Human Factors and Risk Analysis in Conventional System of Marble Mining: Using HFACS Framework and Structural Equation Modeling Technique

Saira Sherin*, Salim Raza, Sajjad Hussain, Zahid Ur Rehman
University of Engineering and Technology, Peshawar
***Corresponding Author:** sairasherin@uetpeshawar.edu.pk

Citation | Sherin. S, Raza. S, Hussain. S, Rehman. Z, "Human Factors and Risk Analysis in Conventional System of Marble Mining: Using HFACS Framework and Structural Equation Modeling Technique", IJIST, Vol. 06 Issue. 03 pp 1505-1523, Sep 2024
DOI | https://doi.org/10.33411/ijist/20246315051523
Received | Aug 21, 2024 **Revised |** Sep 19, 2024 **Accepted |** Sep 20, 2024 **Published |** Sep 23, 2024.

Accidents in mines can occur due to sources of hazards that lead to the loss of hundreds of precious lives every year. Among these sources, human error is considered one of the significant sources that contribute to human errors causing accidents. In this study, different risk factors were analyzed that contribute to human errors and subsequent accidents in the conventional marble mining system. Data was collected from marble mine workers through a questionnaire based on the Human Factors and Classification System framework. Structural equation modeling was applied to examine the interaction between contributory factors that trace back to mine accidents. Two structural models were developed, showing good fit for indices with chi-square to the degree of freedom values of 2.967 and 2.095, respectively, and root mean square error of approximation value below 0.08. The results indicate that the risks caused by individuals or systems have considerable effects on human performance and safety. The findings further explore that safety management at the managerial and supervisory levels is mostly associated with systematic risks, influencing safety policies, procedures, and oversight mechanisms. However, risk caused by lack of PPE, improper machinery, and lack of training has a direct effect on workers, leading to unsafe activities. These risk factors significantly contribute to the development of unsafe conditions that increase the probability and potential severity of accidents. For improving unsafe conditions, the implementation of mechanization can effectively decrease reliance on workers, thereby minimizing human errors and ultimately enhancing safety. The findings of this study will be helpful for the assessment the surface mines safety in a better way.

Keywords: Human Errors, Self-Inflicted Risks, Systematic Risks, HFACS, Mine Accidents, SEM.

Introduction:

The mining industry has been acknowledged for its inherent complexity and hazardous environment that affects safety, productivity, and overall operating performance. [1][2]. Among these factors, human-related issues are identified as significant contributors to incidents, accidents, and inefficiencies within the industry. [2][3]. Despite advancements in technology, human factors continue to pose significant challenges, alongside physical hazards, especially in mines that are not fully mechanized [4][5]. The prevalence of low mechanization in developing countries, driven by the low cost of labor, leads to greater reliance on workers and an increased likelihood of errors [6]. Human error is a major contributor to accidents, yet both the error and its underlying causes are often overlooked in risk assessments, despite their potential for serious consequences [7]. Therefore, thorough analysis and assessment of anthropological factors are necessary to improve operational effectiveness and reduce the probability of human errors in the workplace [8].

To address the critical safety concerns in mines with limited automation, researchers and safety experts have emphasized human factors analysis, along with other hazards and risks to understand the root causes of accidents and incidents [9][10]. Human elements, including the study of human behaviors, decision-making processes, and interactions within complex systems, are recognized as key contributors to safety outcomes in various industries [11]. Identifying factors influencing human error is crucial for safety management and accident reduction. Various models for the identification and evaluation of human errors have been developed but the most common is the Human Factors and Classification System (HFACS) by Shappell and Weigmann based on the Swiss Cheese Model [12]. Originally developed for aviation accidents, HFACS has been adapted for various fields, including maritime, medical, rail accidents, and mining, and consists of four hierarchical levels, including unsafe acts, preconditions for unsafe acts, unsafe supervision, and organizational influences [12][13][14][15][16][17][18].

In the complex environment of mining, focusing solely on identifying and analyzing factors related to human errors is inadequate [19]. It is essential to understand the specific interrelationships among the factors that contribute to human errors, which in turn lead to a higher frequency of accidents [20]. In some cases, it is not the individual factors themselves that are mainly responsible, but rather the interactions between these factors that exacerbate the situation [21]. Thus, a thorough understanding of these relationships and their combined effects within the system is essential. To analyze the impact of these factors, various methods such as Human Error Assessment and Reduction Technique (HEART), Structural Equation Modeling (SEM), Hierarchical Linear Modeling (HLM), and Bayesian Network Analysis (BNA) are used [3][22][23][24]. Among these, Structural Equation Modeling is a commonly utilized method for analyzing relationships among factors and is characterized by its ability to test both direct and indirect effects within hypothesized causal relationships [17]. This approach proves particularly advantageous for testing variables, as the model is assessed for the overall fit by using a range of fit indexes including chi-square (χ^2), the degrees of freedom ratio (χ^2/df), and the Root Mean Square Error of Approximation (RMSEA) [25][26][27]. SEM is widely applied across various industries including the mining sector, to study interactions between operational factors, safety measures, and environmental impacts, aiding process optimization and sustainability, which highlights its extensive value for insights and decision-making across various fields [22][28][29].

In developing countries such as Pakistan, marble mining is carried out using the conventional blasting method [30]. Common hazards in these traditional mining systems include falling rocks, landslides, steep slopes, and blasting-related hazards, which frequently lead to injuries and fatalities [31]. Therefore, this research considered a more comprehensive understanding of the risks associated with individual and system-based factors, that contribute to human errors and consequently lead to accidents in mines with inadequate mechanized processes [32][33]. This study employed the HFACS framework, SEM technique, and risk

factors that contribute to human errors to evaluate the causes of frequent accidents. In the current study, SEM method is applied for the analysis of the relationship between the risk factors and the HFACS framework to effectively investigate the origins of human error and further, for the evaluation of the HFACS framework and accident factors to investigate the deficiencies at different levels of the HFACS framework that are responsible for accident causation [7], [34]. The objective of this research is to identify risk factors and causes of workers' unsafe behaviors in mining accidents using the HFACS framework and SEM. The findings offer practical insights for preventing accidents and enhancing mine safety management. They will help safety professionals and organizations develop targeted interventions that address the root causes of human error, reduce unsafe acts, and prevent accidents. Moreover, the research will inform the development of more effective safety protocols and policies, ultimately enhancing both worker safety and operational efficiency in the mining sector.

Material and Methods:

This study analyzed data obtained from workers of marble mines, focusing on the risks that lead to human errors and the factors influencing accidents in mining operations. The methodology followed in the study is given in Figure 1.

