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Contributions and Consequences coming from Human and Organizational Factors to the Accidents

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Human and Organizational Factors (HOFs) are usually the root causes of complex system failures. Human reliability analysis (HRA) methods to build the structure of HOFs have been proposed. However, they typically lack validated data. To address this limitation, learning from the past has been considered regarding the EU Major Accident Reporting System's (eMARS) records. Category data analysis has been applied to support the quantitative analysis. With the HOFs related near-miss and major accidents recorded by eMARS reports, the obtained results show deep insights about the co-influence and contributions of HOFs to the accidents and the possibility to predict the hazards to the process safety, environment, and cost consequences. Our framework contributes to enhancements in HOFs accidents control and mitigation by enabling risk awareness.

1. Introduction

Safety is always a significant subject for the process industry. Its inherent attributions with many hazardous chemical materials and reactions may lead to severe consequences affecting people, property, and the environment. Human and Organizational Factors (HOFs) are significant contributors to the overall risk of a complex human-machine system. To find the HOFs' influencing mechanism, there have been nearly 50 Human Reliability Analysis (HRA) methods that guide identifying human errors and assessing Human Error Probabilities (HEPs) (Xing et al., 2021). These methods have proposed many sets of HOFs, such as safety culture, training, staffing, procedures. But the long-standing question is the lack of data to validate factors. Learning from the past may be a possible way. (Mourad, 2021) using logistic regression, decision trees, neural networks, support vector machine, naive Bayes classifier and random forests to forecast the occurrence of the human, environmental and material consequences of industrial accidents. Machine learning methods also have been already adopted to analyse accident databases as in (Comberti et al., 2018.) and (Comberti et al., 2015.), accident precursors as in (Baldissone et al., 2019.) and (Comberti et al., 2015.) Category data analysis has been applied to support the quantitative analysis in this work. The research questions of this study are:

- 1) Are there correlations between the HOFs and accidents' consequences?
- 2) What are the contributions of HOFs to the accidents' consequences?

2. Research Method

2.1 eMARS data collection

In this research the eMARS database is used to do the data analysis. eMARS contains reports of chemical accidents and near misses provided to the Major Accident Hazards Bureau (MAHB) of the European Commission's Joint Research Centre (JRC) from EU, EEA, OECD, and UNECE countries (under the TEIA Convention). Among the 73 columns of data of eMARS database, seven columns are selected, including Accident ID, Human, Organizational Causative Factor Type, Human On site Quantity/Effect, Environmental On site Quantity/Effect, Cost On site Quantity/Effect, Disruption Off site Quantity/Effect. To focus on the HOFs cases analysis, 1128 cases are filtered out those not containing/identified 'Human' or 'Organizational Causative Factor Type' factors, then only 532 cases related to the HOFs are selected.

2.2 Categorical data analysis

This study applied the categorical data analysis method to investigate the HOFs contributions to accidents. Categorical data analysis is data analysis where the response variable has been grouped into a set of mutually exclusive ordered or unordered categories. (Watson, 2014). Categorical data transformation is shown in Table 1. IBM SPSS Statistics 24® are used for data analysis.

Table 1: Categorical data transformation

Causes	Disordered categorical variables	Consequences	Disordered categorical variables
Human Error Mode	①operator error	Human On/Off Site Effect	At risk
	②malicious intervention		Injury
	③wilful disobedience/failure to carry out duties		Fatalities
	④ operator health (includes ailments, intoxication, death, etc.)		not known / not applicable
	⑤failure to carry out duties not identified		
	⑥not known / not applicable/empty		
Organizational Causative Factor	①design of plant/equipment/system	Environmental On/Off Site Effect	Freshwater Pollution
	②Installation/construction		Inland Pollution
	③process analysis		Offshore Pollution
	④maintenance/ testing/inspecting	Cost On/Off Site Effect	Atmosphere Pollution
	⑤training/instruction		not known / not applicable
	⑥Supervision/staffing		material losses
	⑦user-unfriendliness (apparatus, system, etc.)		response, cleanup, restoration costs
	⑧management attitude problem		fine and legal costs
	⑨organized procedures/ management organization inadequate		Production loss/ Interruption
			Profit Failure
			not known / not applicable/ empty
	not known / not applicable/empty	Social Effect	Infrastructure influence (telecommunication, roads, railways, waterways, air transport etc.)
	--		nearby factories, offices, small shops
	--		schools, hospitals, institutions
	--		nearby residences, hotels
	--		Other places of public assembly

