Level Increase of Process Safety Culture at the Fuel and Energy Complex Enterprises

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Abstract. The priority development area, according the Russian Federation state policy framework in the field of industrial safety till 2025, is the high process safety formation, ensuring maximum employees involvement and their direct participation in safety issues, as well as the development of behavioral safety audit (BSA) skills. As a result of the studies, development of the safety culture level at the one of the gas transmission enterprises was assessed. The assessment was based on the results of two surveys. The first survey was carried out to assess the current level of safety culture before the BSA procedure implementation in the company, while the second one was conducted after the regular BSA procedure performing during two quarters of 2019. Using mathematical data processing, the statistical significance of variance in safety culture components assessments revealed was proved for professional group: production workers. At the same time, there were no changes identified for professional groups: specialists and executives. Using cluster analysis, the characteristics of the obtained culture levels were determined. The cluster analysis also revealed the increase in the number of production workers who rated the safety culture at the high level. Such results indicate the successful implementation of the BSA procedure in a company.

1. Introduction

Nowadays, one of the priority areas for any enterprise development is to increase the level of process safety culture. The high safety culture ensures the prevention of industrial accidents and emergency cases. Employees and leaders of the organization, as a rule, make an important contribution to the formation of a high culture. Moreover, leaders are the connecting and fundamental link in the implementation and establishment of the high safety culture level in a company [1].

The process safety culture is understood as the qualification and psychological preparedness of all individuals, where ensuring the industrial safety of oil and gas facilities is the main goal and internal need, leading to the personal responsibility realization and self-control during all work; the totality of characteristics and relationships, establishing that safety issues are paid attention to, which corresponds to their significance; a complex of relationships and the results of importance understanding and workers responsibility for ensuring all safety types [2-4]. In general, the key safety culture components are the creation of the necessary working conditions in a company (management responsibility) and the personnel position at all levels, the reaction to these working conditions [5].
2. Relevance
These days, many Russian and foreign companies that aim to achieve the high safety culture level are actively developing the management sector, they focus on leaders who have the necessary knowledge, skills, managerial qualities and are ready to take responsibility for safety [6-8]. Measures to establish safety culture can be implemented in companies of any scale and most of them do not require significant financial costs during implementation process. Thus, many companies strive to raise the industrial safety culture level by carrying out the following activities: company values identification, leadership promotion, required and expected behavioral models establishment, personalization of safety issues results, a positive attitude towards safety issues development, establishment of own safety responsibility, growth of dangers and risks awareness, preventive behavior, effective implementation of safety management systems, monitoring, review and analysis of personal effectiveness [9-11].

Companies use the Bradley curve, as a guideline for increasing the level of safety culture, which directly establishes the connection between the existing level of safety culture and the characteristics inherent in this level [12]. There are 4 levels of safety culture: reactive, dependent, independent and interdependent. The reactive level is based on the lack of risks understanding and, as a consequence, inability to manage them, while safety is not a priority goal. The dependent level involves reducing the number of accidents to a certain level, the only cause of injuries in the opinion of managers is the established rules violation. Independent level is the one where employees understand that safety begins with each of them, while the number of accidents continues to decrease, but to a certain level. The interdependent level is the command one. Workers consciously care about their own safety and safety of others, express their position by intervening and correcting unsafe situations through dialogue, employees believe that only team work can achieve zero injury.

Thus, the desire of companies to reach interdependent level, that means to raise the safety culture level to an implemented high, is currently an urgent task.

3. The impact assessment of the behavior safety audit procedure implementation on the level of process safety culture
As part of the need to gradually increase the level of industrial safety culture, a behavioral safety audit becomes a necessary addition to existing types of control aimed at fulfilling established state norms and standards in the field of labor protection. BSA is a process based on monitoring the actions of the employee during the production task execution, his workplace, and the subsequent conversation between the employee and the auditor [13]. This procedure makes it possible to correct unsafe behavior, identify the causes of safety rules violations, as well as the effectiveness and weaknesses of the labor protection and process safety management systems.

Thus, the behavioral safety audit procedure is a focused system of preventive measures aimed at improving the process safety level and is directly related to it. In [14], a new approach to safety ensuring was proposed, which establishes the rules for conducting behavioral safety audit, the identified dangerous actions assessment, and applying preventive measures.