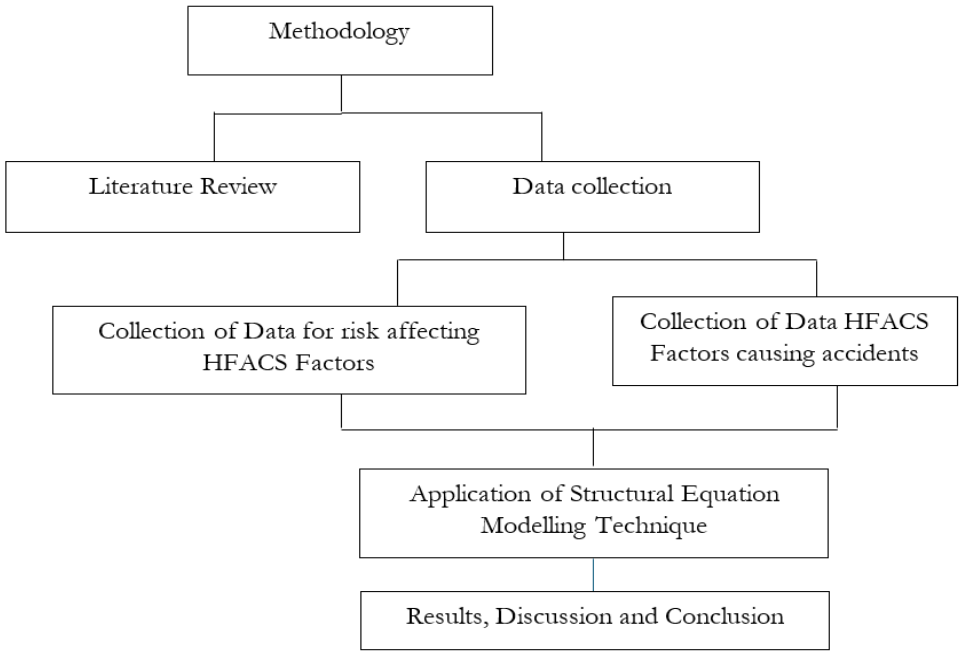

Figure 1. Methodology of the research

Data Collection:

Data collection was conducted using questionnaires distributed to workers in marble mines employing conventional mining methods in Buner, Khyber Pakhtunkhwa, Pakistan. A questionnaire structured on HFACS framework was developed to gather worker's perceptions, as detailed in Appendix-A. The first section addressed the risks contributing to human errors, while the second section focused on the human errors that lead to accidents. In the first section, risks identified as root causes for human errors were categorized into two groups: one related to systematic risks, including observed variables such as lack of safety culture, inadequate mechanized procedure, and enforcement gaps; and another related to self-inflicted risks, encompassing observed variables like lack of Personal Protective Equipment (PPE), improper machinery, and lack of training [2][9][33][35]. In the second section, accidents experienced by workers and their coworkers were classified into five observed variables such as near-miss accidents and injuries resulting in less than three days off work, three to seven days off, eight to twenty days off, and more than twenty days off. Table 1 explains HFACS factors cited in this

research. Prior to conducting the interviews, the survey's purpose was explained to the workers, informed consent was secured, and then data was collected from 318 workers through questionnaires. A 5-point Likert scale was used in the questionnaire, continuing from 1 for strongly disagree to 5 for strongly agree.

Table 1. HFACS factors with explanation in the context of marble mine

Factor	Sub-Factors	Code	Explanation with example
Unsafe Act	Decision Error	UA_11	Failure to determine the risk with the situation. e.g., Failure to assess machinery risks near a high wall led to a rockfall injury.
	Skill-based Error	UA_12	Human error due to lack of attention. e.g., Slip from the top or on same ground.
	Perceptual Error	UA_13	Misjudged the risk of the situation. e.g., misjudging the rock stability and continuing drilling caused the accident.
	Routine Violations	UA_14	Often breaking rules because they seem routine. E.g., Lack of PPE Use.
	Exception Violations	UA_15	Procedure deviations in unusual circumstances. E.g., Taking a steep slope to save time while ignoring the risks.
Pre-Condition	Personal Readiness	PC_21	Individuals inadequately prepare themselves physically or mentally for their responsibilities. E.g., Skipping rest breaks due to unavoidable circumstances led to errors and unsafe conditions.
	Crew Resource Management	PC_22	Ineffective coordination. E.g., Poor team coordination during blasting caused timing and placement errors, resulting in a hazardous rockfall.
	Adverse Mental State	PC_23	Mental and Physical Stress e.g., Stress, fatigue, and cognitive overload affect judgment and performance.
	Adverse physiological state	PC_24	Unfavorable Physical conditions e.g., Extended work shifts without adequate rest affecting performance.
	Physical/ Mental Limitation	PC_25	Circumstances affecting task performance. E.g., Long shift fatigue reduced the driller's strength and coordination, causing imprecise drilling.
	Physical Environment	PC_26	Unfavorable working conditions. E.g., high noise level, uneven roads, extreme temperature etc.
	Technical Environment	PC_27	Factors affecting the worker's performance. e.g., Using traditional drilling and blasting methods caused excessive rock fragmentation.
Unsafe Supervisory	Inadequate Supervision	US_31	Inadequate oversight or enforcement of safety protocols. E.g., conducting infrequent site inspections and missing critical safety hazards and risks.
	Planned Inappropriate Operation	US_32	Planning unsafe activities. E.g., extended shifts without breaks.
	Failed to Correct Problem	US_33	Fail to remove hazards. E.g., Failing to clear loose rocks raises accident risk.

Factor	Sub-Factors	Code	Explanation with example
	Supervisory Violations	US_34	Ignoring rules or permitting unsafe practices. E.g., Permit trucks to be overloaded beyond safety limits.
Organization influence	Resource Management	OI_41	Inadequate staffing, training, and budget. E.g., Limited funds lead to outdated safety equipment, reducing safety.
	Organizational Climate	OI_42	Lack of proper policies and procedures. E.g., Outdated procedures overlook new risks, leaving hazards unresolved.
	Operational Process	OI_43	Lack of updated procedures. E.g., Using outdated machinery and procedures causes inefficiencies and safety hazards.

Data Analysis:

Collected data through questionnaire was screened and verified for analysis by using SPSS software v. 24 [27]. The evaluation of questionnaire reliability yielded a Cronbach's alpha coefficient of 0.843 and 0.893 for sections 1 and 2 respectively, which signifies data consistency [29]. Prior to employing SEM, exploratory factor analysis was carried out to determine the suitable number of factors and their appropriate indicators. All factors had loadings exceeding the acceptable threshold of 0.5, indicating strong relationships between the items and their respective constructs and demonstrating strong convergent validity [22][27]. Table 2 and Table 3 provide evidence of factors with commonalities above 0.5 level, and factors of the pattern matrix exhibiting one-dimensionality, with each sub-factor producing a considerable contribution to its estimated factor, with Cronbach alpha values above 0.9 [22][36].