2.3 Correlation between unordered categorical data

The Chi-square test is often used to analyse the correlation between disordered categorical variables. It can also be used to analyse the relationship between binary categorical variables. The Chi-square test is the degree of deviation between the observed value and the theoretical value regarding the statistical sample. If the chi-square value is more significant, the greater the degree of deviation between the two. On the contrary, the smaller the deviation is. If the two values are exactly equal, the chi-square value is 0, indicating that the theoretical value is completely consistent. Meanwhile, the chi-square test always tests the null hypothesis, which states no significant difference between the expected and observed results (Fisher and Yate, 1971).

3. Results

3.1 HOFs Contributions to the recorded accidents

Table 2 shows the HOFs contributions to the recorded accidents. Human errors contributed to 40% of recorded accidents with these causative factors. Besides, organisational causative factors contributed to 92.97% of recorded accidents. Mainly, organisational factors “⑨①⑤③④” contributes to 76.83%.

Table 2: HOFs Contributions to the recorded accidents

Organizational Causative Factors	Frequency	%	Human Error Mode	Frequency	%
①design of plant /equipment/system	167	16.53%	①operator error	199	37.41%
②Installation/construction	21	2.08%	②malicious intervention	5	0.94%
③process analysis	124	12.28%	③wilful disobedience /failure to carry out duties	19	3.57%
④maintenance/testing /inspecting/recording	124	12.28%	④operator health (includes ailments, intoxication, death, etc.)	1	0.19%
⑤training/instruction	138	13.66%	⑤failure to carry out duties not identified	1	0.19%
⑥Supervision/staffing	93	9.21%	⑥not known / not applicable/empty	317	59.59%
⑦user-unfriendliness (apparatus, system, etc.)	18	1.78%			
⑧management attitude problem	31	3.07%			
⑨organized procedures/ management organization inadequate	223	22.08%			
not known / not applicable//empty	71	7.03%			

3.2 Correlation analysis

Table 3: Correlations between HOFs causative factors and consequences

Correlations between HOFs causative factors and consequences	Case validity		Chi square test		
	N	Percentage	Pearson Values	df	sig. (Two-tailed)
Human On-site Effect * Human Error	532	100.0%	130.311	48	0.000***
Human On-site Effect * Organizational Causative Factor	532	100.0%	657.069	552	0.001***
Human Off-site Effect * Human Error	532	100.0%	36.104	32	0.283
Human Off-site Effect * Organizational Causative Factor	532	100.0%	417.018	368	0.039*
Environmental On-site Effect * Human Error	532	100.0%	4.960	24	1.000
Environmental On-site Effect * Organizational Causative Factor	532	100.0%	257.267	276	0.785
Environmental Off-site Effect * Human Error	532	100.0%	5.895	24	1.000
Environmental Off-site Effect * Organizational Causative Factor	532	100.0%	562.628	276	0.000***
Cost On site Effect * Human Error	532	100.0%	47.326	32	0.040*
Cost On site Effect * Organizational Causative Factor	532	100.0%	400.022	368	0.121
Cost Off site Effect * Human Error	532	100.0%	267.519	64	0.000***
Cost Off site Effect * Organizational Causative Factor	532	100.0%	1529.436	736	0.000***
Disruption Off site Effect * Human Error	532	100.0%	51.965	64	0.860
Disruption Off site Effect * Organizational Causative Factor	532	100.0%	726.563	736	0.591

Note: * sig<0.05, ** sig<0.01, *** sig<0.001

Table 3 shows the correlation between HOFs causative factors and accidents' consequences. Chi-square test has been applied. Regarding the significance values (sig.), the most significant influences from Human Errors

to the results are the pairs: 1) Human On-site Effect * Human Error (sig=0.000***), and 2) Cost Off-site Effect * Human Error (sig=0.000***). Besides, the most significant influences from Organizational Factors to the consequences are the pairs: 1) Human On-site Effect * Organizational Causative Factor (sig=0.001***), 2) Environmental Off-site Effect * Organizational Causative Factor (sig=0.000***), and 3) Cost Off-site Effect * Organizational Causative Factor (sig=0.000***).

