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A FACTORIAL ANALYSIS OF INDUSTRIAL SAFETY

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ABSTRACT: In spite of all the efforts in different industries to reduce the number of undesirable accidents, a lot of events always threaten industrial societies. These events often cause huge damages to the environment, facilities, fatalities and disabilities for people. Therefore, it is important to analyse the numerous variables associated with industrial accident considerations and the inter play among these variables. This paper adopts a novel combination of two statistical methods to analyse the various hazards factors in the most important sector of the economy. In this analysis, critical hazards variables were identified and classified based on HSE (Health Safety and Environment) standards. Kendall's Coefficient of Concordance (KCC) and Principal Component Analysis (PCA) were employed to analyse the set of data generated from respondents and were summarized into a number of factors that promotes occupational safety and health in industries. KCC was used to analyze data matrix generated by thirteen Judges who were requested to rank the thirty two identified hazards variables in merit order of sequentiality scaled with 5-point Rensis Likert's attitudinal scale and administered to 22 respondents where only 13 were retrieved. The PCA aided by StatistiXL software package was proficient to achieving parsimony in factor reduction from thirty-two variables to mere five factors. The results obtained by KCC suggested that the judges ranking of the thirty two variables were consistent with index of concordance computed as W = 0.958. The result by PCA indicates that five factors creatively labelled: Work World Culture, Ground Rule Matters, Safety Considerations, Work Condition and Perception of Safety represent the principal factors that influence the industrial safety. This study unwrapped the deeper meanings associated with multi-dimensional factors in industrial safety.

Keywords: Principal Component Analysis, Parsimony, Hazards, Industrial accident, Concordance

1. INTRODUCTION

The health and safety environment within Oil and Gas Exploration operations is a growing concern as oil and gas production increases to keep up with demand and technology advances creating new hazards. Recent high-profile events have brought safety and environment concerns to the forefront demanded by regulators, general public and within operating companies themselves. Health and safety issues affect oil and gas producing companies, and industrial sectors in general to the extent where the potential risks cannot be ignored. In spite of all the efforts in different industries to reduce the number of undesirable accidents, a lot of events always threaten industrial societies. These events often cause huge damages to the environment, facilities and even in some cases, fatalities and disabilities for people. Therefore, it is important to analyse the numerous variables associated with industrial accident considerations and the inter play among these variables. A lot of factors are associated with industrial accidents considerations; unfortunately, the major problem is that we do not understand the character and the inter-play among these factors.