To achieve the objectives of the study, three hypotheses were initially formulated, and subsequently, two structural models were developed to ascertain the impact of the factors and validate the hypotheses. For assessing the influence of the factors, SEM was applied, using SPSS AMOS software v. 23. SEM, a powerful multivariate regression technique, allows for the simultaneous testing of multiple regression equations, making it ideal for uncovering complex relationships between variables. In addition, SEM considerably facilitates the estimation and testing of causal sequences involving theoretical constructs rather than measured variables.

Hypotheses:

- **H1:** It is hypothesized that all the factors of the HFACS are significantly affected by the exogenous variables of systematic risks and self-inflicted risks.
- **H2:** All the categories of HFACS have a positive significant effect on the variable accidents faced by workers due to human errors.
- **H3:** The category of organizational influence has a positive and significant effect on supervisory factors, which then affect preconditions for unsafe acts and ultimately influence the occurrence of unsafe acts in both models.

Results:

This study employed several overall fit indices to evaluate the models, including chi-square (χ^2), the χ^2/df ratio, the Normed Fit Index (NFI), the Comparative Fit Index (CFI), the Tucker-Lewis Index (TLI), the Parsimony Comparative Fit Index (PCFI), the Incremental Fit Index (IFI), and the Root Mean Square Error of Approximation (RMSEA) as recommended by SEM experts [27][37] The results from Structural Model-1 and Structural Model-2 indicate a good fit: the chi-square value is acceptable, with NFI, CFI, and TLI all exceeding 0.9; PCFI is above 0.8; and the RMSEA is below 0.08, as presented in Table 4 [17][25][26]. Further, the details of regression weight for Structural Model-1 and Structural Model-2 are given in Appendix-B in Table A and Table B respectively.

Table 2. Communalities, Cronbach alpha, and Pattern Matrix for HFACS & Risk Factors

Sub-Factors	Communalities		*Cronbach alpha and Pattern Matrix					
			Pre-conditions	Unsafe Act	Unsafe Supervision	Self-Inflicted Risk	Organizational Influence	Systematic Risk
	Initial	Extraction	0.921*	0.943*	0.951*	0.957*	0.942*	0.930*
UA_11	.837	.858		.933				
UA_12	.804	.837		.930				
UA_13	.688	.666		.796				
UA_14	.690	.661		.795				
UA_15	.810	.829		.907				
PC_21	.540	.473	.665					
PC_22	.540	.479	.691					
PC_23	.682	.701	.833					
PC_24	.745	.786	.885					
PC_25	.620	.525	.722					
PC_26	.666	.684	.818					
PC_27	.742	.790	.902					
US_31	.807	.746			.865			
US_32	.760	.683			.821			
US_33	.905	.959			.971			
US_34	.874	.888			.943			
OI_41	.848	.884					.946	
OI_42	.854	.896					.952	
OI_43	.810	.803					.881	
Lack of PPE	.924	.946				.971		
Improper Machinery	.930	.972				.982		
Lack of Training	.752	.747				.858		
Enforcement Gaps	.720	.743						.854
Inadequate Mechanized Procedure	.807	.880						.938
Lack of Safety Culture	.787	.843						.914

Structural Model-1 was designed to assess the impact of the exogenous variables, systematic risks, and self-inflicted risks, on HFACS factors as hypothesized in H1 and depicted in Figure 2. The results revealed that the effects of all the exogenous variables are statistically significant ($p < 0.05$), except for the effect of systematic risks on the unsafe act variable, and the effects of self-inflicted risks on the organizational influence and supervisory factors variables, which were not significant and were therefore excluded from the model. Moreover, the highest standardized effects of the variables

systematic risks and self-inflicted risks are $\beta = 0.39$ and $\beta = 0.38$, respectively, with $p < 0.05$ for the variable pre-condition for unsafe acts; an increase in one variable will lead to an increase in the other, and vice versa.

Table 3. Communalities, Cronbach alpha, and Pattern Matrix for HFACS & Accidents Factors

Sub-Factors	Communalities		*Cronbach alpha and Pattern Matrix				
			Pre-Conditions	Accidents	Unsafe Act	Unsafe Supervision	Organizational Influence
	Initial	Extraction	0.921*	0.967*	0.963*	0.945*	0.946*
UA_11	.920	.947			.974		
UA_12	.862	.875			.936		
UA_13	.731	.680			.827		
UA_14	.777	.753			.854		
UA_15	.920	.939			.968		
PC_21	.674	.664	.798				
PC_22	.669	.635	.768				
PC_23	.762	.784	.833				
PC_24	.749	.755	.835				
PC_25	.690	.610	.784				
PC_26	.585	.499	.725				
PC_27	.641	.578	.793				
US_31	.834	.794				.898	
US_32	.741	.678				.807	
US_33	.885	.946				.973	
US_34	.815	.828				.908	
OI_41	.858	.907					.949
OI_42	.863	.916					.956
OI_43	.722	.742					.857
Near Miss	.888	.888		.942			
Days-off<3	.869	.859		.931			
Days-off 3-7	.843	.814		.896			
Days-off_8-20	.821	.807		.901			
Days-off >20	.892	.910		.945			

Table 4. Goodness of Fit

Model	X^2	DF	X^2/DF	NFI	CFI	TLI	PCFI	RMSEA
Measurement Model-1	771.24	260	2.967	0.903	0.933	0.923	0.809	0.079
Measurement Model-2	494.41	236	2.095	0.942	0.969	0.964	0.828	0.059

Structural Model-2 was developed to examine the impact of HFACS factors on the accidents faced by workers due to human errors, as hypothesized in H2 and depicted in Figure 3. The results indicated that all exogenous factors in this model, which correspond to the HFACS factors, had a positive and statistically significant effect on the endogenous variable. The most significant standardized effects on the variables related to accidents caused by human errors come from the pre-condition for unsafe acts and supervisory factors, with values of $\beta = 0.25$ and $\beta = 0.20$, respectively.

The third hypothesis (H3) was formulated to evaluate the sequential influence of factors within the HFACS framework, where each factor influences the next, starting from organizational influence and culminating in unsafe acts, as depicted in Structural Models 1 and 2. Structural Model- and Structural Model 2 fully support H3, demonstrating that each factor positively and significantly affects the subsequent factor in the sequence. In Model-1, the strongest standardized effect is the influence of the pre-condition of unsafe acts on unsafe acts, with a coefficient of $\beta = 0.15$. Whereas, Model-2 identifies the most significant effect as the impact of supervisory factors on the pre-condition for unsafe acts, with a coefficient of $\beta = 0.40$.

