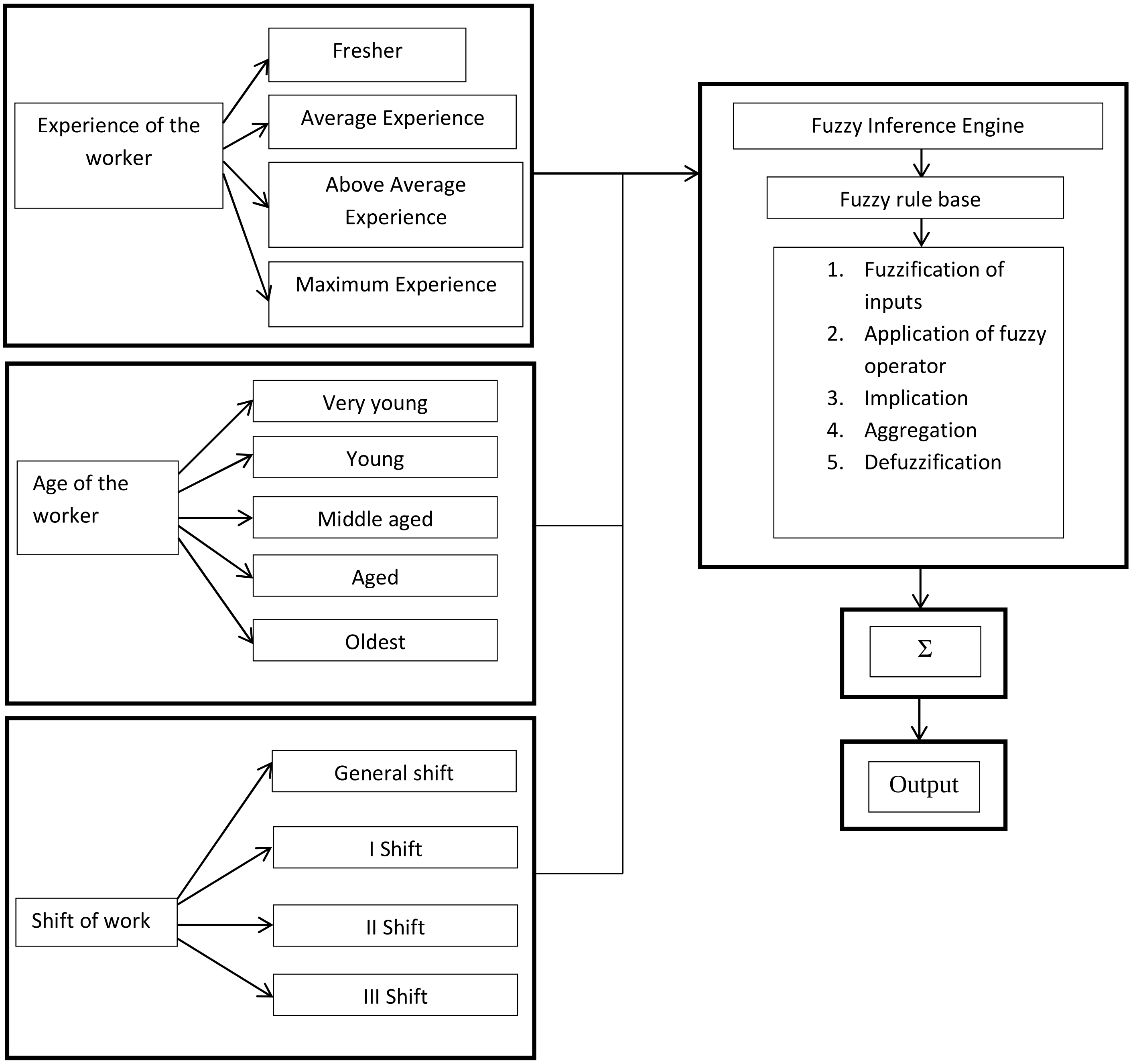

Figure 2 FRA model for risk assessment

Table 8. Yardstick for input and output parameter

Experience of Worker		
Qualitative descriptor	Description	Parameter
Fresher	1 month -1 year	Trapmf [0 0 0.5 1.5]
Minimum	1 year - 5 year	trimf [0.5 1.5 2.5]
Average	6 year- 10 year	trimf [1.5 2.5 3.5]
above average	11 year - 20 year	trimf[2.5 3.5 4.5]
Maximum	above 20 year	trapmf [3.5 4.5 5 5]
Age of Worker		
Qualitative descriptor	Description	Parameter
Very young	18-27 years	trapmf [0 0 0.5 1.5]
Young	28-37 years	trimf [0.5,1.5,2.5]
Middle aged	38-47 years	trimf [1.5 2.5 3.5]
Aged	48-57 years	trimf [3.5 3.5 4.5]
Oldest	58 years and above	trapmf[3.5 4.5 5 5]
Shift of work		

Qualitative descriptor	Description	Parameter
General	8:00am - 4:00 pm	trapmf [0 0 1 2]
I	6:00 am - 2:00 pm	trimf [1 2 3]
II	2:00 pm - 1:00 pm	trimf [2 3 4]
III	10:00 - 6:00 am	trapmf[3 4 5 5]

Risk level

Qualitative descriptor	Description	Parameter
Low	Risk is acceptable	trapmf [0 0 3 4]
Possible	Risk is tolerable but should be further reduced if cost-effective to do so	trapmf [3 4 6 7]
Substantial	Risk must be reduced if it is reasonably practicable to do so	trapmf [6 7 9 10]
High	Risk must be reduced safe in exceptional circumstances	trapmf [9 10 12 12]

Fuzzy inference is the actual process of mapping from a given input to an output using fuzzy logic. Once the input is given to the inference system, then it is mapped with the rules fed into the system and then as an outcome a defuzzified output is generated. In present case there are three input parameters each having different number of qualitative descriptors based upon which the number of rules is decided. 88 rules are developed in the database, there should have been 100 (5 X5X4) rules, based upon qualitative descriptors of input parameters, but few rules were discarded based upon insignificant logic like a fresher can't be of 57 years of age or a middle aged person can't be a fresher or a very young worker can't have 20 years of experience. Such rules are not logically correct. With such screening the rule base is developed and system is tested.