In case of this study, the questionnaire survey method of the enterprise employees was chosen to assess the implementation effectiveness of the BSA procedure. The initial survey was conducted in April 2019 in order to identify the current assessment of the company safety culture by each employee. In order to assess the dynamics of changes after the BSA procedure implementation, all employees participating in the BSA answered the second survey in December 2019, which allowed us to record changes in estimates for each component of the safety culture. The total number of employees who answered the first and repeated second survey at one of the gas transmission enterprises is 1,787 people. The questionnaire survey consists of two parts: the first part introduces general information about the employee (age, length of experience, position), the second part of the survey presents 64 questions divided into 16 blocks called safety culture components: motivation; risk management; assessment of HSE service performance; transparency, information accessibility; competencies and employees training in HSE field; trust/confidence; notification of violations;
assistance of workers; safety management performance assessment; assessment of resources for safety ensuring; mistakes learning; personal responsibility for safety; personal discipline and commitment; communications inside a company regarding safety issues; involvement of workers in safety ensuring and employees personal interest in safety issues. These components were evaluated by employees in scores from 1 to 5.

For reliable and objective assessment of the survey results, mathematical data processing was carried out, which demands the representative data for the future correct results will be got. A representative sample is the one where all the main characteristics of the entire population, the sample is extracted from, are presented in approximately the same proportion or with the same frequency, appearing in this population [15]. While using the methodology of representative sample model constructing, it is possible to solve one of the main problems on its basis: to ensure the validity of the sociological study results [16-18]. To maintain representativeness of the sample, all employees participating in the survey were divided into three professional categories called “production workers”, “specialists” and “executives”.

Mathematical data processing was conducted in STATISTICA software package. Using mathematical calculations, the reliability of the changes for each professional group was determined. An important element in data processing is the statistical significance level of each component in relation to the results obtained after the initial survey. The significance level indicates the reliability degree of the differences between the samples revealed, i.e. shows for how much it is possible to trust if there are really differences. Statistical significance is the probability to obtain the result of a sample study, provided that in fact for the general population the zero statistical hypothesis is true that means there is no connection [19].

To test the statistical hypothesis, it is advisable to use the independent sampling method using Student t-test and Leven criterion. The method allows testing the hypothesis where two populations average values differ from each other.

The empirical value of the Student criterion is calculated with the formula:

\[
I_{emp} = \frac{x - y}{\sigma_{x-y}}
\]  

(1)

where \(x, y\) - arithmetical mean in the experimental and control groups; \(\sigma_{x-y}\) - arithmetical mean difference standard error.

The obtained empirical value is compared with the theoretical distribution of Student: if \(I_{emp} < t_{crit}\), then the null statistical hypothesis is rejected. The obtained empirical value allows us to determine the p-level - the value of the probability that the null statistical hypothesis is true. Moreover, according to Student's test \(p<0.05\) means significance, statistically significant differences were found, \(p<0.01\) means high significance, differences were found at a high level of statistical significance.

To establish the connection, the Leven criterion is also calculated, which allows one to check the variances equality condition of the samples studied [20].

The tested hypothesis about the constancy of \(m\) samples variance has the form:

\[
H_0 : \sigma_1^2 = \sigma_2^2 = \ldots = \sigma_m^2
\]  

(2)

and a competing hypothesis:

\[
H_1 : \sigma_{i1}^2 \neq \sigma_{i2}^2
\]  

(3)

where the inequality holds for at least one pair of indices \(i_1, i_2\).

Let be \(n_i\) - the volume of the \(i\)th sample, \(n = \sum_{i=1}^{m} n_i\), \(X_{ij}\) - \(j\)th observation in the \(i\)th sample.

The Leven criterion statistics has the form:
The analysis was performed for three professional groups for each safety component (Table 1).