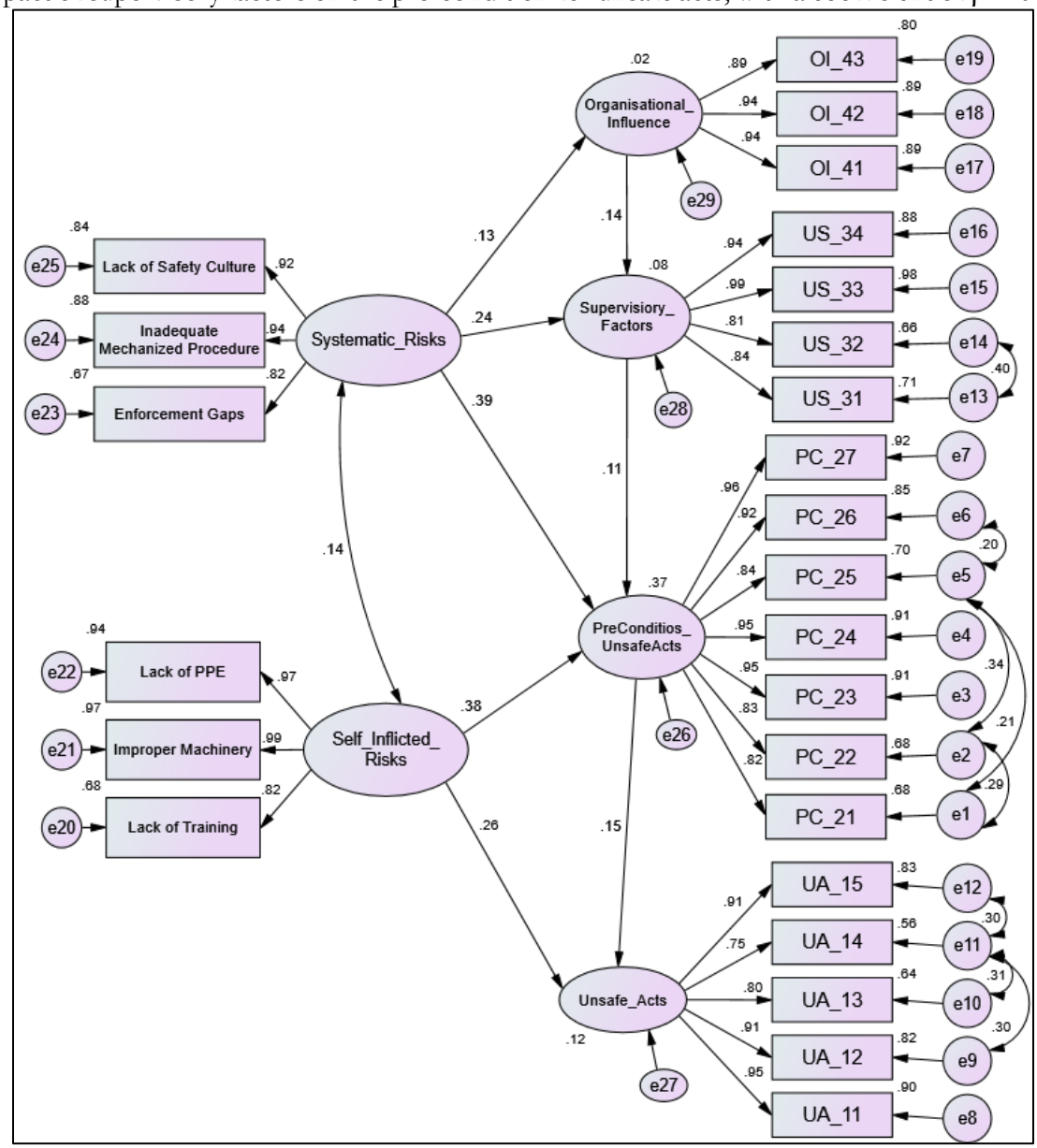

Figure 2. Structural Model-1

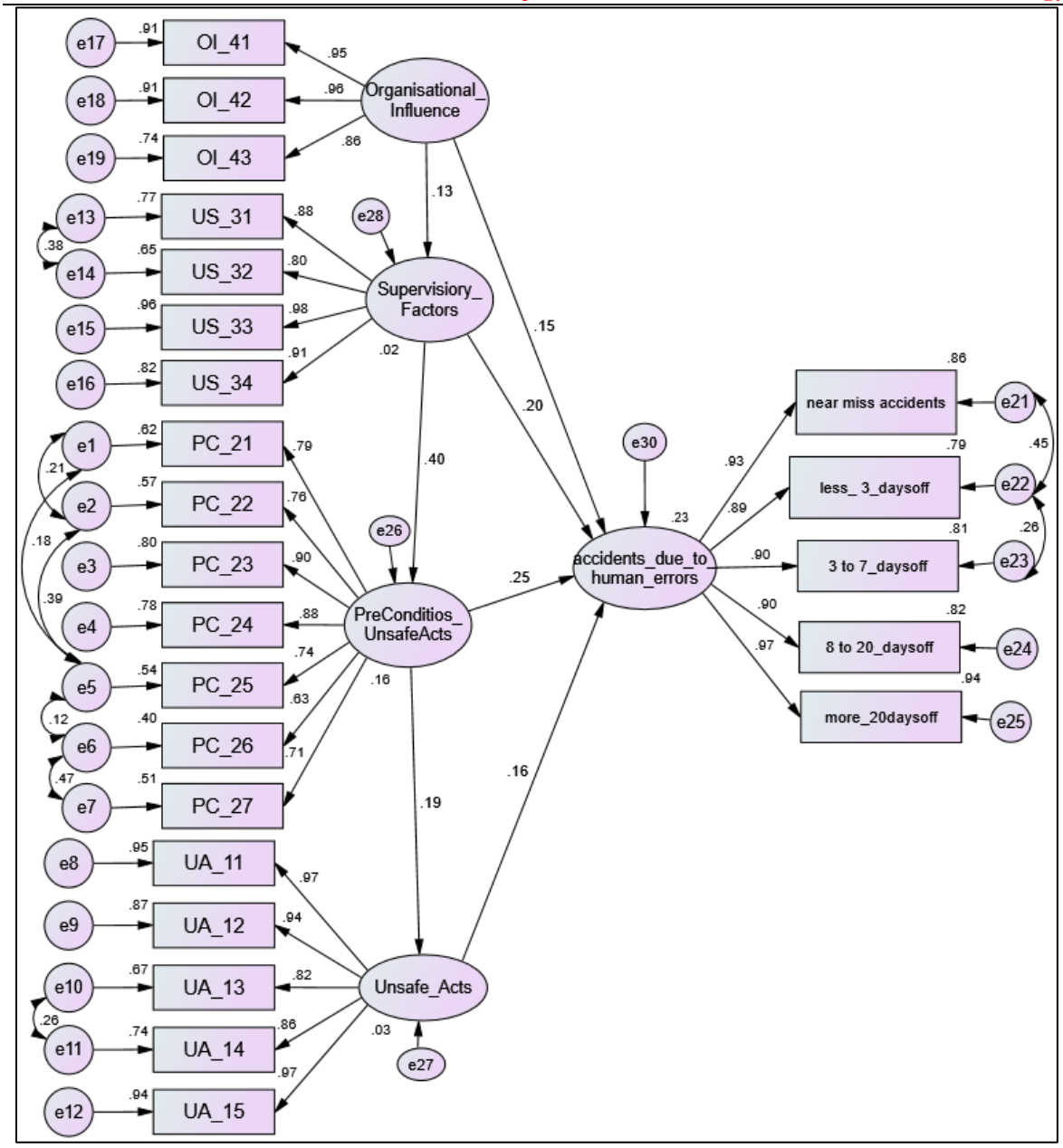

Figure 3. Structural Model-2

Discussion:

