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Development of leading indicators for the assessment of occupational health performance using Reason's Swiss cheese model

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Abstract:

BACKGROUND: The Swiss cheese model of accident causation is a model used in risk analysis and risk management, including aviation safety, engineering, healthcare, and emergency service organizations, and as the principle behind layered security, as used in computer security and defense in-depth. This study aimed to develop and weight the occupational health leading indicators using the Swiss cheese model.

MATERIALS AND METHODS: The present study was a descriptive, cross-sectional study; occupational health performance assessment indicators were classified into five main groups of chemical, physical, ergonomic, psychosocial, and biological harmful agents. In addition, potential hazards and their prevention methods were identified using the Swiss cheese model. The leading performance measurement indicators (n = 64) were developed based on preventive methods and were weighted and rated by fuzzy analytic hierarchy process.

RESULTS: Thirty-six out of 64 indicators were related to the management measures, 25 indicators were related to exposure to harmful occupational agents, and the remaining indicators were occupational-related illnesses and diseases rate. Considering the importance and frequency of indicators, psychological agents were the most important indicators (40%) and physical agents had the greatest frequency (59%).

CONCLUSIONS: Process of indicators' development has demonstrated that the major occupational health prevention measures in the oil and gas industry are concentrated on physical, psychological, and chemical agents, respectively. Thus, to provide protection for employees against occupational diseases and improve health performance indicators, paying special attention to mentioned agents is essential in the oil and gas industry.

Keywords:

Health performance assessment, health status indicators, leading indicators, occupational health, Reason's Swiss cheese model

Introduction

Performance assessment and performance indicators have a great importance in all aspects of life. These indicators can determine appropriate responses for improvement.[1] The primary purpose of health and safety performance measurement is to provide information on the progress and current status of the strategies, processes, and activities used by an organization to control health and safety risks.[2] Evaluating the performance of health indicators is the first step in identifying health risks. Using the results of these assessments, an organization will be able to maintain and promote the health of personnel through various methods such as health education.[3] Lagging indicators are typically

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output oriented while leading indicators are typically input oriented, and they have an impact on the performance of the organization.[4]

There is no globally used set of performance indicators in the oil and gas industry, although companies report some indicators to their national authorities (e.g., OSHA 300 in the USA).[5,6] Only reliance on the lagging indicators of occupational diseases as the health performance measurement criteria is a poor measure, since the absence of occupational diseases, even over a period of years, does not guarantee that hazards have been identified and their associated risks have been effectively managed. It is clear that monitoring systems are needed which provide early feedback on performance before an incident occurs, and thus, the use of proactive monitoring systems and the leading indicators wherever possible is of particular importance.[7-9]

The importance of systematized collections of performance indicators for evaluating the effectiveness of occupational health and safety (OHS) management practices has been already documented in several studies.[10-16] Selecting key indicators among all proposed indicators happens through a wide variety of decision-making techniques. Studies conducted for assessing the usage of multi-criteria decision-making showed that the analytical hierarchy process (AHP) technique is one of the most common methods.[1,17-23] The companies should decide to choose indicators based on their circumstances.[24] Subjective assessment of the indicators can influence results. According to the above-mentioned challenges in indicators' selection, the main objective of this study was to develop indicators for assessing the performance of occupational health management system (MS). Given that the leading indicators have a preventive nature, the use of Swiss cheese model for the development of leading indicators is considered as the main approach of this study. The Swiss cheese model of accident causation is a model used in risk analysis and risk management, including aviation safety, engineering, healthcare, and emergency service organizations. It likens human systems to multiple slices of Swiss cheese, stacked side by side, in which the different layers prevent the risk of a threat becoming a reality. Therefore, lapses and weaknesses in one layer do not let a risk to happen because other layers also are present to prevent a single point of failure.[25] The model integrates the components of all production systems such as "decision-makers, line management, preconditions for effective work, production activities, and safeguards" against the hazard.[26]

Several studies have been carried out on the use of the Swiss cheese model with an accident prevention approach;[27-29] however, in the present study, the concept of Swiss cheese model along with AHP has been used to develop the leading indicators for the prevention of occupational diseases in oil and gas industries.

Materials and Methods

The present study was a descriptive, cross-sectional study; the purpose of this study was to develop weight and rank the occupational health performance indicators. To do so, harmful agents were categorized in five main categories including harmful physical, chemical, ergonomic, biological, and psychological agents in the oil and gas industry. Determination of occupational health leading and lagging performance indicators in this study was originated from Swiss cheese model based on the preventive approach. The expression of this model is schematically shown in Figure 1.

