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ORIGINAL ARTICLE

Psychometrics of Questionnaires Designed for the Evaluation of Safety Levels and Safety Culture Case Study: Power Plant Generator Manufacturing Company

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ABSTRACT

The psychometrics of instruments in safety performance evaluation is essential for the accreditation of an organization's safety evaluation and has been emphasized in many studies. Psychometrics pertains to the validity and reliability of an evaluation instrument and describes its precision and consistency. The aim of the present study was to evaluate the psychometrics of safety level and safety culture questionnaires to provide a reliable and valid instrument for safety performance evaluation in industries. This descriptive cross sectional study was conducted with the intention of psychometric instruments used to evaluate the safety level and the safety climate at the Mapna Pars power plant generator manufacturing and engineering company. The face validity of the questionnaires was analyzed quantitatively and qualitatively. In the quantitative method, the importance of the influence score was applied and the content validity was calculated using the Lawshe method. Content Validity Ratio (CVR) and Content Validity Index (CVI) were also used. For this purpose, elicitation was obtained from experts within the professional health and safety community. The reliability of the instruments was determined via the Cronbach's alpha test and the Interclass Correlation Coefficient (ICC) test. Finally, the standardized questionnaires were used to evaluate the safety level and safety climate of the industry as a case study. The obtained data were analyzed using SPSS software solution v20. Based on the quantitative face validity results obtained at the Mapna Pars Company, one question was removed from each of the final instruments. The content reliability analysis revealed that the safety level questionnaire had a CRI of 0.99, CVR of 0.91, and was accepted. The safety climate questionnaire had an acceptable CVI of 0.95 and an acceptable CVR of 0.82. Regarding the reliability analysis, a Cronbach's alpha of 0.72 and 0.89 was obtained for the safety level questionnaire and the safety climate questionnaire, respectively. It can be concluded that both questionnaires had an acceptable level of internal consistency. The re-application of the questionnaires after two weeks revealed a relatively consistent safety level (ICC=0.90) and safety climate (ICC=0.74). Analyzing the data obtained in the present study showed that the safety level questionnaire with 66 questions and the safety climate questionnaire with 93 questions had acceptable validity and reliability. Thus, it may provide a useful approach for safety evaluations in similar industries.

KEYWORDS: *Safety level; Safety climate; Safety performance; Power plant generator manufacturing*

INTRODUCTION

The safety climate has recently become a leading indicator in high-risk enterprises. Unlike lagging indicators, which are only relevant after an incident has already occurred, the safety climate indicator can provide useful information regarding the potential dangers within the enterprise and has received much attention. The aim of safety climate evaluation was the identification and prospective management of issues related to occupational safety and the monitoring of changes and repercussions thereof [1].

The concept of the safety climate as a multi-dimensional factor in occupational safety was first introduced in 1980. Later, especially after the Chernobyl incident, numerous studies were conducted on safety climate evaluation and the various affecting factors [2]. The overall concept of the safety climate involves the perceptions and presumptions of workers regarding their work environment, the level of interest and attention paid by management regarding safety issues, and their level of participation in risk control and mitigation [3-5]. In other words, safety climate evaluation is an attempt in identifying weak points in safety and also opportunities for their mitigation [2].

Zohar believed that there was a correlation between safety climate scores and the performance of incident prevention programs and safety measures. Zohar claimed a direct relationship between safety climate and the actual level of safety within an enterprise (3,6-8). Many instruments have been accredited for the assessment of safety climate, of which, the Safety Climate Assessment Questionnaire of the British Health and Safety Executive devised in 2001 was a notable example. The psychometrics and accreditation of this questionnaire were conducted by Jafari et al., in a mining complex in Iran [9-10].

Safe worker behavior is a specific type of occupational behavior that reflects the extent of the worker's awareness regarding his safety or the safety of his peers while also showing how important this is to him. Various instruments have been designed for safety performance evaluation. Barkhordari et al., conducted a study in which they expanded an instrument for analyzing safety performance using active indicators [11-12]. Eskandari et al., also accredited an instrument for estimating the level of safety based on the organizational, personal, and environmental factors using a specific weight to each indicator [13].

Psychometrics or psychometrics evaluate the validity and reliability of an assessment instrument and describe its stability and precision. Validity determines the degree to which an instrument can measure that which it claims to measure. In general, a questionnaire measurement validity reflects the precision of the concepts presented in different sections of the questionnaire compared to other measurement instruments. Validity was measured using four methods which included criterion-related validity, construct validity, content validity, and face validity [14-15].

