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Relationship between Reactive and proactive Safety Indices: A Case Study in the Chemical Industries

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Abstract

Background: Investigating the influence of various proactive factors on reactive indices in the chemical industries can result in providing preventive and control measures in these industries. This study was designed and conducted to measure the relationship between reactive and proactive safety indices in the chemical industry. **Methods**: This cross-sectional study was conducted in 2018 in 12 chemical industries. The study data were associated with a period of 5 years (2013-2017). Study data has been analyzed based on factor analysis using analytical software IBM SPSS AMOS v. 22.0. $\chi 2$ / df, RMSEA, CFI, NFI, and NNFA (TLI) indices were used to evaluate the model's goodness fit in this study. **Results**: The mean reactive indices of recurrence coefficient and accident severity in this study was 14.15(18.32) and 182.112(10.50) days, respectively. The exploratory factor analysis results determined that 16 indicator variables were categorized into 4 groups of proactive indices, including safety training, risk management, control of unsafe situations, and unsafe acts. Analyzing the confirmatory factor additionally confirmed that there is a significant relationship between the two groups of reactive and proactive indices in this study(P <0.05), and the goodness of model fit was also recognized appropriate (RMSEA = 0.055). **Conclusion**: This study's findings approved that the proactive indices affect the incidence and severity of accidents as safety reactive indices in the chemical industries. Also, the risk management proactive index and insecurity conditions were more effective than other indices.

Keywords: Chemical industry; Accident; Reactive index; Proactive index; Factor analysis

Introduction

The chemical industries, as an upstream industry, have many safety-related risk factors. There is a high risk of occurring different events, accidents, and stops of operations and industrial processes in these industries.[1-3] There are different incidents in the chemical industries and their critical consequences that had been a cause for concern. Disastrous examples of these accidents in Iran include accidents in some refineries, petrochemicals, and other chemical industries in the country. Also, there is a risk of all kinds of accidents and damages for everyone due to the nature of the chemical industry's processes. Occurring a variety of devastating consequences can create consequences such as stopping the production

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process of other downstream industries because of these industries' upstream role. The results obtained by some studies have determined that occurring disastrous events such as fire, explosion, and release of toxic substances in the chemical industries are higher than in other industries. Furthermore, the complicated nature of work in these industries accompanying the intrinsic jeopardies of chemical substances and compounds can bring significant economic and human damage.[4, 5]

It is highly important to measure different kinds of safety-related indices, including post-incident or reactive indices that evaluate safety efficiency and effectiveness across a definite period for the industry and determine pre-incident or proactive indices that evaluate the effectiveness of preventive safety programs. These indices are widely applied in planning to provide preventive, control measures as well as making the environment safe. One of the significant challenges in this field is to evaluate and analyze the relationship between these two types of indices and evaluate the type and extent of the influence of proactive indices on reactive indices. The effectiveness of each index and proactive parameter can be determined through this evaluation, and based on it, better and more comprehensive safety strategies can be designed and executed.[6-9]

Accordingly, it is essential to investigate the relationship between reactive and proactive safety indices in the chemical industry and is preferred because occurring different events and incidents in these industries can threaten the health and safety of employees and stop the production operations and impose costs and indirect environmental, human, and economic consequences by disrupting industrial processes. Therefore, this study has been designed and conducted to investigate the relationship between reactive and proactive safety indices in the chemical industries based on structural equation modeling.

Methods

This cross-sectional study is a comprehensive retrospective investigation conducted to evaluate the relationship between reactive and proactive safety indices in the chemical industries in 1397. The study data were related to a period of 5 years (2013-2017). The studied industries included 12 volunteer industries for this study, from the statistical population, including 25 chemical industries.

Data collection tools and study parameters

The information needed in this study comprises the safety analytical report of the studied chemical industries (including the report of safety reactive indices such as accident recurrence coefficient and accident severity coefficient). The collected information concerning the proactive indices gathered using a researcher-made checklist. Experts confirmed Cronbach's alpha coefficient confirmed the validity of this questionnaire and its reliability at 0.92. The proactive indices applied in this study comprised four criteria and 16 sub-criteria. (1) training index including the parameters of periodical safety training, training and learning from accidents, quantity or duration of the training and evaluating content or quality of training, (2) risk management index including identifying the risk, evaluating the risk, safety audit, and chemical safety management program; (3) Index of unsafe acts including reporting of unsafe acts and semi- incidents, human error and dangerous behavior based on knowledge and understanding, human error based on skills, and (4) index of unsafe conditions identifying and decreasing the violations and unsafe designs, unsafe working methods, the defect of protecting the system.

