RELIABILITY AND VALIDITY OF ORGANIZATIONAL FACTORS MEASUREMENT IN RISK MANAGEMENT OF PROCESS INDUSTRY EQUIPMENT

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Original Scientific Paper

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In recent decades, process safety control and process safety risk assessment have become very attractive topics. The way control is carried out, using tools such as HAZOP, FMEA, FTA, and similar is not sufficient to adequately prevent or control accidents with serious consequences in the process industry. The need to analyze the causes of the causes themselves, with special emphasis on the impact of organizational factors has arisen. This research results in the development of an original, reliable, and valid measuring instrument for assessing organizational factors important for risk assessment methodologies in working with pressure equipment. The initial instrument was designed based on the previous research and then checked by statistical analysis, using the Kaiser-Meyerto-Olkin test, exploratory factor, and reliability analysis. The proposed instrument has reduced 71 to 48 dimensions, describing 10 organizational factors important for risk management of pressure equipment. Providing a valid and reliable measurement instrument is essential for a proactive approach, which enables managers employed in the organization to mitigate the risks of pressure equipment operation, and prevent accidents. The proposal of further research is the application of confirmatory factor analysis or/and structural equation modeling on data collected.

Keywords: Organizational factors; Risk management; Process Industry; Pressure Equipment; Reliability; Validity.

INTRODUCTION

Intensive work is done through decades on the introduction, implementation, and improvement of standards related to safety and health at work, which has certainly led to some improvements and progress in accident prevention, but the situation is far from the objectives of Vision Zero. This issue requires constant work and is striving for better results (Alheriani et al., 2021; Marhavilas et al., 2011; Spasojević-Brkić et al., 2019; Timovska, 2013). The number and cause of accidents and failures with serious consequences in factories and plants of the process industry is a topic, i.e. a problem which, despite frequent consideration, still requires attention and which will be given a lot of attention for a long time (Golubović et. al., 2021; Schmitz, et al., 2021; Swuste, et al., 2016). As the history of industrial incidents shows, the process industry is the most critical in terms of equipment failures and the consequences that accompany those failures. Consequences of failure of pressure equipment include consequences for humans (injury or fatal outcome), consequences for the environment (which may also indirectly affect human safety and health), and consequences in terms of material and financial losses of interruptions in production and remediation of

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consequences) (Greenberg & Cramer, 1991). Precisely because of the seriousness of the stated consequences, it is extremely important to control the potential causes of accidents and failures in a way that one does not learn from one's own experience, but from the experiences of others. In theory and practice, there are several solutions and procedures for risk assessment of various technical systems, including systems in the process industry. However, to date, there is no universally accepted and sufficiently comprehensive risk assessment methodology for pressure equipment. In addition, the API 581 and RIMAP standards are extremely complicated, very comprehensive, and very time and financially demanding to implement (Jovanovic, 2004; Kauer et al., 2004; Khan & Abbasi, 1998), so they pose a challenge in the case of smaller process plants and factories. The analysis of the history of accidents also shows that the mechanical integrity of the equipment is a significant indicator and in that sense, the risk analysis of such a system focuses on a given direction (Baker et al., 2007; Golubović et al., 2021; Hopkins, 2000; Nivolianitou et al., 2006). However, a more detailed analysis makes it clear that in most cases there would be no equipment failure or the consequences would be significantly less if there were no omissions in the organization (Pate-Cornell & Murphy, 1996; Skogdalen & Vinnem, 2011; Smith et al., 2013). Organizational culture is a factor of significant impact on risk in the process industry (Cooper, 2000; Glendon & Stanton, 2000; Guldenmund, 2000; Knegtering & Pasman, 2009; Mearns et al., 2003). What is common to all the above existing models of the risk assessment, and which will be the subject and goal of this research, is the fact that in previous research, risk assessment indicators are not sufficiently included indicators of organizational factors.