Reliability reflects the repeatability of the results. In other words, to what extent does the instrument give the same results each time. Many methods exist for the reliability evaluation which includes test-retest reliability, parallel forms reliability, Rater reliability, and internal consistency reliability. The internal consistency reliability further includes Cronbach's alpha and Kuder-Richardson's Formula 20 and 21 [16-17].

The psychometrics of instruments designed for the safety performance evaluation in enterprises was essential for the accreditation of the safety evaluations and has been emphasized in many studies [18-21]. However, in investigating the constituent aspects of a safety climate, a main group of researchers used self-reporting questionnaires based on their own definition of a safety climate and then proceed to analyze the results. Therefore, the psychometrics of the safety performance questionnaires is a necessity due to its importance to determine the safety performance of an enterprise or organization. Thus, this approach played a significant role in designing the fundamental aspects of questionnaires for the safety climate, safety culture, safety level, and safe behavior evaluation [1-22].

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In the studies in industrial safety, Guldenmund stated that only face validity was considered in most of the assessments performed on safety climate evaluation instruments, and the psychometrics or the construct validity of these instruments were mostly neglected [22-23]. Considering the above-mentioned issues, the present study was conducted to standardize the Eskandari's et al., safety level questionnaires and the safety climate questionnaires of the British Health and Safety Executive using approved statistical methods. So a valid and reliable questionnaire may be devised which can evaluate the level of safety and the climate of safety at the Mapna Pars company or other similar enterprises.

MATERIALS AND METHODS

This descriptive cross sectional study was conducted at the Mapna Pars Company (manufacturing of power plant generators) in 2018 to standardize the instruments used for the evaluation of the safety level and safety climate indicators. Employees with 3 or more years of work experience and the ability to work in different stations were selected as inclusion criteria (rotor and stator manufacturing, generator assembly, machining, metal structure manufacturing, machining).

Participants were informed on how to complete the questionnaires in the form of a training course before the study was conducted. The minimum sample size per manufacturing workshop was 70 with a total of 280 participants overall (Equation 1). Data analysis was performed using SPSS version 20 and Excel 2010. Cronbach's alpha test and the test-retest method were used for the reliability evaluation of the questionnaire.

$$n = \left[\frac{z_1-\frac{\alpha}{2}+z_1-\beta}{C}\right]^2 \qquad \text{Equation (1)}$$

Instruments

Eskandari's et al., safety level indicator assessment questionnaire was only validated for use in the petrochemical sector [13]. Therefore, this instrument was designed to assess the safety level of an enterprise using 67 questions based on personal, organizational, and environmental factors. The accredited safety climate questionnaire devised by the British Health and Safety Executive was also used in the present study [9]. Due to the lack of validity of this questionnaire, we re-accredited it at the Mapna Pars Company. This safety climate questionnaire had 94 questions which evaluated 8 safety climate factors, including training and competence, production pressure, communications, participation (intervention) of personnel in health and safety issues, managerial commitment, suitability of approaches and health and safety regulations, rule violations, and state of safety.

Instrument Psychometrics and Validation:

Figure 1 shows the safety level and safety climate questionnaires psychometrics process at the Mapna Pars Company. As can be seen, face validity, content validity, internal consistency reliability, and the stability of both questionnaires are evaluated. Qualitative face validity was obtained from experts in the field and also workers in the relevant industry. Quantitative Face validity was obtained using the impact score method via the Likert scale. The questionnaires were then presented to the target group (n=20) to determine their face validity. In the impact score method, an impact score was obtained by multiplying the frequency of an item by the impact of an item. An impact score above 1.5 means that the item was suitable for later analyses and will be kept [24-25].

In order to assess validity, 11 experts in the field (7 safety experts, 2 occupational health experts, and 2 educational administers) were voluntarily involved in the study. The qualitative content validity of the questions was re-evaluated multiple times and necessary revisions were made with the consultation of the expert group. The quantitative validity of the questionnaire was calculated based on the experts' opinions and according to CVR and CVI. Expert elicitation regarding the importance of each question was classified as "necessary", "useful but unnecessary" and "unnecessary" to calculate CVR according to the equation in Figure 1. In this equation, ne is the number of experts who deem the question to be necessary and N is the total number of experts who have opined on the question. A minimum acceptable CVR value of 0.59 was obtained as per the Lawshe table [26]. The criteria of the content validity indicator were determined within a Likert scale and according to the opinions of the experts. In this indicator, the verdict and acceptability of the questions depend on the CVI score obtained, like those above 0.79 were

deemed suitable, those between 0.70 and 0.79 were considered as questionable and thus in need of revision and those below 0.70 were unacceptable and needed to be removed [27].