This study assesses the human aspects that contribute to unsafe circumstances in marble mines that employ conventional mining techniques. The assessment utilizes the Human Factor Analysis and Classification System (HFACS) framework for analyzing the factors that influence human errors and contribute to the occurrence of accidents in mines [38]. In mining operations, certain human errors impact only individuals, while others, frequently associated with management and supervisory responsibilities, can have wider consequences that contribute to a hazardous environment, as recognized in various studies [34][39]. Workers reported that the preconditions for unsafe acts, including the physical and technical environment, are more influenced by management and supervision issues rather than by the acts of individual workers. In addition, the study also indicated that managerial practices and organizational culture have a more substantial impact on the preconditions for unsafe acts that are responsible for accident causation in mining, suggesting that addressing systematic concerns is essential in enhancing safety in the mining industry, as reported by Quiroz et al. [40].

Moreover, it has been assessed that the increased probability of self-inflicted risk is significantly influenced by individual lack of PPE, improper machinery, and lack of training [41][42]. These factors greatly impact the unsafe acts themselves and the preconditions for them, such as the mental and physical well-being of workers that make them more susceptible to errors. Although these factors do not directly impact organizational regulations or supervisory roles, strengthening them can greatly enhance safety and effectiveness [43]. Consequently, this approach will effectively address the enforcement gaps, adopt managerial and policy-related concerns, as well as promote a safety culture and individual attitude [39].

Analysis of the direct effects at different levels of the HFACS framework, considering both the self-inflicted risks and systematic risks, it is evident that every tier has a substantial impact on the next one, starting with organizational factors and finally influencing the potentially harmful acts of workers. Understanding this interdependence highlights the necessity of addressing the root causes of risks that influence all levels to successfully reduce human errors and enhance safety results [7]. Analysis of HFACS variables in the second model of the study revealed that all levels within the framework significantly contribute to the occurrence of accidents ranging from near misses to severe accidents. Preconditions for unsafe acts and supervisory factors have a higher impact on accident causation, highlighting their critical importance in the frequency of accidents [37]. Moreover, the unsafe acts of workers and the influence of management also play an integral part in the occurrence of accidents. It is essential to consider all aspects of HFACS, particularly unsafe conditions and supervision on priority, to minimize the number and severity of incidents and accidents in mining operations, this finding supports the results of Joe-Asare et al., [18] that the workplace condition and leadership deficiencies are the most frequently identified contributing factors.

The findings of this study emphasize the importance of improving safety management and reducing human errors in the mining industry through comprehensive training programs that focus on operational competency and leadership abilities. Setting clear work standards, conducting regular workplace examinations, and developing safety culture that encourages reporting unsafe behaviors are important, the implementation of safe and mechanized mining techniques can significantly reduce workload, fatigue, and stress as described by Flores-Castañeda et al., [5] and Hattingh et al., [44]. Furthermore, implementing such findings into regulatory frameworks and working with industry stakeholders to develop standardized safety indicators helps drive continuous improvement and increase responsibilities across the industry.

Conclusion:

In mines with limited mechanization, addressing human errors and their root causes along with the assessment of physical hazards is important to effectively reduce the probability of accidents. This study analyzed the complexities of safety management in mines with the conventional system of mining by determining the different ways through which the risk factors affect safety practices. The findings revealed a strong relationship among the root causes of human errors, HFACS factors, and accidents faced by the workers. Deficiencies in mechanized procedures, safety culture, enforcement, and individual behavior due to lack of PPE, machinery, and training have a higher influence on human errors that result in minor to fatal accidents in mines. It is illustrated that the high influence of managerial and supervisory practices on workplace conditions, as well as the unsafe environment and individual behaviors that contribute to unsafe acts of workers, needs attention to reduce the associated risks. The unsafe conditions of the mine are dependent upon its physical and technological factors, which can be efficiently controlled by a mechanized system. It is recommended that mining operations should be mechanized to reduce the probability of human errors and improve safety [44].

Conflict of Interest: All the authors declare no conflicts of interest for publication of this paper. All authors have contributed to the paper.

References:

[1] S. Sherin and S. Raza, "Risk Analysis and Prioritization with AHP and Fuzzy TOPSIS Techniques in Surface Mines of Pakistan," J. Min. Environ., vol. 15, no. 2, pp. 463–479, Apr. 2024, doi: 10.22044/JME.2023.13687.2533.

[2] G. Dhoorgapersadh and E. Awuor, "Developing a Framework for Occupational Safety at a Global Mining Company Based in South Africa," Bus. IT, vol. XIV, no. 1, pp. 36–52, 2024, doi: 10.14311/BIT.2024.01.04.

[3] M. Mirzaei Aliabadi, I. Mohammadfam, A. R. Soltanian, and K. Najafi, "Human Error Probability Determination in Blasting Process of Ore Mine Using a Hybrid of HEART and Best-Worst Methods," Saf. Health Work, vol. 13, no. 3, pp. 326–335, Sep. 2022, doi: 10.1016/J.SHAW.2022.03.010.

[4] R. Norouzi Masir, M. Ataei, A. Mottahedi, "Risk assessment of Flyrock in Surface Mines using an FFTA-MCDM Combination", [Online]. Available: https://jme.shahroodut.ac.ir/article_1666.html

[5] R. O. Flores-Castañeda, S. Olaya-Cotera, M. López-Porras, E. Tarmeño-Juscamaita, and O. Iparraguirre-Villanueva, "Technological advances and trends in the mining industry: a systematic review," Miner. Econ., pp. 1–16, Jul. 2024, doi: 10.1007/S13563-024-00455-W/METRICS.

[6] A. K. Branson, "The Effect of Mechanization on Safety and Productivity of a Gold Mine," J. Environ., vol. 6, no. 1, pp. 14–20, Sep. 2020, doi: 10.20448/JOURNAL.505.2020.61.14.20.

[7] A. Appiah, Z. Li, E. K. Ofori, and C. Mintah, "Global evolutional trend of safety in coal mining industry: a bibliometric analysis," Environ. Sci. Pollut. Res., vol. 30, no. 19, pp. 54483–54497, Apr. 2023, doi: 10.1007/S11356-023-26714-X/METRICS.