ORGANIZATIONAL FACTORS MEASUREMENT MODEL DESIGN

It is necessary to define the influential organizational factors on the risk assessment in the exploitation of equipment in the process industry, such as pressure equipment, and determine the measurement scale of their impact (quantification of the obtained factors). In that sense, it is necessary to first design a preliminary list of organizational factors based on existing standards, available literature, research, history of major accidents related to pressure equipment, and conversations and consultations with experts in the field. Then it is necessary to make a procedure for forming a data collection plan. This is followed by conducting research, i.e., collecting the necessary data on a representative, large enough sample. Finally, the analysis and processing of the results obtained from the questionnaire by the methods of multivariate statistics follow.

The starting point for creating a measurement instrument is the formation of dimensions that will describe the factors that describe the influential latent variables. In this particular case, the dimensions will be the questions within the questionnaire and the factors will be the areas of the questionnaire described by the given questions. As a minimum, each 3-dimensional factor should be described to achieve the effect of greater validity, accuracy, and reliability of the questionnaire (Hair et al., 1998; Yong & Pearce, 2013). As it can be expected that part of the question will be rejected after the statistical analysis of the questionnaire, it is necessary to form at least twice as many questions for the preliminary questionnaire as the required minimum (Hinkin et al., 1997). Each dimension should reflect the factor to which it belongs and/or to which it is related. This can be achieved by forming each dimension within one factor so that it has a common cause or common consequence (e.g. communication in a company). The criterion for the selection of items (questions) is based on the assumption that the theoretical and/or empirical results support their validity in terms of the impact on risks related to processing safety and pressure equipment. The questionnaire should be comprehensive to cover a sufficient number of such items to be able to adequately assess the impact of organizational factors.

Initially, 10 factors were identified, as in Table 1, while each of them was described by many dimensions.

The questionnaire for examining organizational factors had the following structure - each factor was described by many dimensions, i.e. questions: D1: communication (6 questions), D2: hazardous materials and equipment (5 questions), D3 process safety (4 questions), D4: personal safety (5 questions), D5: organizational change management (8 questions), (D6) Subcontractors from other companies (6 questions), D7: maintenance/ inspection (13 questions), D8: human error (4 questions), D9: training and competencies of employees for crises (12 questions), and D10: conducting research after accidents (4 questions).

Table 1: Formed factors within the questionnaire for measuring the impact of organizational factors

Organizational factors
D1 Communication
D2 Potentially hazardous materials and equipment
D3 Process safety
D4 Safety and health at work
D5 Organizational change management
D6 Subcontractors from other companies
D7 Maintenance / inspection
D8 Human error
D9 Training and competencies of employees for crises
D10 Conducting research after accidents

Then, the recent studies such as the paper by Hof (2012) have shown that in most cases a sample of 150 subjects should be sufficient to obtain a precise solution by research analysis of factors, as long as their mutual correlations are strong enough. However, if there are several high values of load factors (> .80) among the data, then even a smaller sample (n <150) would be sufficient (MacCallum et al., 1999). Thus, representatives of senior management of domestic companies representing the electricity sector (thermal power plants, thermal power plants, and hydropower plants) were contacted; oil, coal, and natural gas sector; pharmaceutical industry, food industry, etc., they were provided with electronic surveys by e-mail, or printed surveys by mail, or were taken in person, according to their choice. Participation was voluntary and anonymous. The initial sample size was 321 employees and responses were obtained from 253, meaning that the response rate was 79%. The demographic characteristics of the sample are shown in Table 2.

Table 2 shows that in the sample were mostly larger companies, that mostly men replied, and mostly those with huge experience.

After the described procedure of collecting answers, it was necessary to check the reliability and validity of the questionnaire (Pett et al., 2003). The SPSS Statistics Package 20 (SPSS Statistics 20) was used for analysis purposes in this paper.

Table 2: Demographic characteristics of the sample

	Mean	**Std. Deviation**
Number of employees in the company	628.98	1060.618
Age of respondents	45.92	10.394
Gender of respondents	1.09	.284
Years of work experience of the respondents	19.36	11.019

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Sampling adequacy

Each factor was evaluated by using the Kaiser-Meyerto-Olkin (KMO) parameter, and only factors with a KMO value greater than 0.6 were retained for further analysis. The results showed a good degree of data covariance in the range of 0.72 to 0.91, as shown in Table 3.