**Table 1. The statistical significance of safety culture components for each professional group.**

| Variable                                                                 | Production workers |          | Specialists |          | Executives |          |
|--------------------------------------------------------------------------|--------------------|----------|-------------|----------|------------|----------|
|                                                                          | P Student | P Leven | P Student | P Leven | P Student | P Leven |
| Motivation                                                               | 1e-7      | 0.07    | 0.06       | 0.43    | 0.21       | 0.74     |
| Risk management                                                          | 3e-4      | 0.13    | 0.47       | 0.43    | 0.31       | 0.27     |
| Assessment of HSE service performance                                    | 0.85      | 0.01    | 0.42       | 0.04    | 0.61       | 0.53     |
| Transparency, information accessibility                                   | 0.01      | 0.08    | 0.56       | 0.98    | 0.94       | 0.77     |
| Competencies and employees training in HSE field                         | 9e-3      | 0.23    | 0.12       | 0.31    | 0.66       | 0.48     |
| Trust/confidence                                                         | 0.04      | 0.35    | 0.59       | 0.73    | 0.94       | 0.16     |
| Notification of violations                                               | 0.02      | 0.23    | 0.34       | 0.40    | 0.28       | 0.13     |
| Assistance of workers                                                    | 0.01      | 0.48    | 0.25       | 0.18    | 0.23       | 0.28     |
| Safety management performance assessment                                  | 0.06      | 0.38    | 0.21       | 0.33    | 0.09       | 0.11     |
| Assessment of resources for safety ensuring                               | 4e-3      | 0.12    | 0.69       | 0.24    | 0.07       | 0.79     |
| Mistakes learning                                                        | 0.07      | 0.67    | 0.94       | 0.34    | 0.06       | 0.71     |
| Personal responsibility for safety                                       | 0.01      | 0.54    | 0.11       | 0.71    | 0.33       | 0.41     |
| Personal discipline and commitment                                       | 7e-4      | 0.14    | 0.76       | 0.44    | 0.80       | 0.01     |
| Communications inside a company regarding safety issues                  | 0.01      | 0.78    | 0.81       | 0.10    | 0.89       | 0.93     |
| Involvement of workers in safety ensuring                                 | 4e-4      | 0.72    | 0.02       | 0.45    | 0.40       | 0.64     |
| Employees personal interest in safety issues                              | 0.24      | 1e-3    | 9e-3       | 0.06    | 0.23       | 0.32     |

The Leven criterion is used to verify that the tested hypothesis of variances equality (4) is rejected if $W \geq F_{crit}$, where $F_{crit}$ – critical point of the Fisher distribution.

The Leven criterion is used to verify that $m$ samples have equal variances, if $P_{Leven} > 0.05$ that means the statistical significance of differences, if $P_{Leven} < 0.05$ then differences are not statistically significant. It is believed that the Leven criterion is less sensitive to deviations from normality, therefore, statistical significance is established only if the significance conditions of t-student and Leven are simultaneously satisfied.

The analysis was performed for three professional groups for each safety component (Table 1).

The statistical significance of safety culture components for each professional group.
Analyzing the results obtained, it can be observed that all the components highlighted in red italics have a statistical significance, which means they are different from the results of the first survey stage.

For the professional category “production workers”, the conditions of significance for such safety components as “Motivation”, “Risk management”, “Transparency, information accessibility”, “Competencies and employees training in HSE field”, “Trust/confidence”, “Notification of violations”, “Assistance of workers”, “Assessment of resources for safety ensuring”, “Personal responsibility for safety”, “Personal discipline and commitment”, “Communications inside a company regarding safety issues” and “Involvement of workers in safety ensuring”, where Student's significance level changes from \( p=0.000001 \) to \( p=0.044 \) (less than 0.05) and the significance level according to Leven's criterion varies from \( P \text{ Leven}=0.07 \) to \( P \text{ Leven}=0.78 \) (more than 0.05), which indicates qualitative changes in these categories even from the point of complex mathematical calculations view.

However, in the professional group “production workers” there are no changes observed in the components “Assessment of HSE service performance”, “Safety management performance assessment”, “Mistakes learning” and “Employees personal interest in safety issues”. This indicates an insufficient number of efforts to improve the situation in these areas.

Analyzing the results for the professional category “specialists”, we can observe a significant change in the situation. In this case, we can talk about differences in only two components: “Involvement of workers in safety ensuring”, where \( p=0.02, P \text{ Leven}=0.45 \) and “Employees personal interest in safety issues”, where \( p=0.009, P \text{ Leven}=0.055 \), means the conditions of t-student and Leven significance are fulfilled simultaneously. However, there are no statistically significant changes seen for all remaining components of the safety culture.

After analyzing the interpretation of the obtained criteria for executives, we can see the absence of statistical significance at all (the significance level of the Student and Leven criteria does not satisfy the fixed boundary values), that is, no changes are observed for all components of the safety culture. It turns out it is easier to influence production workers and they are ready for changes, which cannot be said about executives and, to a lesser extent, about specialists.

In conclusion, as a result of mathematical calculations in the software package, it was revealed the professional group “executives” should focus further attention on future measures implementation to improve the level of safety culture in enterprises, since there is a mathematically justified absence of changes in each category.