3.3 The Most Significant Human Errors' Contributions

To have an in-depth study on the most significant influences from Human Errors to the consequences, "Human On-site Effect" and "Cost Off-site Effect" have been further investigated. Figure 1a shows that the human error mode of "①-operator error" contributed to 190 accidents (88.37%; excluded the 'Not known/not applicable' cases). After that, "③-willful disobedience" contributed to 9%, and remains contributed to 3.26%. Figure 1b further shows the significant influences of operator errors on the human on-site effect. The consequences of "injury (37.03%)", "injury & fatalities (28.40%)", and "fatalities (24.69%)" are highlighted.

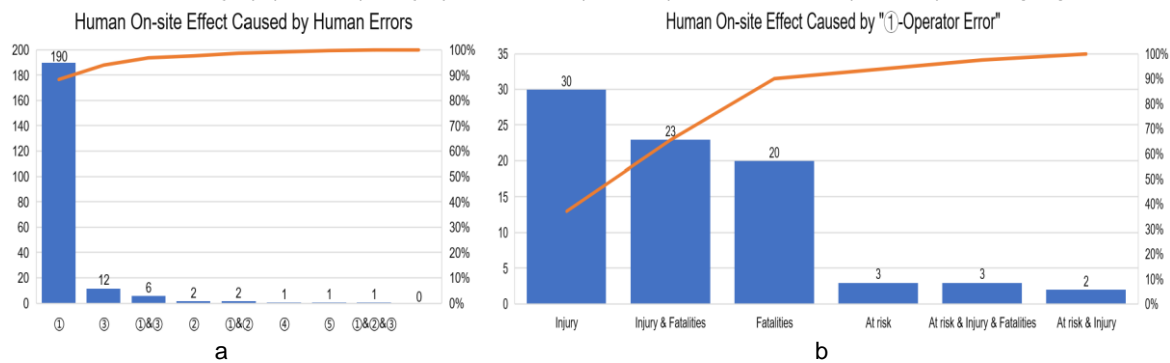


Figure 1. Human On-site Effect * Human Error (sig=0.000***)

Figure 2a shows that the combined human error mode of "①-operator error" and "②-malicious intervention" contributed to 59.70% of the cost off-site effect. Apart from "unknown" recorded accidents, Figure 2b shows that "①-Material losses (58.33%)" and "②-Restoration costs (25%)" are the major consequences of cost off-site effect caused by human errors.

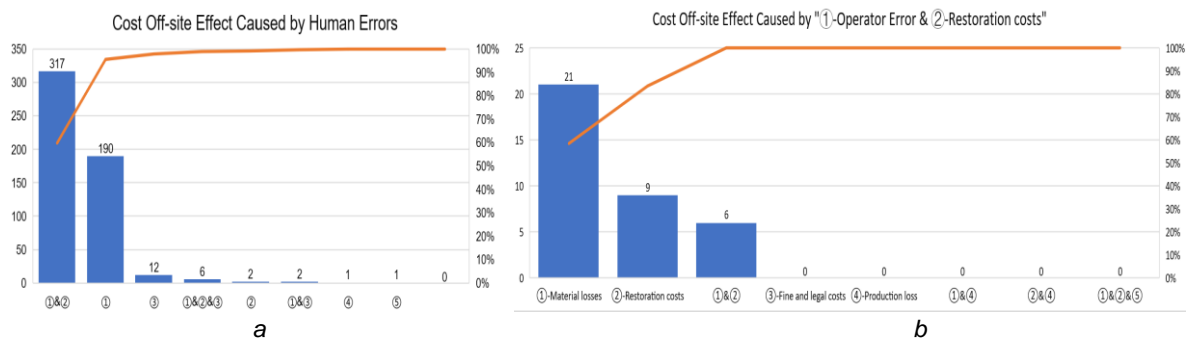


Figure 2. Cost Off site Effect * Human Error (sig=0.000***)