Industrial accidents studies have been carried out using several models. Such work on the use of Markov model to study industrial accidents has been reported. Typical studies include: [1-4] among others who also employed other models to safety. These studies go to underscore the importance of industrial safety. Also, a gargantuan of literature on general management of industrial safety exists. See, for example, [5-8]. Others are [9-11]. Specifically, victims show inherent tendencies to make causality attributions of industrial accidents. Research interest on safety is on constant increase, there is yet to be a research analysing the correlation among all levels of accident variables. Okwu et al. [4] used Markov theoretical approach to forecast the severity and exposure levels of workers in the oil and gas sector. The perils were classified into four states which include: catastrophic, critical, marginal and negligible. The result showed 41.45% of workers would likely transit from negligible state to catastrophic state. Monday [12] researched on occupational health and safety in the oil and gas industry by investigating the various hazard workers are exposed to, the effect of these hazards to the health of the workers, the effectiveness of the existing means of mitigating these hazards and the adequacy of the legislation that impacts on the provision of occupational health and safety in the oil and gas industry. Statistical package for social sciences (SPSS) software was used for the analysis. Achojakimoni [13] studied hazards control measurement by evaluating the effective use of personal protective equipment, good housekeeping, adequate maintenance, good maintenance of machinery, emergency procedures to follow when there is accident in confined space. Confined space include but are not limited to storage tanks, compartments of ships, process vessels, pits, silos, vats, reaction vessels, boilers, ventilation and exhaust ducts, sewers, tunnels, underground utility vaults, and pipelines. Amol [14] carried out hazard identification and risk analysis in iron ore and coal mining operations. The study revealed that the number of high risks hazards in the coal mining operations was more than the one of the iron ore mining operations. Jeong et al. [15] used Hazard and Operability Method (HAZOP) to identify the potential hazards and operability problems of decommissioning operations and concluded that the decommissioning of a nuclear research reactor must be accomplished according to its structural conditions and radiological characteristics. Jelemenesky et al. [16] applied the probabilistic safety assessment in chemical industry. The method was applied to a pressurized spherical tank for ammonia storage in order to estimate reliable risk of its casual rupture with different magnitude of the tank damage. Dziubinski et al. [17] studied basic reasons for pipeline failure and its probable consequences taking individual and societal risk into consideration and proposed methodology of risk assessment for hazards associated with hazardous substance transport in long pipelines. Ramin [18] examined the application of semi-Markov models to the phenomenon of earthquakes in Tehran province. In his research, the province of Tehran was divided into six regions and grouped the earthquakes using their magnitude into three classes. Semi-Markov model was used to predict the likelihood of the time and place of occurrence of earthquakes in the province under stochastic environment. Peng et al. [19] in the study on “prediction of Ship Traffic Flow Based on BP Neural Network and Markov Model’’ concluded from their work that the prediction accuracy of short-term ship traffic flow is of great significance to ensure the safety of navigation, efficient use of resources and reduce maritime accidents. A prediction model based on BP neural network and Markov Chain to improve the prediction accuracy of short-term ship traffic flow was set up. The empirical study indicated that using this method can achieve forecasting accuracy improvement feasible. This work only forecast the ship traffic flow from the macro and did not consider the impact of other factors, such as weather, sea conditions, and policies and so on as well as the correlation among them. Oluoch et al. [20] determined the effects of occupational safety and health awareness on work environment in the Kenyan Kisumu County Water Service industry. The study utilized a descriptive research design with simple random sampling employed to draw the respondents from each site. Self-administered semi-structured questionnaire was used to acquire the data used. The data was analyzed using Statistical Package for Social Sciences version 21. Frequencies and percentages were obtained and correlations carried out using Spearman's correlation coefficients. The study analyzed the relationship between staff awareness of occupational safety and health and work environment using Spearman's coefficient at Confidence Level (CL) of 95%. The result showed that there is a significant moderate positive relationship between staff awareness of occupational safety and health and work environment in the water service industry in Kisumu County. Katsuro et al. [21] assessed the impact of occupational health and safety (OHS) on workers' productivity in the commercial food industry. The study explored OHS problems of different work areas and their impact on productivity. The study found out that OHS related problems negatively affect workers' productive capacity in the food industry resulting in reduced worker output. It was also observed that the workers develop a negative attitude and low morale towards work and that high incidents of accidents at work also occur. According to Manduku and Munjiri [22], a closer scrutiny of the OSHA, 2007 revealed that many of the dangerous occurrences and prescribed occupational diseases in the 1st and 2nd schedules may exist. The author noted that there are several instances of unsafe working conditions and work behaviour that both employees and employer should place emphasis on. Malek et al., [23] explored the possible benefits of focusing on the occupational health and wellness of construction and industrial workers as a separate category from safety. According to the authors, the occupational health of workers has an impact on the workers' wellbeing, state of mind, overall attitude and morale; therefore the safety, quality of work and inevitably the profitability of the company is affected. Bibay and Agapito [24] carried out a study to determine the commonly encountered occupational hazard of laboratory animal workers in Singapore and the Philippines. The study determined the percentage of hazard exposure according to the workers' personal profile, work profile, and frequency of exposure. The result showed no significant difference between the three hazards studied when compared to one another. These hazards were consistent regardless of age, gender, education, job, biosafety level of the facility, years of work experience and type of animal exposures. Otitolaiye et al., [25] investigated the indirect effect of safety management system in the relationship between organizational safety culture and safety performance. The study employed the use of a 5-point Likert questionnaire to collect data from 134 respondents who are head of safety officers in F&B industries located in Lagos, Nigeria. The results from the path analysis revealed that safety culture and safety management system positively relate to safety performance. The mediation analysis carried out indicated an indirect effect of safety management system in the relationship between safety culture and safety performance. A more efficient model on variables associated with industrial accident analysis with considerations on the inter-play among the variables is considered in this research.