Reliability was measured based on the repeatability and reproducibility, with a reliability coefficient of 0 reflecting a lack of reliability and a coefficient of 1 suggesting a 100% reliability. The internal and external consistency of the questionnaire was obtained via the Cronbach's alpha and the Interclass correlation coefficient (ICC) which was also referred to as the test-retest method. A Cronbach's alpha above 0.7 means that the questionnaire has acceptable reliability. The numerical value of Cronbach's alpha was equal to the mean reliability coefficient which was obtained from all possible combinations of questions after being divided by two. Cronbach's alpha is a reliability measure that requires a single run of the test to provide a reliability estimate.

As for external reliability, a test-retest was applied which measures how cohesive two identical values are at two different times [24-28]. For this, the validated draft of the questionnaire was given to 30 workers and two weeks later they were asked to answer the questionnaires again. Finally, after validation and psychometrics of the instruments, the safety level, and safety climate indicators were estimated for the 280 workers employed in the four sections of the Mapna Pars factory.

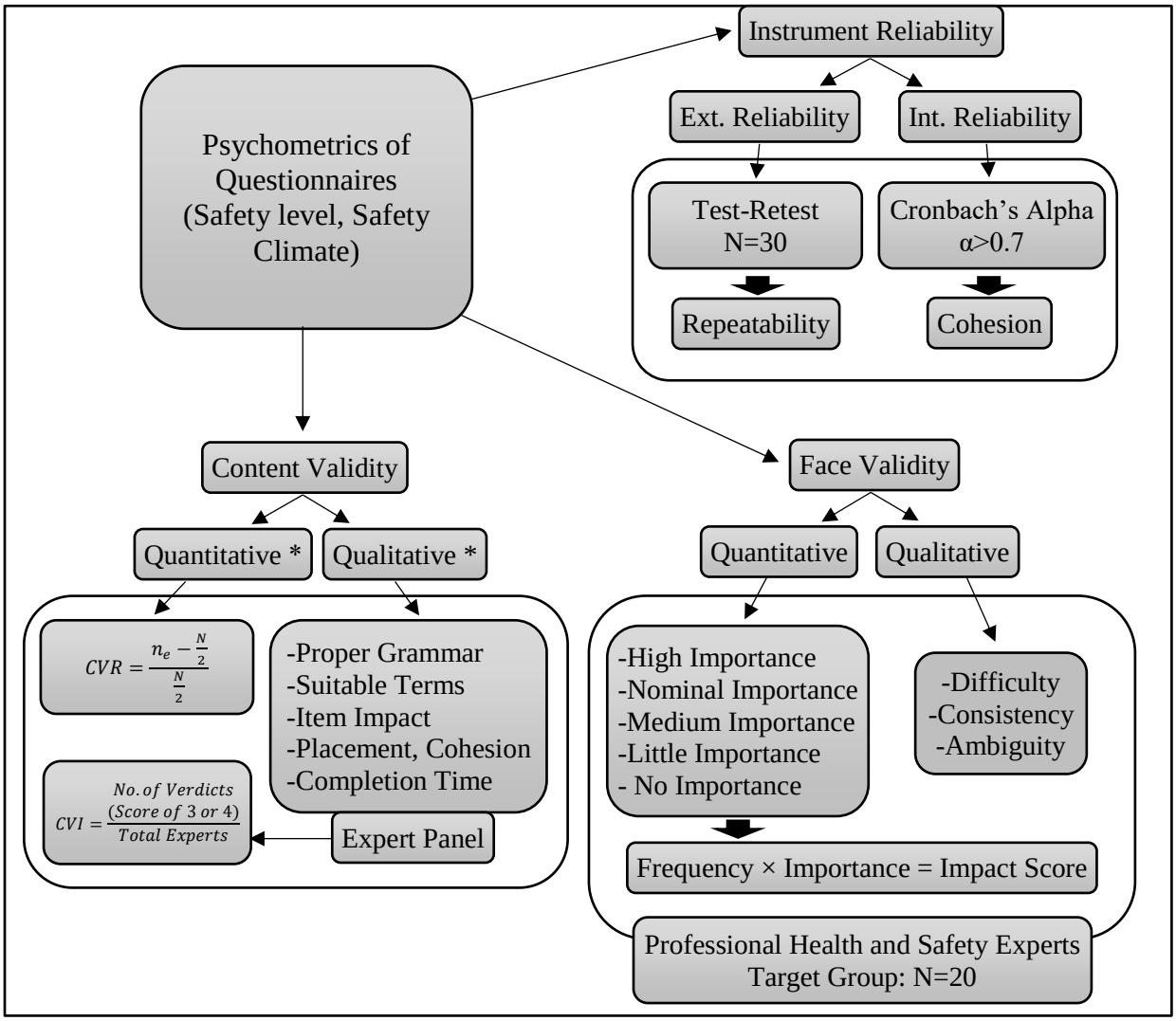

Fig 1. The instrument psychometrics flowchart [25-28]