3.4 The Most Significant Organizational Causative Factors' Contributions

To have an in-depth study on the most significant influences from Organizational Factors to the consequences, "Human On-site Effect", "Environmental Off-site Effect", and "Cost Off-site Effect" have been further investigated. Figure 3a shows that the organisational causative factors of "①③④⑤⑨" contributed to 75.11% of the human on-site effect. Figure 3b further shows the major influences of the organisational causative factors of "①③④⑤⑨". The consequences of "injury" (33.17% of all human on-site effect from "①③④⑤⑨"), "at-risk" (28.65%), and "injury & fatalities (22.71%)" are highlighted. Meanwhile, the factor of "⑨-organized procedures/management organisation inadequate" contributed the largest numbers of accidents (27.4%), followed by "①-design of plant/equipment/system" (22.44%), "④-maintenance/inspecting" (17.43%), "⑤-training/instruction" (16.45%), and "③-process analysis" (16.29%).

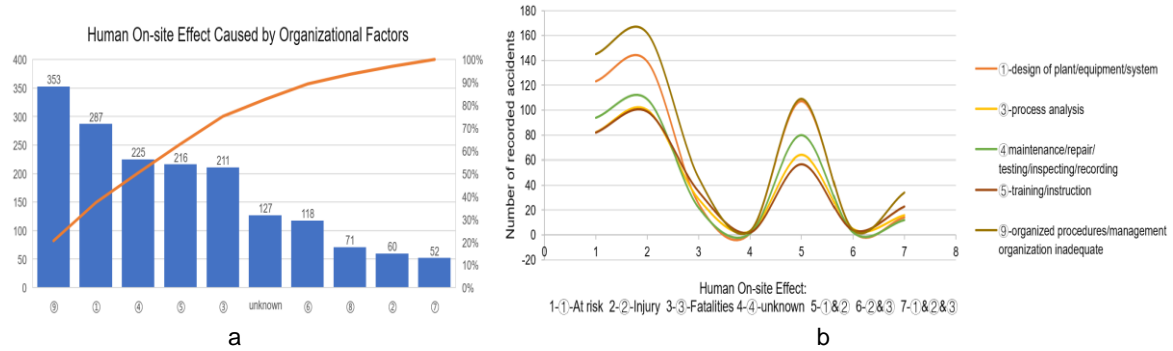


Figure 3. Human On-site Effect * Organizational Causative Factor ($\text{sig}=0.001^{***}$)

Figure 4a shows that the organisational causative factors of “①③④⑤⑨” contributed to 76.95% of the environmental off-site effect. Figure 4b further shows the major influences of the organisational causative factors of “①③④⑤⑨”. The consequences of “atmosphere pollution” (98.34% of all off-site environmental effects from “①③④⑤⑨”) are highlighted. Meanwhile, the factor of “⑨-organized procedures/management organisation inadequate” contributed the largest numbers of atmosphere pollution (27.99%), followed by “①-design of plant/equipment/system” (23.05%), “⑤-training/instruction” (17.06%), “③-process analysis” (16.15%), and “④-maintenance/inspecting” (15.76%).

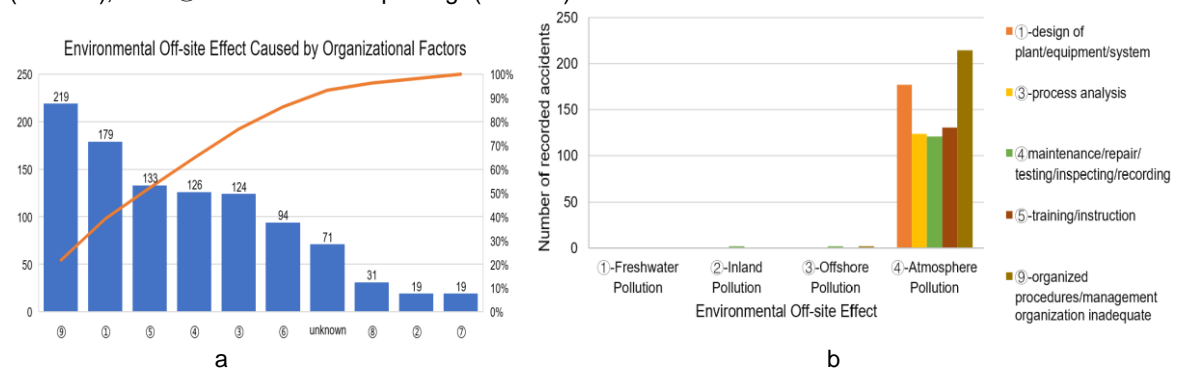


Figure 4. Environmental Off-site Effect * Organizational Causative Factor ($\text{sig}=0.000^{***}$)