Bartlett's test of sphericity showed that the matrices of our factors were statistically significantly different from the identity matrix, as for each factor the significance was <0.001, which again confirms that the data are suitable for the application of factor analysis.

Table 3: Kaiser-Meyerto-Olkin (KMO) values for organizational factors

Organizational Factor	**Number of questions**	**KMO**
D1	6	0.86
D2	5	0.81
D3	6	0.72
D4	5	0.73
D5	8	0.77
D6	6	0.84
D7	15	0.91
D8	4	0.79
D9	12	0.9
D10	4	0.77

Exploratory factor analysis

Exploratory factor analysis, in combination with Varimax and Kaiser Normalization Rotation, was applied to analyze the dimensional structures of the questionnaire.

A set of factor analyses tested whether all questions from a certain group really belong to that group, e.g. whether all communication issues really relate to communication. If the analysis would show 1 factor, it practically means that all questions correlate with each other, i.e. that they belong to the same group and that based on the one general score can be further calculated, e.g. communication score. For most factors, a single factor is obtained based on three criteria:

– "Scree" diagram
– Percentage of explained variance
– Eigenvalue.

The percentage of explained variance was about 60% for each factor, while the eigenvalues were above 2 for the first extracted factor, and below 1 for the second. The "Scree" diagram showed an obvious cut-off from the first factor, for all factors. Factor loads were calculated for all factors. A value of 0.4 was chosen for the lower limit of the factor load, which is in line with the sample size in this study and also allows us to observe only practically significant items (Hair, et al., 1998).

The results of the factor analysis are shown in Table 4.

Table 4: Factor loadings

Question number	**Factor D1**	**Factor D2**	**Factor D3**	**Factor D4**	**Factor D5**	**Factor D6**	**Factor D7**	**Factor D8**	**Factor D9**	**Factor D10**
D11 – Operators reporting details	0.796	-	-	-	-	-	-	-	-	-
D12 – Importance of reporting	0.767	-	-	-	-	-	-	-	-	-
D13 – Communication efficiency	0.695	-	-	-	-	-	-	-	-	-
D14 – Reporting procedures	0.756	-	-	-	-	-	-	-	-	-
D17 – Procedures and shifting	0.708	-	-	-	-	-	-	-	-	-
D18 – Safety procedures	0.526	-	-	-	-	-	-	-	-	-
D21 - Potentially hazardous materials and equipment identification	-	0.705	-	-	-	-	-	-	-	-
D22 – Probability of potentially hazardous materials and equipment	-	0.679	-	-	-	-	-	-	-	-
D23 - Potentially hazardous materials and equipment regulation	-	0.783	-	-	-	-	-	-	-	-
D24 - Potentially hazardous materials and equipment measures	-	0.782	-	-	-	-	-	-	-	-
D25 - Potentially hazardous materials and equipment recommendations	-	0.594	-	-	-	-	-	-	-	-
D32 – Process safety policy	-	-	0.688	-	-	-	-	-	-	-
D34 – Process safety performance indicators	-	-	0.633	-	-	-	-	-	-	-
D35 – Process safety responsibilities	-	-	0.702	-	-	-	-	-	-	-
D42 – Work and personal protective equipment availability	-	-	-	0.862	-	-	-	-	-	-
D43 – Work and personal protective equipment usage	-	-	-	0.702	-	-	-	-	-	-