4. Cluster analysis using to characterize the safety culture levels obtained

According to the results of mathematical processing, the most susceptible and ready for changes group are production workers. The next stage of this study involves cluster data analysis. Cluster analysis is a method of classification analysis; its main purpose is to break down the set of studied objects and signs into groups, or clusters, homogeneous in a certain sense. Homogeneity is understood as the objects proximity in a multidimensional space of signs, and then the task is reduced to isolate in space natural clusters of objects, which are considered homogeneous groups [21, 22].

Cluster analysis involves dividing a sample of source data given into similar sets, with each cluster including objects extremely similar in genus, and correlating significantly different elements to other clusters. Thus, the initial data of professional category “production workers”, using the STATISTICA program, were divided into three clusters - three levels of safety culture: high, medium and low (Figure 1).

There are 16 components of the safety culture on the horizontal axis. The vertical axis indicates the average estimates of production workers for each component. The results of the repeated questionnaire survey (bold line) were compared with the results of the one conducted before the implementation of the BSA procedure (thin line). Thus, on the graph, it is possible to observe an increase in the values of average ratings for each safety culture component, which manifests itself in a shift of each cluster by several units higher. Such results indicate the effectiveness of the BSA procedure implementation. The largest increase in assessment is observed in the category “Trust/confidence”, while the smallest
growth is recorded by components “Notification of violations”, “Assessment of HSE service performance” and “Communications inside a company regarding safety issues”, which requires a detailed focus on these issues.

![Cluster analysis based on the survey results before and after the BSA procedure implementation for the professional category “production workers”.

Figure 1. Cluster analysis based on the survey results before and after the BSA procedure implementation for the professional category “production workers”.](image)

Each cluster (the level of safety culture) was analyzed for the presence of distinctive socio-biographical characteristics of production workers included in a particular cluster.

Analysis of the cluster with the high safety culture level shows: workers are in the age category from 20 to 49 years, mostly with work experience from 6 to 25 years. According to the survey results, the majority (79%) contributes to security, but a tenth is not involved in this process at all. At the same time, 81% believe that it is possible to achieve zero injuries, which is a good motivation for safe behavior. Also, almost every employee (95%) believes that it is possible to fulfill all safety requirements, which indicates the quality work of HSE department. At the same time, only 75% are ready to interrupt the process if they detect violations of safety requirements, but it is necessary to achieve the figure of 100%.

The middle cluster involves: production workers in the age category from 20 to 35 years old, both with work experience of up to 6 years and with experience from 6 to 25 years. The majority (74%) contributes to safety, while 70% believe that it is possible to achieve zero injuries, which is a good motivation for safe behavior. Also, the majority of employees (89%) believe that it is possible to fulfill all safety requirements. At the same time, only 69% are ready to interrupt the process if they detect violations of safety requirements. The main task in this matter is to explain to all employees that it is better to prevent an undesirable event (to interrupt the technological process) than to mitigate the consequences.

In cluster with the low safety culture level, it is possible to observe an identical age category of production workers, mainly with experience from 6 to 25 years. Analyzing the data obtained, it is interesting to note a downward trend in the number of workers who believe that it is possible to achieve zero injuries at the enterprise, as well as those who are ready to make their own contribution
to safety. Most employees (71%) believe that it is possible to fulfill all safety requirements. At the same time, only 56% are ready to interrupt the process if they detect violations of safety requirements.

5. Conclusion
In the framework of this study, a comparative analysis of safety culture levels was carried out on the basis of the initial and repeated questionnaires results of employees in order to assess the effectiveness of the preventive measures taken (implementation of the BSA procedure).

Using complicated mathematical calculations, the statistical significance (presence of changes) of most safety culture components for the professional category “production workers” was revealed. However, there were no significant changes for the professional group “executives” (leaders), which indicates the need to focus further attention on this professional group during the further measures implementation to improve the safety culture level in companies. It is necessary to change the leaders consciousness as the main connecting link for further successful development in the field of corporate safety and the high safety culture level establishment.

A cluster analysis was also carried out for the professional category “production workers”, as the group most committed to changes, which made it possible to compare safety culture levels (high, medium, low) with relative to each other, as well as the results obtained during the initial survey. Each cluster has shifted several units higher, which indicates high ratings and is the result of the BSA procedure implementation. Based on the cluster analysis results, more detailed socio-biographical characteristics of production workers belonging to a particular cluster were constructed, as well as their relation to safety aspects.

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