2. MATERIALS AND METHODS

A massive literature survey was carried out in the subject area to identify various industrial safety variables for the study and thirty-two industrial safety variables were identified. These identified variables were utilized to make a well-structured questionnaire with the aid of Rensis Likert's 5-point attitudinal scale whose dimensions include strongly agree, agree, undecided, disagree, and strongly disagree as shown in Table 1.

Table 1. Rensis Likert's 5-Point Response Option

S/NO	RESPONSE OPTION	WEIGHT ASSIGNED
1	Completely-Agree	5
2	Agree	4
3	Undecided	3
4	Disagree	2
5	Completely-Disagree	1

The descriptive sample size of the small and medium sized enterprises population employed for this study was obtained by using Eq. (1) to validate an adequate population size for the study.

$$\textit{Sample}\ \text{Size} = \frac{p(100-p)z^2}{E^2} \tag{1}$$

where, p is the percentage occurrence of a state or condition

E is the percentage maximum error required

z is the value corresponding to level of confidence required (Taherdoost, 2017).

The questionnaires were then administered to the respondents in the oil and gas industry; those with enormous knowledge on the subject matter.

2.1 Data collection

The data used for this study was obtained through the well-structured questionnaire administered to the knowledgeable respondents in the oil and gas industry after carefully defining the sample size. The 95% confidence level was chosen to ensure an adequate representative population size and to validate the data used for the study. The respondents' scores were collated into m x n data matrix.

2.2 Data analysis

The m x n data matrix obtained served as an input variable that were analyzed in two different ways: first through the use of Kendall's coefficient of concordance (KCC) in which the knowledgeable respondents (thirteen selected judges) in the oil and gas industry were requested to rank the first set of questionnaire in descending order of importance. The respondents' scores were collated into data matrix having a dimension of 13 by 32. The measure of agreement among the judges who ranked the variables was computed. A test statistic called chi square ($\chi 2$) was used to appraise how consistent the judges were in ranking the variables. The Chi-square test, moored on a null hypothesis (H_0) proposes that the ranking by the 13 judges are discordant while the alternate hypothesis (H_1) proposes that the 13 judges were consistent.

Decision Rule: if $\chi^2_{cal} > \chi^2_{tab}$, we reject the null hypothesis, H_0.

if $\chi^2_{cal} < \chi^2_{tab}$, we accept the null hypothesis, H_0.

Kendall coefficient of concordance is given by

$$W = \frac{S}{\frac{1}{12}K^2\left(N^3 - N\right)} \tag{2}$$

where,

$$S = \sum\left(R_j - \frac{\sum R_j}{N}\right)^2$$

R_j = Column sum of ranks
N = Total number of Variables
S = Variance
K = Number of Judges

The second analysis was carried out through the use of Principal Component Analysis (PCA) where the respondent's scores were collated as data matrix and fed into StatistiXL software that provided the following output namely: descriptive Statistic, correlation matrix, eigenvalues, eigenvector, unrotated factor loading, case-wise factor scores, varimax rotated factor loadings, explained variance and factor plot, among others. On the basis of this statistiXL output, 5 factors with eigenvalues ($\lambda > 1$) were extracted and labeled for significant interpretations. The fundamental reason of using the principal component analysis (PCA) is to reduce the dimensionality of the data set containing large number of interrelated variables while retaining as much as possible of the variation present in the data set.

3. RESULTS AND DISCUSSION

3.1 Result of Kendall Coefficient of concordance (KCC)

The Kendall coefficient of concordance (*W*) was obtained as 0.96 using equation 2, and substituting that into chi square (χ^2) equation 3, we have $\chi^2_{cal} = 356.4$

$$\chi^2_{cal} = K (N - 1) W \quad (3)$$

where, K = 13, N = 32, W = 0.96

Since $\chi^2_{cal} = 356.376 > \chi^2_{tab} = 52.1914$, we fail to accept the null hypothesis (H_0) and therefore conclude that the judges ranking of the 32 scaled items were consistent.
The judges ranking were shown as a data matrix in the column which was arranged in ascending order. The Rj connote the ranking coefficients.