D44 – Employees' decision making on working hours	-	-	-	0.436	-	-	-	-	-	-
D45 – Policy of all employees' working hours	-	-	-	0.633	-	-	-	-	-	-
D51 – Working procedures on technological changes	-	-	-	-	0.745	-	-	-	-	-
D52 – Formal procedures for technological changes	-	-	-	-	0.709	-	-	-	-	-
D53 – Star up and shut down procedures	-	-	-	-	0.716	-	-	-	-	-
D54 – Outsourced works equipment quality	-	-	-	-	0.688	-	-	-	-	-
D55 – Communication in outsourced activities	-	-	-	-	0.709	-	-	-	-	-
D56 – Competencies for outsourced activities	-	-	-	-	0.74	-	-	-	-	-
D57 – Training for outsourced activities	-	-	-	-	0.665	-	-	-	-	-
D58 – Outsourced companies and regular training	-	-	-	-	0.71	-	-	-	-	-
D61 – Documentation of pressure equipment	-	-	-	-	-	0.727	-	-	-	-
D62 – High-risk pressure equipment control methods	-	-	-	-	-	0.853	-	-	-	-
D63 – New equipment special inspection	-	-	-	-	-	0.848	-	-	-	-
D65 – Pressure equipment of high-hazard level is registered in the central pressure equipment register	-	-	-	-	-	0.816	-	-	-	-
D67 – Pressure equipment inspection plan	-	-	-	-	-	0.63	-	-	-	-
D68 – Person dedicated to central pressure equipment register	-	-	-	-	-	0.487	-	-	-	-
D71 – Human error in manual processes	-	-	-	-	-	-	0.71	-	-	-
D72 – Risk prevention in human error	-	-	-	-	-	-	0.638	-	-	-
D73 – Human error control procedure	-	-	-	-	-	-	0.592	-	-	-
D74 – Human error practice	-	-	-	-	-	-	0.765	-	-	-
D75 – Human error prevention	-	-	-	-	-	-	0.762	-	-	-
D76 – Human error and process safety	-	-	-	-	-	-	0.786	-	-	-
D77 – Overtime, poor communication, pressure to get the job done as soon as possible, etc.,	-	-	-	-	-	-	0.834	-	-	-

and human error										
D78– Human error and experience	-	-	-	-	-	-	0.823	-	-	-
D79– Human error and training	-	-	-	-	-	-	0.753	-	-	-
D81 – Training of employees for crises situations	-	-	-	-	-	-	-	0.84	-	-
D82 – Competences of employees for crisis situations	-	-	-	-	-	-	-	0.882	-	-
D84 – Training and competences of employees for crisis situations documents	-	-	-	-	-	-	-	0.637	-	-
D91 – Conducting research after accidents procedure	-	-	-	-	-	-	-	-	0.75	-
D92 – Conducting research after accidents on time	-	-	-	-	-	-	-	-	0.782	-
D93 – Conducting research after accidents with operators involved	-	-	-	-	-	-	-	-	0.743	-
D94 – Conducting research after accidents with subcontractors involved	-	-	-	-	-	-	-	-	0.871	-

The reliability of a measurement instrument depends on its internal consistency which can be assessed via Cronbach α, Spearman-Brown coefficient, and Kendall W coefficient.

Reliability analysis

After the initial EFA analysis, each factor was evaluated by the usage of Cronbach α. After questioning Cronbach's α (Table 5), 63 questions remained in the questionnaire for organizational factors.

Table 5: Value of Cronbach α for organizational factors

Organizational Factor	Cronbach α
D1	0.86
D2	0.83
D3	0.74
D4	0.75
D5	0.86
D6	0.87
D7	0.93
D8	0.74
D9	0.94
D10	0.82

Kendall’s W (also known as Kendall’s coefficient of agreement) is a nonparametric statistical test and uses an assessment of agreement among respondents (Mearns et al., 2003). Kendall's W ranges from 0 (without any agreement) to 1 (total agreement). The results for Kendal's W showed that it is statistically significant, 0.15 in the case of managers, which is quite a satisfactory value.

The Spearman-Brown coefficient is the reliability coefficient that can be obtained from all possible combinations of dividing questions into two sets (splitting in half) (Cooper, 2000). Spearman-Brown needs to be more than 0.8 to be acceptable. The results of this study show that the Spearman-Brown coefficient is 0.848, so it is also adequate.