[8] C. M. La Fata, A. Giallanza, R. Micale, and G. La Scalia, "Ranking of occupational health and safety risks by a multi-criteria perspective: Inclusion of human factors and application of VIKOR," Saf. Sci., vol. 138, p. 105234, Jun. 2021, doi: 10.1016/J.SSCI.2021.105234.

[9] E. Sundström and M. Nygren, "Safety Initiatives in Support of Safety Culture Development: Examples from Four Mining Organisations," Mining, Metall. Explor., vol. 40, no. 4, pp. 1007–1020, Aug. 2023, doi: 10.1007/S42461-023-00809-Y/TABLES/2.

[10] "Prioritizing the factors affecting the occupational health and safety of workers in the mining industry using the SWARA Technique | Journal of Current Science and Technology." Accessed: Sep. 26, 2024. [Online]. Available: https://ph04.tci-thaijo.org/index.php/JCST/article/view/204

[11] S. Supardi and D. Sudiantini, "How the Mediation Effect of Job Stress on the Relationship between Safety Leadership , Safety Culture and Safety Performance," vol. 5, no. 2, pp. 434–441, 2024.

[12] S. A. Wiegmann, "The Human Factors Analysis and Classification System--HFACS," 2000.

[13] D. A. Wiegmann and S. A. Shappell, "A Human Error Approach to Aviation Accident Analysis : The Human Factors Analysis and Classification System," A Hum. Error Approach to Aviat. Accid. Anal., Dec. 2017, doi: 10.4324/9781315263878.

[14] "Identifying and Prioritizing the Factors Affecting on the Human Errors and Ways to Reduce it in Oil and Gas Industry: Systematic Review | Request PDF." Accessed: Sep. 26, 2024. [Online]. Available: https://www.researchgate.net/publication/373096458_Identifying_and_Prioritizing_the_Factors_Affecting_on_the_Human_Errors_and_Ways_to_Reduce_it_in_Oil_and_Gas_Industry_Systematic_Review

[15] A. Galieriková, "The human factor and maritime safety," Transp. Res. Procedia, vol. 40, pp. 1319–1326, Jan. 2019, doi: 10.1016/J.TRPRO.2019.07.183.
[16] M. Jalali, E. Habibi, N. Khakzad, S. B. Aval, and H. Dehghan, "A novel framework for human factors analysis and classification system for medical errors (HFACS-MES)—A Delphi study and causality analysis," PLoS One, vol. 19, no. 2, p. e0298606, Feb. 2024, doi: 10.1371/JOURNAL.PONE.0298606.
[17] L. Yang, X. Wang, J. Zhu, L. Sun, and Z. Qin, "Comprehensive Evaluation of Deep Coal Miners' Unsafe Behavior Based on HFACS-CM-SEM-SD," Int. J. Environ. Res. Public Heal. 2022, Vol. 19, Page 10762, vol. 19, no. 17, p. 10762, Aug. 2022, doi: 10.3390/IJERPH191710762.
[18] T. Joe-Asare, E. Stemn, and N. Amegbey, "Applicability and Usefulness of the HFACS-GMI," Ghana Min. J., vol. 21, no. 2, pp. 33–45, Dec. 2021, doi: 10.4314/GM.V21I2.5.
[19] D. Fu, S. Gao, Z. Yan, H. Wu, X. Xu, and K. Xu, "Fault tree analysis of large-scale blackout accidents," E3S Web Conf., vol. 118, p. 01049, Oct. 2019, doi: 10.1051/E3SCONF/201911801049.
[20] R. Liu, W. Cheng, Y. Yu, and Q. Xu, "Human factors analysis of major coal mine accidents in China based on the HFACS-CM model and AHP method," Int. J. Ind. Ergon., vol. 68, pp. 270–279, Nov. 2018, doi: 10.1016/J.ERGON.2018.08.009.
[21] I. Mohammadfam, M. Bascompta, A. A. Khajevandi, and H. Dehghani, "Modeling of Causes and Consequences of Human Error in Mining Processes Design: A Qualitative Study," Sustain. 2022, Vol. 14, Page 14193, vol. 14, no. 21, p. 14193, Oct. 2022, doi: 10.3390/SU142114193.
[22] S. Sherin, S. Raza, and I. Ahmad, "Conceptual Framework for Hazards Management in the Surface Mining Industry—Application of Structural Equation Modeling," Safety, vol. 9, no. 2, p. 31, Jun. 2023, doi: 10.3390/SAFETY9020031/S1.
[23] M. Mirzaei Aliabadi, H. Aghaei, O. Kalatpour, A. R. Soltanian, and A. Nikravesh, "Analysis of human and organizational factors that influence mining accidents based on Bayesian network," Int. J. Occup. Saf. Ergon., vol. 26, no. 4, pp. 670–677, Oct. 2020, doi: 10.1080/10803548.2018.1455411.
[24] Z. Chen, G. Qiao, and J. Zeng, "Study on the Relationship between Worker States and Unsafe Behaviours in Coal Mine Accidents Based on a Bayesian Networks Model," Sustain. 2019, Vol. 11, Page 5021, vol. 11, no. 18, p. 5021, Sep. 2019, doi: 10.3390/SU11185021.
[25] S. Xu, P. X. W. Zou, and H. Luo, "Impact of Attitudinal Ambivalence on Safety Behaviour in Construction," Adv. Civ. Eng., vol. 2018, no. 1, p. 7138930, Jan. 2018, doi: 10.1155/2018/7138930.
[26] E. Yamaga, Y. Sato, and S. Minakuchi, "A structural equation model to test a conceptual framework of oral health in Japanese edentulous patients with an item weighting method using factor score weights: A cross-sectional study," BMC Oral Health, vol. 18, no. 1, pp. 1–8, Apr. 2018, doi: 10.1186/S12903-018-0527-1/FIGURES/2.
[27] A. Stojanović, I. Milošević, and Đ. Nikolić, "Developing a novel quantitative approach to evaluate the organizational factors affecting occupational health and safety in the mining industry," XX Int. May Conf. Strateg. Manag. – IMCSM24 Proc., vol. XX, no. vol. 20, iss. 1-Smart miner, pp. 60–68, May 2024, doi: 10.5937/IMCSM24006S.
[28] S. Phiakoksong, S. Niwattanakul, and T. Angskun, "An Application of Structural Equation Modeling for Developing Good Teaching Characteristics Ontology," Informatics Educ., vol. 12, no. 2, pp. 253–272, Apr. 2013, doi: 10.15388/INFEDU.2013.17.
[29] L. Yang, X. Wang, J. Zhu, L. Sun, and Z. Qin, "Comprehensive Evaluation of Deep Coal Miners' Unsafe Behavior Based on HFACS-CM-SEM-SD," Int. J. Environ. Res.

Public Health, vol. 19, no. 17, Sep. 2022, doi: 10.3390/IJERPH191710762.