Two safety performance reactive indices were defined in this study including (1) accident recurrence coefficient and (2) accident severity coefficient based on the formula introduced by the US Occupational Safety and Health Administration (OSHA) and based on 100 workers with 200,000 hours of activity per year.[10] Proactive safety indices in this study included 4 factors: safety training, risk management, unsafe acts control program, and unsafe conditions.[4] proactive safety indices was performed were calculated based on exploratory factor analysis (EFA). In this field, activities and proactive indices' desirability were evaluated based on a 5-point Likert scale (very low, low, medium, high, and very high). We can note that if there is no guess about the structure of the relationships between the variables, exploratory factor analysis can be used. In other words, Exploratory factor analysis is performed to examine experimental data to identify and recognize the relationships between them.[11, 12]

Analyzing the study data

The relationship between the studied indices has been examined based on factor analysis and employing analytical software IBM SPSS AMOS v. 22.0. Factor analysis is a method to analyze the variance between several dependent variables based on their description regarding several hidden variables or factors. Factor analysis is a comprehensive statistical approach to test hypotheses about the relationships between observable and latent variables, that sometimes named covariance structural analysis, causal modeling, or structural equation modeling. Structural equation modeling can exhibit complicated relationships between variables because this model can utilize and run simultaneously the relationships between internal and external factors and, besides, can include hidden factors and variables in the model.[11, 13-15]

We measured the model presented in this study by goodness-of-fit indices. The goodness of fit presumed from structural equation modeling using $\chi2$ / df (2-3) and root mean square error of approximation (0.05-0.08) and comparative fit index (0.95-1.95), normed-fit index (-0.1) 0.95), and non-normed fit index or tucker-Lewis index (0.95-1.95)(19-19). The estimate of each parameter and index on each other has been defined based on the shape (arrow) and numerical relationships, including the amount of estimate, standard error (SE), and *P*-value.

Results

According to the results of 92 accidents recorded in this study, (27.2%) 25 accidents were related to the release of chemical compounds, (22.8%) 21 fires, and (50%) 46 accidents caused by warehousing, transporting, and displacing of chemicals. It should be noted that the events were analyzed as accidents in this study that produced a direct and damaging consequence to human and capital. The injured people's mean age and work experience were 34.13(5.08) and 6.11(3.53) years, respectively. (39.1%) 36 accidents occurred at night, and (60.9%) 56 accidents occurred during the day. Desirability (high and very high) of the variables associated with safety training, including periodic training, training in accident learning, quantity (duration), and quality (content) of training in the 12 studied chemical industries were estimated at 14.3% and 0.4%, %, 10.5%, and 0.8% respectively. The desirability rate of variables related to safety risk management, including identifying the risk, evaluating the risk, systematic analysis of accidents, and using chemical safety management program in the studied 12 chemical industries were estimated at 20.5% and 15.0 %, 6.0% and 12.4%, respectively. The desirability rate of variables related to controlling unsafe conditions, including unsafe design, defects in equipment and tools, defects in protection and protection system, and unsafe working methods was estimated at 18.2% and 25.6%, 22.5%, and 16.0%, respectively. The desirability rate of variables related to the control of unsafe acts, including lack of safety knowledge, not applying the personal protective equipment (PPE), occurring the dangerous behavior, and being in an unsafe situation was estimated at 8.5% and 24.0%, 18.5%, and 15.0%, respectively.

The results determined that the mean reactive indices of repetition coefficient and accident severity (AFR and ASR) were 14.15(18.32) and 182.10(112.50) days, respectively, for the 12 studied industries over 5 years (2013-2014). The exploratory factor analysis results determined that the 16 studied variables are classified into 4 groups of proactive indices of safety education, risk management, unsafe acts control program, and unsafe conditions. Table 1 shows

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the findings related to exploratory factor analysis. As specified, the variables of quantity (duration) of training (Estimate = 1.50), risk assessment (Estimate = 1.45), defects in protection and protection system (Estimate =1.34), respectively. and not using personal protective equipment (Estimate =1.35) affected mostly the four criteria of proactive indices.

Figure 1 shows evaluating the relationship between safety creative and proactive indices based on the results of confirmatory factor analysis (CFA). As specified, the confirmatory factor analysis findings showed that there is a significant relationship between these two types of indices (P <0.005); also, there is an inverse relationship between negative parameters. The results of evaluation and measurement of goodness of model fit also determined that the values of $\chi2$ / df, root mean square error of approximation, comparative fit index, and non-normed fit index (tucker-Lewis index) indices were calculated and estimated at 2.01, 0.055, 0.984, and 0.985, respectively.

Table 1. Results of exploratory factor analysis

Latent factor	Indicator variable	Estimate	SE	*P*-value*
Training	Periodic training	0.86	0.013	0.001
	Accident Learning	1.00	-	-
	Quantity (Duration)	1.50	0.018	0.001
	Quality (content) of education	1.12	0.011	0.001
Management Risk	Identifying the hazards	1.00	-	-
	Evaluating the risk	1.45	0.06	0.001
	Systematic analysis of accidents	0.84	0.14	0.003
	Applying a chemical safety management program	0.87	0.09	0.001
Controlling unsafe conditions	Unsafe design	0.75	0.02	0.001
	Defects in equipment and tools	1.00	-	-
	Defects in protection and protection system	1.34	0.08	0.001
	Unsafe working methods	0.88	0.023	0.002
Controlling unsafe acts	Lack of safety knowledge	1.25	0.09	0.001
	Not using personal protective equipment	1.35	0.25	0.001
	Occurring dangerous behavior	1.00	-	-
	Placing in an unsafe situation	0.79	0.018	0.002

* A significant level was obtained in this study (P <0.05) based on the results of exploratory factor analysis.