This model was presented by Reason. He states that a combination of errors and negligence occurs at different levels of the organization, and if all of these errors align in a line, the accidents will happen. Some of these factors are defects in human activities or in workplace situations, and others relate to weak management or poor design in the system.[30] Hence, if, in any of the levels, necessary considerations be regarded, the probability of an accident will be greatly reduced.[31] In this model, leading indicators, preventive barriers, lagging indices, and barriers status are evaluated. In addition, the status of staff exposure to occupational hazards and the rate of occupational diseases are considered in this model. Based on the defined model, the indicators were developed and weighed in three steps.

Step 1: Classification of work-related risk factors

First, occupational harmful agents were classified in five categories to determine the leading performance indicators [Figure 2]. The harmful agents of the

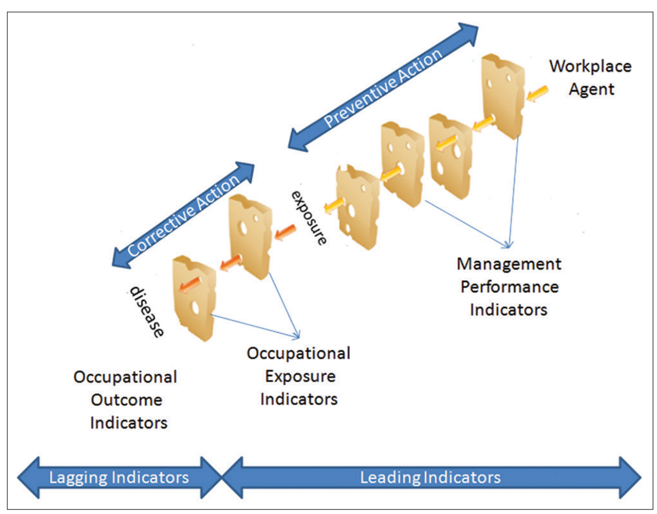

Figure 1: Swiss cheese model was used in performance indicators' developing

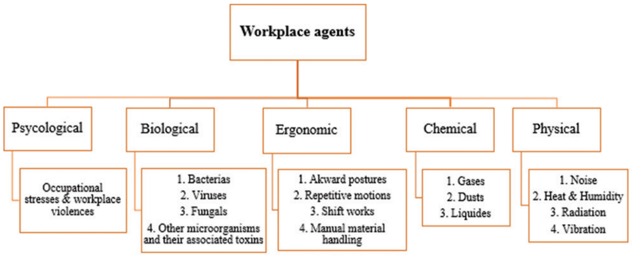

Figure 2: Classification of workplace harmful agents for developing health performance indicators

workplace were included psychological, biological, ergonomic, chemical, and physical agents. Each of these agents was classified into several hazards, for example, physical harmful agents included hazards such as noise, heat and humidity, radiations, and vibrations.

Step 2: Categorization of indicators based on the nature of performance measurement

In this step, in accordance with Swiss cheese model, occupational health performance indicators were developed at three levels of management performance, occupational exposure, and occupational disease indicators.

The categorization of performance measurement indicators at this stage was based on determining the status of the effectiveness of preventive and corrective actions to reduce the exposure to harmful agents and determination of the diseases and disability rate. Then, through a field inspection and reviewing the documentation and procedures related to the processes of the occupational health MS, the performance measurement indicators were proposed in the three aforementioned.

Step 3: Weighting and prioritizing indicators

To create an effective method for measuring health performance, it is critical to reduce the number of leading performance indicators (LPIs) to the number of less important key performance indicator (KPIs). That is, among the existing indicators, the best and most important indicators should be selected. After compiling the indicators, the priority and preference of each indicator were determined using the table provided in AHP method as follows:

- A: Determination of the importance of each group of harmful agents (Criterion A)
- B: Determination of the number of indicators in each group of harmful agents (Criterion B).

In this step, according to the algorithm [Figure 3] and priority rating scale [Table 1], paired comparison was used. The preference scale for paired comparisons of items ranges from the maximum value 9 to 1/9.

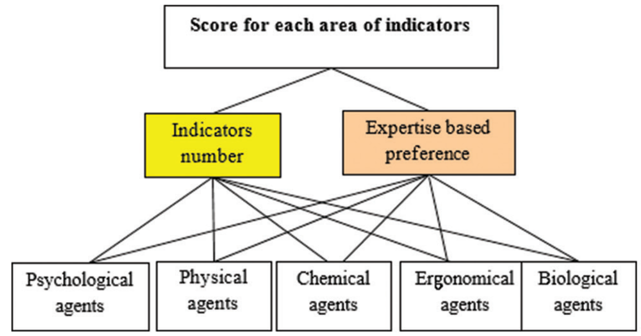

Figure 3: Paired comparison algorithm for importance and frequency of indicators

Table 1: Preferences of analytical hierarchy process in paired comparison

AHP scale of importance for comparison pair	Numeric rating
Extreme importance	9
Very strong importance	7
Strong importance	5
Moderate importance	3
Equal importance	1