Table 2. Merit order of sequentiality of the 32 industrial safety variables

S/N	Rj	Variables	S/N	Rj	Variables
1	13	Work environment	17	251	Complexity of work-zone
2	39	Nature of existing workplace	18	251	Work-zone speed limit
3	86	Workspace design	19	257	Traffic volume
4	98	Nature of task	20	263	Disabled vehicles
5	133	Human error	21	264	Adverse weather condition
6	137	Drowsiness and distraction	22	268	Spilled load
7	153	Personal organization	23	286	Hazardous material
8	155	Logistic pattern	24	291	Driver impairment
9	155	Maintenance on demand	25	298	Mentally challenged faculty
10	164	Response to warning	26	301	Ignoring headlamp usage
11	167	Sub-system failure	27	306	Driver's error
12	182	Catastrophic accident	28	316	Poor lateral control
13	182	Compound failure	29	324	Poor longitudinal control
14	198	Power flow overload	30	344	Poor manoeuvring
15	209	Voltage instability	31	344	Tool type
16	247	Aging of parts	32	686	Poor performance

3.2 Result of Principal Component Analysis (PCA)

The five factors extracted by the principal component analysis loaded clusters of industrial safety variables with several factor loadings. Figure 1 depicts the scree plot of the factorial analysis carried out showing the number of factors extracted by the analysis. It explains how much variation each principal component exerted in the data examined. This shows that there is significant parsimony in factor reduction from 32 to mere 5.

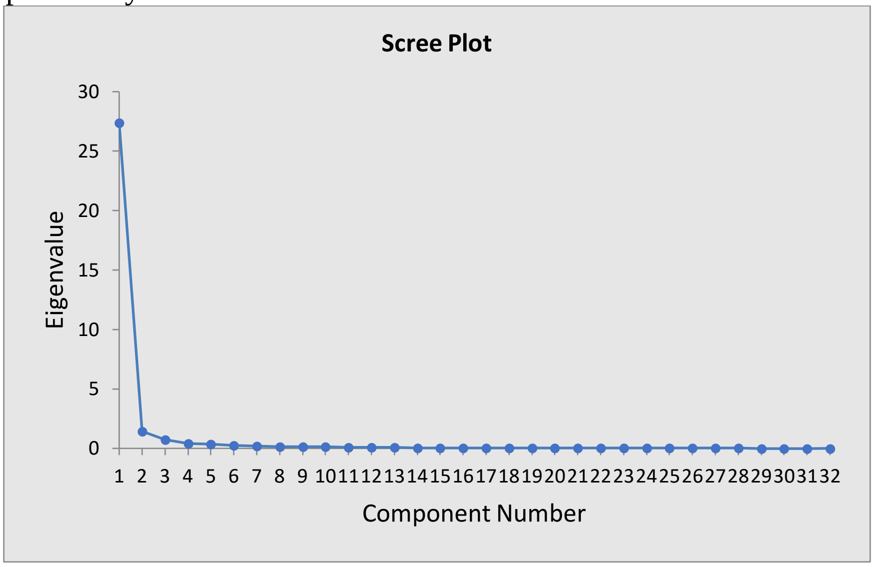

Figure 1: Scree Plot

The result of the varimax rotated factor matrix is depicted in Table 3

Table 3. Varimax Rotated Factor Loadings matrix of 32 variables of industrial accidents