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RESULTS

Table 1 presents the characteristics of the workers participating in the face validity evaluation of the questionnaires. According to the results of the face validity evaluation, the safety level questionnaire had a mean impact score of 2.25 with a standard deviation of 0.53. The highest impact score (3.6) belonged to question 28 while the lowest (1.1) belonged to question 41. The safety climate questionnaire had a mean impact score of 2.20 with a standard deviation of 0.50. Question 53 had the highest impact score (4) and question 75 had the lowest (0.60). The results of the quantitative face validity evaluation showed that in each questionnaire, at least one question did not obtain an acceptable score (1.5) and was removed from the final revision. Figures 2 and 3 show the impact score distribution for each questionnaire.

Table 1. Characteristics of workers participating in the face validity evaluation of the questionnaires (n=20).

No	Education	Count	Employment Duration				Age			
			Mean	SD	Min	Max	Mean	SD	Min	Max
1	Diploma	11	12.90	4.25	7	19	37.27	5.83	27	44
2	Associate	6	11.83	5.34	6	21	38.16	7.54	28	50
3	Bachelor	3	5.00	1.00	4	6	29.66	1.52	28	31

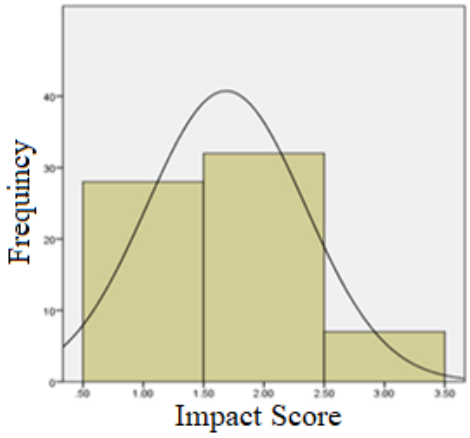

Fig 2. Impact score distribution (Safety level questionnaire)

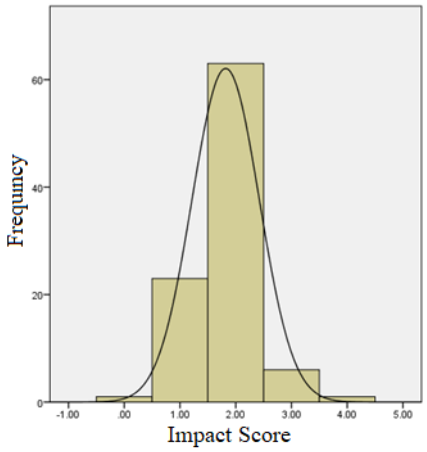

Fig 3. Impact score distribution (Safety climate questionnaire)

Table 2 shows the characteristics of the experts participating in the content validity evaluation of the questionnaires. Table 3 shows CVR and CVI values obtained for the two questionnaires. The safety level and safety climate questionnaires had a CVI of 0.99 and 0.95 along with a CVR of 0.91 and 0.82, respectively.

Table 2. Characteristics of the experts participating in the content validity evaluation

			Age				Employment Duration			
		Count	Mean	SD	Min	Max	Mean	SD	Min	Max
Gender	Male	9	33.44	7.17	28	52	8.44	5.93	5	24
	Female	2	40.00	7.07	35	45	17.00	8.48	11	23
Education	Bachelor	6	34.16	8.88	28	52	9.33	7.31	5	24
	Master	5	35.20	5.80	30	45	10.80	7.08	6	23
Title	Administrator	2	43.50	12.02	35	52	17.50	9.19	11	24
	Occupational Health	2	38.00	9.89	31	45	14.50	12.02	6	23
	Safety	7	31.14	2.03	28	34	6.57	1.27	5	9

Table 3. CVR and CVI values obtained for the two questionnaires

			Mean	SD	Max	Min
Safety Level		CVR	0.91	0.12	0.45	1.00
	CVI	Related	0.99	0.01	0.90	1.00
		Simple	0.99	0.02	0.90	1.00
		Clear	0.99	0.01	0.90	1.00
Safety Climate		CVR	0.82	0.15	0.45	1.00
	CVI	Related	0.95	0.05	0.81	1.00
		Simple	0.96	0.06	0.80	1.00
		Clear	0.94	0.06	0.81	1.00

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Based on the reliability evaluation results, a Cronbach's alpha of 0.72 and 0.89 was obtained for the safety level and safety climate questionnaires, respectively. This indicated an acceptable internal consistency. The re-application of the questionnaires after two weeks showed a consistent safety level (ICC=0.90) and safety climate (ICC=0.74).