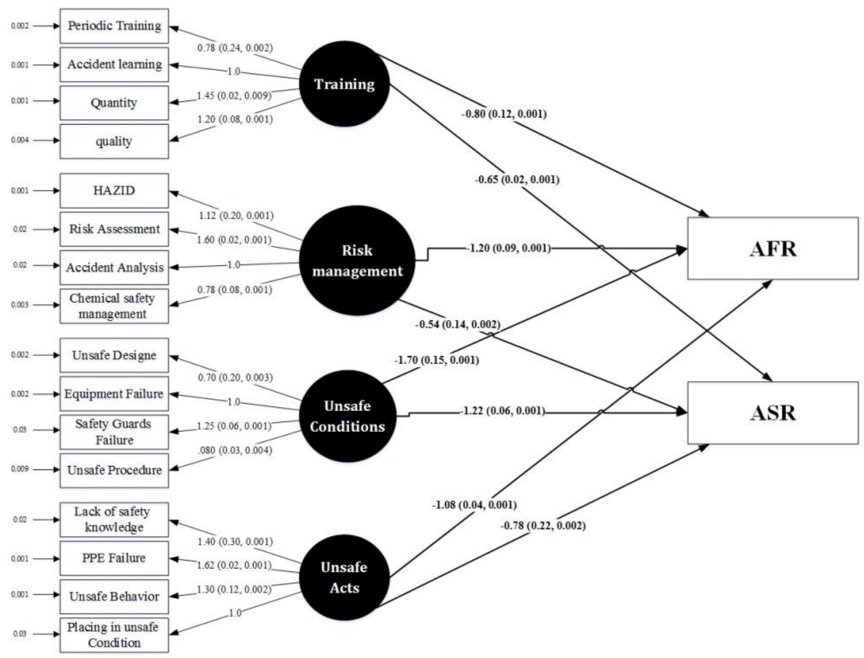

Figure 1. The final model of the relationship between proactive and reactive indices in the chemical industries

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Discussion

In this study, the findings achieved by analyzing 92 accidents in the 12 chemical industries under the study over 5 years, determined that the frequency and severity of these accidents are high (based on the reactive coefficients of recurrence coefficient and severity of accidents). The latent factor of unsafe conditions (-1.70) and risk management (-1.20) had the most estimate. Consequently, this finding again confirmed that the chemical industry is considered one of the most sensitive sectors of industry and production and is always influenced by different events due to the dynamics of chemical processes and the dangerous nature of materials and compounds employed in it.[20-23]

Findings achieved in this study based on the results of exploratory factor analysis and confirmatory factor analysis determined that accidents in the chemical industry follow a multi-factor approach and defects in various structures can affect the frequency and severity of accidents in these industries, also, the role and share of each cause can be different due to the diverse functions of varied factors.[24, 25] As these findings explain, defects in the processes associated with safety training, risk and hazard management of this industry, as well as defects in the management and control of unsafe conditions and unsafe acts, can influence significantly the recurrence as well as the severity of accidents and damages caused by it.[26, 27] Also, the exploratory factor analysis findings showed that the weight and influence/estimate have various effects on different variables on the proactive and preventive indices. According to these results, the variables of quantity and duration of the training, evaluation, and monitoring of safety risks in the workplace, the effectiveness of control measures in the field of defects in protection and protection system, as well as management of individuals and workers to prevent non applying the proper personal protection equipment at the time of exposure to a variety of chemical risk factors influences significantly the proactive and preventive indices of training, risk management, controlling the conditions and unsafe acts, respectively. This finding can be applied as a critical step in planning and advancing the safety level and empowering the work environment to prevent disastrous accidents.[28, 29]

Although this study aimed mainly to analyze and evaluate the relationship between safety and reactive and proactive indices in the chemical industries under the study, this point can be obtained by an accurate and comprehensive study in the proposed model that the indicator variables and their kinds of relationship with accidents and also, the severity of accidents and injuries caused by accidents have been discussed in a dispersed way in many studies, which can confirm these findings and be in agreement with these findings.[7-9, 22, 26, 30] Consequently, unsafe conditions and unsafe acts are considered as one of the integral elements of the causal chain of accidents based on the findings of most studies,[7-9] and defects in risk-based processes, including identification, evaluation, and control of risk, can affect directly and also under the influence of others conditions a variety of accidents.[12, 26] Additionally, the proactive and preventive index of training and its variables as a basic factor, directly and indirectly, affect all types of events.[9, 12, 31]

Conclusion

The findings of this study, considering the strong and significant relationship between safety proactive and reactive indices in the chemical industries, indicated the important and practical result that investing in short, medium, and long term time on safety proactive and preventive indices could influence the reactive safety indicators significantly and reduce the frequency and severity of accidents. Also, the frequency and severity of accidents in the chemical industry follow the multi-causal theory in accidents; therefore, it should be noted in accident safety management programs that all variables, indices, and factors in this field should be considered reducing safety proactive and reactive indices.

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