Varimax Rotated Factor Loadings matrix of 32 variables of industrial accidents						
S/N	**Variable**	**Factor 1**	**Factor 2**	**Factor 3**	**Factor 4**	**Factor 5**
1.	Work environment	0.516	0.385	0.316	**0.684**	0.097
2.	Nature of existing workplace	**0.815**	0.463	0.228	0.057	0.103
3.	Workspace design	0.452	**0.776**	0.255	0.236	0.134
4.	Nature of task	**0.594**	0.437	0.380	0.266	0.333
5.	Human error	0.530	**0.742**	0.207	0.137	0.126
6.	Drowsiness and distraction	0.540	**0.724**	0.300	0.142	0.067
7.	Personal organization	**0.811**	0.465	0.208	0.150	0.144
8.	Logistic pattern	0.543	**0.737**	0.222	0.185	0.081
9.	Maintenance on demand	**0.739**	0.376	0.245	0.359	0.033
10.	Response to warning	**0.527**	**0.555**	0.458	0.193	0.181
11.	Sub-system failure	**0.830**	0.425	0.211	0.165	0.144
12.	Catastrophic accident	**0.723**	0.344	0.355	0.268	0.113
13.	Compound failure	0.405	**0.597**	**0.619**	0.223	0.114
14.	Power flow overload	0.382	**0.793**	0.312	0.246	0.146
15.	Voltage instability	0.411	**0.826**	0.260	0.107	0.121
16.	Aging of parts	**0.819**	0.433	0.214	0.192	0.109
17.	Complexity of work-zone	**0.624**	**0.500**	0.361	0.093	**0.426**
18.	Work-zone speed limit	0.426	**0.667**	0.238	0.115	0.149

19.	Traffic volume	**0.787**	0.480	0.270	0.100	0.134
20.	Disabled vehicles	**0.790**	0.498	0.233	0.101	0.078
21.	Adverse weather condition	**0.771**	0.384	0.264	0.263	0.244
22.	Spilled load	0.506	**0.776**	0.212	0.157	0.089
23.	Hazardous material	0.461	**0.584**	**0.561**	0.233	0.123
24.	Driver's impairment	**0.592**	**0.469**	0.383	0.176	**0.468**
25.	Mentally challenged faculty	0.470	**0.786**	0.234	0.124	0.106
26.	Ignoring headlamp usage	**0.783**	0.380	0.267	0.254	0.031
27.	Driver's error	0.312	**0.599**	**0.694**	0.176	0.105
28.	Poor lateral control	0.395	**0.721**	0.334	0.165	0.174
29.	Poor longitudinal control	**0.667**	0.344	0.374	0.320	0.126
30.	Poor manoeuvring	0.398	**0.710**	0.419	0.204	0.124
31.	Tool type	0.418	**0.789**	0.297	0.232	0.133
32.	Poor performance	**0.725**	**0.567**	0.182	0.168	0.022

3.2.1 Creative labeling of the three factors:

Table 4. Factor 1: Work World Culture

Clusters 1 (Factor 1): Work World Culture.		
S/N	Variable description	Factor loading
2	Nature of existing workplace	0.815
4	Nature of task	0.594
7	Personal organization	0.811
9	Maintenance on demand	0.739
10	Response to warning	0.527
11	Sub-system failure	0.830
12	Catastrophic accident	0.723
16	Aging of parts	0.819
17	Complexity of work-zone	0.624
19	Traffic volume	0.787
20	Disabled vehicles	0.790
21	Adverse weather condition	0.771
24	Driver's impairment	0.592
26	Ignoring headlamp usage	0.783
29	Poor longitudinal control	0.667
32	Poor performance	0.725

A principal factor embodying sixteen (16) variables which we creatively labelled, work world culture emerged. The variables all bear positive factor loadings suggesting that it is a sturdy or stocky factor. Seven (7) variables emerged top in the list on the basis of their high factor loadings. We shall discuss these (7) and then give a general review of the rest nine (9). First on the list is Subsystem failure wielding a factor loading of **0.830.** Under this work world culture, a sub- system can be figuratively compared to the heart or kidney as a sub- system (organ) of the human system. If any of this sub- system fails in a human system, the important role they perform collapses and the human dies. Aging of parts with factor loading **0.819** deals with fatigue failure. Again, metaphorically, when the organs and body parts of human system are ageing, it will eventually lead to human death. So it is in all mechanical systems. Next in other of importance is nature of existing workplace, with factor loading of **0.815.** Workplace, work environment or work conditions skulk in stillness as surprise awaits in ambush. So it is in a work place. Work environment is full of potential hazards which can only be avoided by good safety culture rules. Next is personal organization with a factor loading of **0.811** which implies the way a worker organizes themselves. In safety parlance it is referred to as personal trouble. And, if you permit, in African parlance it is called home trouble. Therefore, the way an individual organizes his world goes to a large extent to determine how they react to hazard in work environment. That presupposes that nervousness, slowness in learning and suchlike are indicators of lack of personal organization. Disabled vehicles **0.790** imply vehicles in bad repair state. It could lead to system or sub system failure thereby causing injuries and even fatalities. Traffic volume with a factor loading of **0.789**, in this context, could refer to vehicle traffic, human traffic, or entities traffic. When such movements are beyond certain limit they pose great hazard to industrial safety. Again, adverse weather condition may constitute an act of God and that is why flights and even vehicular movements are suspended. But where flight is already on course it might constitute great hazard to human and equipment. The rest variables under this factor in themselves are potential hazard that could be avoided through appropriate safety culture.