Table 4. Internal consistency and stability of the two questionnaires

Questionnaire	Cronbach's Alpha	ICC
Safety Level	0.718	0.896
Safety Climate	0.893	0.739

RESULTS AND CONCLUSION

Site managers and safety administrators were always interested to get information about the level of safety in industrial sites. Various instruments have been designed for the assessment of the safety level including instruments based on the structural equation modeling. Some of these models give specific weight to factors involved in safety [29]. The reliability of these instruments and especially the relationship between the estimated safety level and the actual safety performance of the assessed site were a major challenge associated with these instruments [30-31].

In the present study, the validity of the questionnaires was determined using the Lawshe method and via CVR and CVI calculations while the reliability of the questionnaires was determined via Cronbach's alpha and the ICC test.

In the present study, same as the findings of Jafari's et al., [10], we used the impact factor score for determining the face validity of the safety level questionnaire. Any question with an impact factor score of less than 1.5 was removed. Question 41 of the safety level questionnaire was removed since, in the particular industry chosen, workers were rarely exposed to biological or infectious materials. In the safety climate questionnaire, question 75 (I have received rewards for breaking rules) was deemed unimportant by the workers of Mapna Pars and did not obtain an acceptable score.

Content validly evaluation showed that 66 remaining questions in the safety level questionnaire had a CVI of 0.99 and a CVR of 0.91 while 93 remaining questions in the safety climate questionnaire had a CVI of 0.95 and a CVR of 0.82 which were all acceptable. This approach was used in similar studies conducted by Hoseini et al., [32]. It should be noted that the CVR and CVI of both questionnaires were above the acceptable 0.7 value [26]. Also, the CVR obtained for two questionnaires was higher than the CVR obtained in a similar study conducted by Hoseinzade et al., which evaluated the validity and reliability of occupational failures using the Lawshe method [33].

The content validity of the questionnaires was also evaluated by 11 members of the Mapna Pars health and safety panel. This exceeded the 5-member minimum and the 10-member average usually seen in similar studies [34].

Based on the results of the present study, acceptable internal consistency reliability existed between the questions of the questionnaires. Most studies use Cronbach's alpha coefficient for reliability evaluation. Lu et al., [35] found a Cronbach's alpha of 0.89 to 0.95

for the safety climate questionnaire used in the container transportation industry. Hoseini et al., reported a Cronbach's alpha of 0.86 for the safety attitude questionnaire used in their study [32]. Hoseinzade et al., [33] mentioned earlier a Cronbach's alpha of 0.96 in their study. Although the Cronbach's alpha obtained in the present study (0.72 and 0.89) was lower than that of similar studies, they were still above acceptable levels (0.7) [36].

In the present study, reliability was evaluated via the internal consistency coefficient (ICC) as in many similar studies. Hoseini et al., [32] obtained an ICC of 0.94 in their study. In another study in Norway, the test-retest method was used to evaluate the reliability of a Nordic safety climate questionnaire with re-application being conducted after 2 weeks [36]. The same 2-week period was used in the present study for the test-retest of the questionnaires.

The reliability coefficients obtained in the present study were similar to those found in other studies which can be considered as a strong point. Another strong point was that the methods used in the present study for the psychometrics of the questionnaires were all approved by statistical and occupational experts. Psychometrics was performed step by step and with a sufficient sample size [34]. Since the results of the present study were in agreement with the results obtained by other researchers, it can be said that the questionnaires had suitable reliability and validity and can be used in similar industries. The present study also confirmed the validity and reliability of the safety level questionnaire devised by Eskandari et al.the current study, we used appropriate validity and reliability which were statistically valid methods. It would be interesting that in future studies other industries with a larger sample size take into consideration.

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CONFLICT OF INTEREST

This article extracted from the master's thesis of occupational health with NO 96/9496 and the code of ethics 138/1396 approved by the Faculty of Health and Safety, Shahid Beheshti University of Medical Sciences.

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