[30] "Mitigation Plan for Identified Problems Faced by the Marble Industry in Khyber Pakhtunkhwa." Accessed: Sep. 26, 2024. [Online]. Available: https://researcherslinks.com/current-issues/Mitigation-Plan-for-Identified-Problems-Faced/31/1/3617

[31] S. Sherin, Zahid-Ur-rehman, S. Hussain, N. Mohammad, and S. Raza, "Hazards identification and risk analysis in surface mines of Pakistan using fault tree analysis technique," Min. Miner. Depos., vol. 15, no. 1, pp. 119–126, 2021, doi: 10.33271/MINING15.01.119.

[32] A. Esmailzadeh et al., "Risk Assessment in Quarries using Failure Modes and Effects Analysis Method (Case study: West-Azerbaijan Mines)," J. Min. Environ., vol. 13, no. 3, pp. 715–725, Jul. 2022, doi: 10.22044/JME.2022.12117.2209.

[33] F. K. Opoku, I. Kosi, and D. Degraft-Arthur, "Enhancing Workplace Safety Culture in the Mining Industry in Ghana," Ghana J. Dev. Stud., vol. 17, no. 2, pp. 23–48, Oct. 2020, doi: 10.4314/GJDS.V17I2.2.

[34] L. Yang, G. E. Birhane, J. Zhu, and J. Geng, "Mining Employees Safety and the Application of Information Technology in Coal Mining: Review," Front. Public Heal., vol. 9, p. 709987, Aug. 2021, doi: 10.3389/FPUBH.2021.709987/BIBTEX.

[35] I. Milošević, A. Stojanović, Q. Xiaoju, Đ. Nikolić, and S. Arsić, "The impact of safety factors on the safety sustainability of operators in mining companies: A manager's perspective," XX Int. May Conf. Strateg. Manag. – IMCSM24 Proc., no. vol. 20, iss. 1-Smart miner, pp. 92–100, May 2024, doi: 10.5937/IMCSM24009M.

[36] C. H. A. Dirgatama, "Exploratory and confirmatory factor analysis of digital entrepreneur skills," Probl. Perspect. Manag., vol. 22, no. 2, pp. 299–312, 2024, doi: 10.21511/PPM.22(2).2024.23.

[37] H. C. Merrett, W. T. Chen, and J. J. Horng, "A Structural Equation Model of Success in Drinking Water Source Protection Programs," Sustain. 2020, Vol. 12, Page 1698, vol. 12, no. 4, p. 1698, Feb. 2020, doi: 10.3390/SU12041698.

[38] L. Yang, X. Wang, J. Zhu, and Z. Qin, "Risk Factors Identification of Unsafe Acts in Deep Coal Mine Workers Based on Grounded Theory and HFACS," Front. Public Heal., vol. 10, p. 852612, Mar. 2022, doi: 10.3389/FPUBH.2022.852612/BIBTEX.

[39] M. M. Aliabadi, H. Aghaei, O. Kalatpour, A. R. Soltanian, and M. S. Tabib, "Effects of human and organizational deficiencies on workers' safety behavior at a mining site in Iran," Epidemiol. Health, vol. 40, no. 40, p. e2018019, 2018, doi: 10.4178/EPIH.E2018019.

[40] "Occupational Safety and Health Risks The situation of direct and outsourced mining workers in Bolivia, Colombia, and Peru." Accessed: Sep. 26, 2024. [Online]. Available: https://www.researchgate.net/publication/370845298_Occupational_Safety_and_Health_Risks_The_situation_of_direct_and_outsourced_mining_workers_in_Bolivia_Colombia_and_Peru

[41] "Comparative Analysis of Coal Miner's Fatalities by Fuzzy Logic", [Online]. Available: https://jme.shahroodut.ac.ir/article_1774_23f0636d7eb76840b2925428f69a3950.pdf

[42] J. Wang and M. Yan, "Application of an Improved Model for Accident Analysis: A Case Study," Int. J. Environ. Res. Public Health, vol. 16, no. 15, Aug. 2019, doi: 10.3390/IJERPH16152756.

[43] T. Joe-Asare, N. Amegbey, and E. Stemn, "Human Factor Analysis Framework for Ghana's Mining Industry," Ghana Min. J., vol. 20, no. 2, pp. 60–76, Dec. 2020, doi: 10.4314/GM.V20I2.8.

[44] "HUMAN FACTORS IN MINE MECHANIZATION 255".

Appendix - A

Questionnaire for Workers' Interviews:

The purpose of this survey is to gather insights from workers in the mining industry regarding safety practices, challenges, and human factors that influence workplace incidents. By understanding the experiences and perceptions of workers, we aim to identify critical areas for improvement in safety measures and training programs. Your feedback will help us enhance safety culture, reduce risks, and create a safer working environment for all employees. Participation in this survey is crucial for developing strategies that address the unique safety concerns faced in mining operations. In response to the following statement, please tick (✓) in the appropriate block with a scale ranging from Strongly Disagree with the value of 1 to Strongly Agree with the value of 5.

Demographic:

- Name (optional) _____
- Age _____
- Level of education_____
- Current job position_____
- Total experience_____

Section-1:

1a: Safety Risk Factors in Mining Operations:

Please choose one response from the scale, the risks factors in mining operations that contribute to human errors and lead to accidents.

S. No	Statement/Question	Strongly Disagree (1)	Disagree (2)	Up to some extent Agree (3)	Agree (4)	Strongly Agree (5)
a.	Lack of PPE					
b.	Improper Machinery					
c.	Lack of Training					
d.	Enforcement Gaps					
e.	Inadequate Mechanized Procedure					
f.	Lack of Safety Culture					

1b: Human Factors/Errors Affecting Mining Operation:

Please choose one response from the scale, which ranges from "Strongly Disagree" to "Strongly Agree," about the HFACS factors influenced by the risks factors in mining operations that contribute to human errors.

S. No	HFACS Factors	Strongly Disagree (1)	Disagree (2)	Up to some extent Agree (3)	Agree (4)	Strongly Agree (5)
1	Decision Error					
2	Skill-based Error					
3	Perceptual Error					
4	Routine Violations					
5	Exception Violations					
6	Physical Environment					
7	Technical Environment					

S. No	HFACS Factors	Strongly Disagree (1)	Disagree (2)	Up to some extent Agree (3)	Agree (4)	Strongly Agree (5)
8	Adverse Mental State					
9	Adverse physiological state					
10	Physical Mental Lt					
11	Crew resource management					
12	Personal readiness					
13	Inadequate supervision					
14	Planned inappropriate operation					
15	Failed to correct known problem					
16	Supervisory violations					
17	Resource management					
18	Organizational climate					
19	Operational process					

Section-2:

2a: Human Factors/Errors Affecting Mining Operation:

Please choose one response from the scale, which ranges from "Strongly Disagree" to "Strongly Agree," regarding the HFACS factors that are contributing to mine accidents.