6. **Results and discussion**

Present work demonstrates the causal factors in the genesis of mining accidents using the HFACS framework. Total 21 causal categories are reviewed to assess an incidence with aim to highlight the dominant participation of the human error, including latent conditions leading to unacceptable consequence like a mishap. The results are indicative, the *unsafe act* causal factor was observed to be responsible in maximum number of cases. When this category was analyzed in detail with respect to factors like *category of working, place of accident, age of worker, experience of worker, shift of work; skill based errors* were found to be having a dominant impact and *age of worker, experience of worker, shift of work* having significant correlation with *unsafe acts* performed leading to accidents, followed by *decision errors* on second priority in all the cases discussed. *Outside causal factors,* were not found to be contributing in accidents, but this does not signify that these factors are dormant. It can be an outcome of partially preserved data/insufficient records pertaining to regulations or any other influences. Based upon the findings of HFACS, the model is proposed that is found to be working satisfactorily to identify the level of risk associated with the given situation considering the age of worker, experience of worker, shift of work as input factors and risk level associated with the situation as output. The accident statistics indicated the age group, the experience slab performing unsafe acts in certain time of work. The trend is being utilized to test the model and predict the level of risk. To validate, the input given to the model is fresher in the category of experience, very young in the category of age and general shift (8:00 am to 4:00 pm) as the time of work, then risk level obtained is 1.8 which is low level (with reference to the yardstick for risk level given above). The outcome obtained as expected. Thereafter the shift timing was changed to III (10:00 pm to 6:00 am) and risk level came out to be 5.4 i.e. possible. This can be interpreted as, if this worker is to be assigned work then being the worker a fresher and very young, it can be avoided to give him immediately III shift, since this might develop accidental scenarios. Similarly, a reverse case is tested with this model i.e. the level of risk if the worker is middle aged with average experience of 5 to 10 years and assigned to work in III shift, then level of risk is 9.15 which is high, so it should be avoided to allocate such worker under the given circumstances in III shift. In such cases the ideal combination of worker having experience between 1 to 5 years and is young with age between 27 to 37 years can be allocated during III shift since the risk levels coming out with FRA model is 4.7 i.e. low. Similarly, many such input combinations can be tested and suitable allocations of the workers can be made to control unsafe working environment. This way accident inducing situations can be predicted in advance and prevention can be taken accordingly. Further, to control the errors performed by the operator or worker, following recommendations in organizational front can be made,

1. Provision for repeated training modules for workers. At the time of employment *initial vocational training* along with *refresher training* within a suitable span to upgrade workers' skill set with changing technology and finally with changes in job *special training* should mandatorily be given to workers.
2. *Effective supervision* of work to avoid cases of non-compliance to standard operating procedures.
3. Use of latest devices or personnel protective equipment with proper demonstration/training for the usage to the workers.

4. Mechanization of selected activities like ore cleaning on OCF (Ore cleaning floor).
5. Deployment of advanced transportation machineries with provision for rear view camera.
6. Automatic coordination of movement of man and material winding instead of manual coordination and communication (Observation: The conventional bellman system is presently followed).
7. Mechanization of manual loading activity of ore.
8. Provision to maintain better illumination and ventilation levels in underground workings.
9. Safety week celebration to sensitize workers with the importance of safety and develop safety minds in them.
10. Quality of the materials like timber for support, explosives with appropriate shelf life, shaft winding rope etc. should be retained as per the standard since it directly affects the safety levels in worksites.
11. The human tracking machine shall be used in underground mines.

7. Conclusions

The work presents detailed analysis of mine accidents occurred in underground as well as opencast manganese mines in India. HFACS framework is adopted to perform the analysis and significant findings are obtained. Based upon the findings a FRA model is proposed to assess the risk level with a given situation and modify the same if found critical. The outcome of the research work is highlighted below:

1. *Unsafe acts* of worker found to be most critical factor in developing accidental scenarios in mining sites with a maximum contribution of *skill based errors* performed by the workers.
2. *Underground mining approach, stopping area, I shift of work, worker within the age group of 33-47 years and with 6-10 years of working experience* are most critical to be considered in developing intervention strategies.
3. *Faulty behavioral traits, organizational lacunas* indicated as outcome of HFACAS analysis can be considered further to develop mitigation plan and intervention strategies for the industry.
4. *Age, Experience of the Worker and Shift of Work* has a significant correlation with unsafe acts performed ultimately leading to accidents.
5. *A Fuzzy Reasoning Approach based risk prediction model proposed* can be adopted by the safety analyst to predict the risk associated with a given situation and perform task allocation accordingly to prevent hazardous outcome.

Present work demonstrates a noble approach to risk and safety assessment. So far significant research performed in the area of safety management found to be limited with respect to scope since pro data based, questionnaire and interview based analysis of the data is performed and outcome indicated merely the trend for accidents or reasons behind the mishap. But, the present work is a step further of conventional research performed in this area where the outcome of micro level accident analysis has been utilized to develop accident prediction model to interpret the risk levels associated with a given situation and alter them accordingly. In future, the work can further be extended for other minerals extracted for commercial purpose in India and safety levels in sites can be improved.

Conflicts of interest

The author has no conflicts of interest to declare.

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