Table 5. Factor 2: Ground Rule Matters

Clusters 2 (Factor 2): Ground Rule Matters.		
S/N	Variable description	Factor loading
3	Workspace design	0.776
5	Human error	0.742
6	Drowsiness and distraction	0.724
10	Response to warning	0.555
13	Compound failure	0.597
14	Power flow overload	0.793
15	Voltage instability	0.826
17	Complexity of work zone	0.500
18	Work zone speed limit	0.607
22	Spilled load	0.776
23	Hazardous material	0.584
24	Driver’s impairment	0.469
25	Mentally challenged faculty	0.786
27	Driver’s error	0.599
28	Poor lateral control	0.721
30	Poor manoeuvring	0710
31	Tool type	0.789
32	Poor performance	0.567

Cluster 2 is creatively labelled Ground Rule matters. The factor loadings are all positive. The variables therein are majorly ergonomic/work conditions and they constitute veritable matters for forging safety ground rules.

Table 6. Factor 3: Safety Considerations

Clusters 3 (Factor 3): Safety Considerations		
S/N	**Variable description**	**Factor loading**
13	Compound failure	0.619

23	Hazardous material	0.561
27	Driver's error	0.694

The third factor is a trio comprising compound failure, hazardous materials and driver's error. They have middling factor loadings suggesting that their influence in safety is moderate

Table 7. Factor 4: Work Condition

Clusters 4 (Factor 4): Work Condition.		
S/N	**Variable description**	**Factor loading**
1	Work environment	0.694

There is also a lone factor in this cluster creatively labelled work condition. It is a lone factor that is almost a work world of its own in that variables under work conditions are multifarious and it is a major factor that causes accident in the work world. Its factor loading is almost substantial.

Table 8. Factor 5: Perception of Safety

Clusters 5(Factor 5): Perception of Safety.		
S/N	**Variable description**	**Factor loading**
17	Complexity of work- zone	0.426
24	Driver's impairment	0.468

Finally, we encounter a dual factor creatively labelled perception of safety under this cluster. It comprises complexity of work zone and driver's impairment. As the saying goes, beauty is in the eyes of the beholder; and so is safety perception depend upon how an individual perceives safety condition. A worker with one impairment or another may not be able to have the right or correct perspective of the work world. The work zone may appear too complex for them to analyse, comprehend and appreciate.

4. CONCLUSION

Arising from the foregoing results and discussions, it is evident that safety in an organisation depends on the prevailing safety culture, the ground rule guiding safety practices, safety considerations observed by management and workers alike. The nature of hazards (work conditions) existing in the organisation as well as the way workers and managements perceive safety. Hence the PCA and KCC statistical models adopted appear to provide enlightenment on the complexion of multi- factor work world. This study focused on the panoramic view of the work world containing multifarious variables that characterize multi -factor world of work and the PCA models adopted was quite successful in achieving parsimony by reducing the 32 identified variables of work world to mere 5. This is indeed a significant parsimony in factor reduction. The study is therefore successful in explaining the dynamism of multi-factor culture of work world. This study therefore unwrapped the deeper meanings associated with multi-dimensional factors in industrial safety.

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