S. No	HFACS Factors	Strongly Disagree (1)	Disagree (2)	Up to some extent Agree (3)	Agree (4)	Strongly Agree (5)
1	Decision Error					
2	Skill-based Error					
3	Perceptual Error					
4	Routine Violations					
5	Exception Violations					
6	Physical Environment					
7	Technical Environment					
8	Adverse Mental State					

S. No	HFACS Factors	Strongly Disagree (1)	Disagree (2)	Up to some extent Agree (3)	Agree (4)	Strongly Agree (5)
9	Adverse physiological state					
10	Physical Mental Lt					
11	Crew resource management					
12	Personal readiness					
13	Inadequate supervision					
14	Planned inappropriate operation					
15	Failed to correct known problem					
16	Supervisory violations					
17	Resource management					
18	Organizational climate					
19	Operational process					

2b: Information About Mine Accidents You Faced:

S. No	Statement/Question	0 time	1 time	2-3 times	More than 3 times
a.	Average number of near miss accidents you faced during last one year.				
b.	Number of accidents you faced with having minor injury having less than 03 days off from work.				
c.	Number of injuries you faced with having at least 03 to 07 days off from work.				
d.	Number of injuries you faced with 08 to 20 days off from work.				
e.	Number of accidents you faced with more than 20 days off from work.				

Appendix-B

Table A. Regression Weights of Structural Model - 1

Factors		Influencing factors	Estimate	S.E.	C.R.	P
Organisational__Influence	<---	Systematic_Risks	.184	.086	2.134	.033
Supervisiory__Factors	<---	Systematic_Risks	.376	.091	4.144	***
Supervisiory__Factors	<---	Organisational__Influence	.151	.061	2.478	.013
PreConditios__UnsafeActs	<---	Supervisiory__Factors	.171	.075	2.280	.023
PreConditios__UnsafeActs	<---	Self_Inflicted__Risks	1.000			

Factors		Influencing factors	Estimate	S.E.	C.R.	P
PreConditios__UnsafeActs	<---	Systematic_Risks	1.000			
Unsafe_Acts	<---	Self_Inflicted__Risks	.397	.093	4.274	***
Unsafe_Acts	<---	PreConditios__UnsafeActs	.082	.035	2.380	.017
PC_23	<---	PreConditios__UnsafeActs	1.000			
PC_24	<---	PreConditios__UnsafeActs	.808	.021	39.261	***
PC_25	<---	PreConditios__UnsafeActs	.667	.028	24.204	***
PC_26	<---	PreConditios__UnsafeActs	.804	.024	33.173	***
PC_27	<---	PreConditios__UnsafeActs	.825	.020	40.294	***
UA_11	<---	Unsafe_Acts	1.030	.036	28.946	***
UA_12	<---	Unsafe_Acts	1.000			
UA_13	<---	Unsafe_Acts	.864	.044	19.599	***
UA_14	<---	Unsafe_Acts	.859	.044	19.467	***
UA_15	<---	Unsafe_Acts	.993	.038	26.076	***
US_31	<---	Supervisiory__Factors	.813	.031	25.944	***
US_32	<---	Supervisiory__Factors	.819	.035	23.161	***
US_33	<---	Supervisiory__Factors	1.000			
US_34	<---	Supervisiory__Factors	.943	.024	38.825	***
OI_41	<---	Organizational__Influence	1.000			
OI_42	<---	Organisational__Influence	1.020	.032	31.863	***
OI_43	<---	Organisational__Influence	.968	.035	27.339	***
F13	<---	Self_Inflicted__Risks	1.000			
F12	<---	Self_Inflicted__Risks	1.342	.053	25.438	***
F11	<---	Self_Inflicted__Risks	1.324	.053	24.920	***
F21	<---	Systematic_Risks	1.000			
F22	<---	Systematic_Risks	1.222	.057	21.366	***
F23	<---	Systematic_Risks	1.292	.062	20.854	***
PC_21	<---	PreConditios__UnsafeActs	.609	.026	23.184	***
PC_22	<---	PreConditios__UnsafeActs	.616	.026	23.306	***

Table B. Regression Weights of Structural Model -2

Factors		Influencing Factors	Estimate	S.E.	C.R.	P
Supervisiory__Factors	<---	Organisational__Influence	.141	.060	2.338	.019
PreConditios__UnsafeActs	<---	Supervisiory__Factors	.352	.049	7.126	***
Unsafe_Acts	<---	PreConditios__UnsafeActs	.196	.061	3.188	.001
accidents_due_to__humanerrors	<---	Unsafe_Acts	.142	.046	3.116	.002
accidents_due_to__humanerrors	<---	PreConditios__UnsafeActs	.230	.055	4.212	***
accidents_due_to__humanerrors	<---	Supervisiory__Factors	.157	.046	3.396	***
accidents_due_to__humanerrors	<---	Organisational__Influence	.129	.044	2.934	.003
PC_23	<---	PreConditios__UnsafeActs	1.000			
PC_24	<---	PreConditios__UnsafeActs	.930	.042	22.095	***
PC_25	<---	PreConditios__UnsafeActs	.825	.052	15.916	***
PC_26	<---	PreConditios__UnsafeActs	.682	.054	12.700	***
PC_27	<---	PreConditios__UnsafeActs	.729	.048	15.167	***

Factors		Influencing Factors	Estimate	S.E.	C.R.	P
UA_11	<---	Unsafe_Acts	1.026	.026	39.195	***
UA_12	<---	Unsafe_Acts	1.000			
UA_13	<---	Unsafe_Acts	.874	.040	21.976	***
UA_14	<---	Unsafe_Acts	.947	.038	24.998	***
UA_15	<---	Unsafe_Acts	1.039	.027	38.393	***
US_31	<---	Supervisiory__Factors	.835	.030	28.237	***
US_32	<---	Supervisiory__Factors	.793	.036	22.089	***
US_33	<---	Supervisiory__Factors	1.000			
US_34	<---	Supervisiory__Factors	.930	.029	31.770	***
OI_41	<---	Organisational__Influence	1.000			
OI_42	<---	Organisational__Influence	1.006	.029	34.752	***
OI_43	<---	Organisational__Influence	.896	.035	25.264	***
F21	<---	accidents_due_to__human_errors	1.000			
F23	<---	accidents_due_to__human_errors	1.051	.041	25.525	***
F22	<---	accidents_due_to__human_errors	1.043	.034	30.937	***
PC_21	<---	PreConditios__UnsafeActs	.833	.047	17.730	***
PC_22	<---	PreConditios__UnsafeActs	.806	.049	16.546	***
F13	<---	accidents_due_to__human_errors	.981	.034	28.513	***
F12	<---	accidents_due_to__human_errors	1.019	.037	27.346	***