CONCLUSION

In recent decades, process safety control and process security risk assessment have become a burning issue that requires further analysis and research. Despite the accentuated problems, a large number of process industry companies continue to base their process safety and risk control on the application of these tools. However, experience has shown that these tools are not sufficient to adequately prevent or control accidents with serious consequences. Accidents that continue to occur are a combination of the influence of several factors such as organizational factors, human factors as well as technical factors that can be interpreted through the aging of equipment, ie through the integrity of the structure. The development of sophisticated design within complex industries, such as process, as well as the growing need to reduce the hard, supervised work of staff, have led to the need to look at this problem more comprehensively, analyzing the causes of the causes, and emphasizing the impact of organizational factors. However, the analysis of existing models and tools for risk assessment leads to the definitive conclusion that the influence of organizational factors is not sufficiently or in a sufficiently accurate and precise way taken into account in existing models of risk assessment in working with pressure equipment. Accordingly, within this paper, the need to conduct research on this very attractive topic was recognized, which resulted in a significant contribution to the development of an original measurement instrument for assessing organizational factors important for risk assessment methodologies in working with pressure equipment. The initial measurement instrument was checked by statistical analysis, using the Kaiser-Meyerto-Olkin test, and then by exploratory factor and stress analysis methods and reduced from 71 to 48 dimensions, which in a sufficiently accurate, precise, and reliable way describe 10 organizational factors identified in previous studies. Providing a valid and reliable measurement instrument is essential for a proactive, as opposed to a reactive approach, and offers information on the impact that managers employed in the organization have on the risks of pressure equipment in the process industry, and as carriers of control of organizational factors. Thus, the results of this paper contribute to ways that prevent the present adverse effects of an organizational nature from leading to accidents with serious consequences.

The proposal of further research is the application of confirmatory factor analysis, intending to determine the links between factors and dimensions, which describe the considered factors.

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POUZDANOST I VALIDNOST MERNOG INSTRUMENTA ZA OCENU ORGANIZACIONIH FAKTORA U MODELU MENADŽMENTA RIZIKOM OPREME POD PRITISKOM

Poslednjih decenija, kontrola procesne bezbednosti i procena rizika vezanog za procesnu bezbednost, je postala goruća tema. Način kako se kontrola sporovodi, putem identifikacije i proučavanja potencijalnih opasnosti svedenih na određene materijale i procese pomoću alata kao što su HAZOP, FMEA, FTA i slično, nije dovoljna da bi se nesreće sa ozbiljnim posledicama sprečile ili kontrolisale u adekvatnoj meri. Razvoj sofisticiranog dizajna u okviru kompleksnih industrija, kao i sve veća potreba za smanjenjem napornog rada osoblja, doveli su do potrebe da se ovaj problem posmatra sveobuhvatnije, analizirajući i uzroke samih uzroka, a sa posebnim akcentom na uticaj organizacionih faktora. Shodno tome, u okviru ovog rada, prepoznata je potreba se sprovede istraživanje ove vrlo atraktivne teme, koje je rezultiralo razvojem originalnog, pouzdanog i validnog mernog instrumenta za ocenu organizacionih faktora značajnih za metodologije procene rizika u radu sa opremom pod pritiskom. Početni instrument je statističkom analizom proveren, primenom Kaiser-Meyerto-Olkin testa, eksplorativne faktorske i analize pouzdanosti i sveden sa 71 na 48 dimenzija, koje opisuju 10 organizacionih faktora. Obezbeđivanje validnog i pouzdanog mernog instrumenta je suštinski značajno za proaktivno, nasuprot reaktivnom, informisanje o uticaju koji imaju menadžeri zaposleni u organizaciji na rizike rada opreme pod pritiskom, koje onemogućava da dati uticaji dovedu do nesreća sa ozbiljnim posledicama. Predlog daljih istraživanaj uključuje primenu faktorske analize i modeliranja strukturnim jednačinama.

Ključne reči: Organizacioni faktori; Menadžment rizikom; Procesna industrija; Oprema pod pritiskom; Pouzdanost; Validnost.