Figure 5a shows that the organisational causative factors of “①②③④⑤” contributed to 64.82% of the cost off-site effect. Figure 5b further shows the major influences of the organisational causative factors of “①②③④⑤”. The consequences of “material losses” (72.86% of all cost off-site effect from “①②③④⑤”) are highlighted. Meanwhile, the factor of “①-design of plant/equipment/system” contributed the largest numbers of “material losses” (32.41%), followed by “②-Installation/construction” (22.07%), “③-process analysis” (17.93%), “④-maintenance/inspecting” (14.48%), and “⑤-training/instruction” (13.10%).

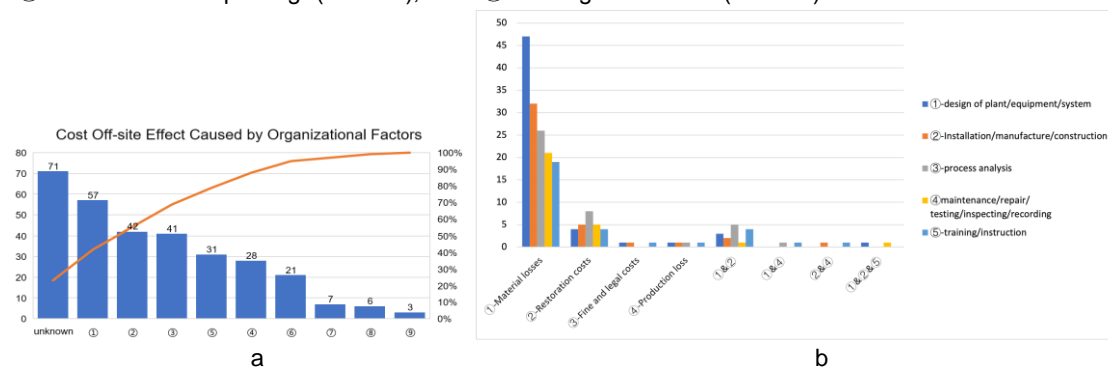


Figure 5. Cost Off site Effect * Organizational Causative Factor ($\text{sig}=0.000^{***}$)

4. Discussion and Conclusions

4.1 HOFs Contributions to the recorded accidents

The eMARS database provided an effective data resource to investigate the HOFs influences on those reported accidents. Using the eMARS database, this study applied categorical data analysis and correlation analysis. The results show that human errors contributed to 40% of recorded accidents. Within all labelled human error modes, “① operator error” contributed to 88% when the unknown cases were excluded. Organisational causative factors contributed to 92.97% of recorded accidents. Especially, organisational factors “⑨①⑤③④” contributes to 76.83%. The results indicated that operator error should be the most important consideration for human error control. Further, since organisational factors nowadays become the major causative factor, “⑨ organized procedures/management organisation inadequate”, “① design of plant/equipment/system”, “⑤ training/instruction”, “③ process analysis”, and “④ maintenance/testing/inspecting/recording” should pay more attention.

4.2 Correlations of the HOFs and accidents' consequences

According to the Chi-square test, five pairs of the most significant influences from HOFs to the consequences have been figured out. For the human on-site effect, both human errors and organisational factors have contributions. Human errors contributed to the accident consequences of “injury” (37.03%), “injury & fatalities” (28.40%), and “fatalities” (24.69%). Organisational factors contributed to the consequences of “injury” (33.17% of all human on-site effects from “①③④⑤⑨”), “at-risk” (28.65%), and “injury & fatalities” (22.71%). For the environmental off-site effect, only organisational factors contributed to the consequences of “air pollution” (98.34% of all ecological off-site effects from “①③④⑤⑨”). For the cost off-site effect, both human errors and organisational factors have contributions. Human errors contributed to the major accident consequences of “material losses” (58.33%) and “restoration costs” (25%). In comparison, organisational factors contributed to the major results of “material losses” (72.86% of all cost off-site effects from “①②③④⑤”).

4.3 Limitation and future work

This research is based on the simplifying hypothesis that human error and organizational factors are independent. The future work can discuss the relationship between them more deeply.

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