AHP=Analytical hierarchy process

The paired comparison was done for A and B Criteria based on the experts' opinions. For this, paired comparison tables were prepared in the form of a questionnaire. The pair comparison was calculated according to the paired comparison matrix.

$$\tilde{A} = \begin{bmatrix} 1 & \tilde{a}_{12} & \cdots & \tilde{a}_{1n} \\ \tilde{a}_{12} & 1 & \cdots & \tilde{a}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{a}_{1n} & \tilde{a}_{2n} & \cdots & 1 \end{bmatrix} = \begin{bmatrix} 1 & \tilde{a}_{12} & \cdots & \tilde{a}_{1n} \\ \frac{1}{\tilde{a}_{12}} & 1 & \cdots & \tilde{a}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \frac{1}{\tilde{a}_{1n}} & \frac{1}{\tilde{a}_{2n}} & \cdots & 1 \end{bmatrix}$$

Equation 1: paired comparison matrix for calculating of importance and frequency of indicators.

In this step, the indicators were weighted based on the opinions of 13 selected safety experts employed in the oil and gas industries [Table 2].

After obtaining the pairwise comparison matrix, the results were averaged using the geometric mean method and integrated matrix of paired comparisons calculated by Equation 2.

$$\mu_g = \left(\prod_{i=1}^{n} a_i\right)^{1/n} = \sqrt[n]{a_1 . a_2 \ldots . a_n}\,\tilde{a}_{ij} = (\tilde{a}_{ij}^{1} \times \tilde{a}_{ij}^{2} \times \ldots \times \tilde{a}_{ij}^{m})^{\frac{1}{m}}$$

Equation 2: The geometric mean method and integrated matrix of paired comparisons.

The normal weight of the elements at each column was calculated as follows:

$$W_i = \frac{\pi_i}{\sum_{i=1}^{n} \pi_i}$$

Equation 3: The normal weight of the elements at each column.

Pair comparison of the indicators and gravimetric determination of indicators were done by Expert Choice 11 software because of their application facility and easy access.

The B Criterion was based on the number of indicators and the number of indicators in represented its score. Moreover, given scores based on the Criterion A were determined based on the experts' opinions. After scoring different parts of occupational health management and control exposure to harmful agents, rating of every selected indicator in each sector was calculated through following equation:

$$\text{Indicator score}=\frac{\text{Total score}\times 100}{\text{Indicators numbers}}$$

Equation 4: Rating of every selected indicator in each sector.

Further, scoring of physical agents subcategory was done similarly based on two Criteria A and B.

Results

In this study, field inspection and documentation and procedures' review related to occupational health management processes were conducted to determine the occupational health performance indicators in three parts, including preventive measures against harmful agents, exposure to harmful agents, and effects of exposure to the agents. Hence, 64 indicators were determined in three areas containing management indicators, occupational exposure indicators, and adverse health effect indicators [Table 3].

The results of Table 3 showed that 96% belonged to leading indicators. Before pairwise comparison of indicators, the importance of five categories of harmful agents in the oil and gas industry was determined. The results are presented in Figure 4.

Table 2: Experts profile

n	Department	Position	*n*	Experience (years) [c]
1	HSE	Manager	3	14, 15, 9
2	HSE	Expert	5	5, 11, 9, 6, 7
3	Manufacture	Manager	3	25, 27, 19
4	QC	Manager	2	23, 28

Psychosocial risks and work-related stress in the oil and gas industry have the highest priority (40%). In addition, the importance of chemical, physical, ergonomic, and biological agents was 28%, 19%, 8%, and 5%, respectively.

Five different categories of harmful agents in terms of outcome indicators using AHP pairwise comparison are presented in Figure 5.

Physical agent was the highest ranked agent (59%) in terms of the number of performance measurement indicator in the occupational health MS. Moreover, chemical (16%), ergonomic (10%), biological (8%), and psychological (7%) agents took the next ranks, respectively.

Results of combined scores for both Criteria A and B are depicted in Figure 6.

The results of Figure 6 showed that physical agent's indicator with 44% of the total combined scores was in the highest rank. The psychological, chemical, ergonomic, and biological agents received the next ranks, respectively. Indicators of physical agents (noise, vibration, heat, radiation, and ultraviolet and infrared) were compared separately using AHP method. The results are presented in Table 4.

The results of Table 4 showed that noise with 32% of the total scores in the physical agents have the greatest weight.

Overall ranking of the physical agent groups and other detrimental agents are shown in Figure 7.

The results of Figure 7 showed that the performance indicator of psychological agents, chemical agents, and noise pollution took the largest portion in oil and gas industry, respectively.

In Table 5, the number of given indicators is presented.

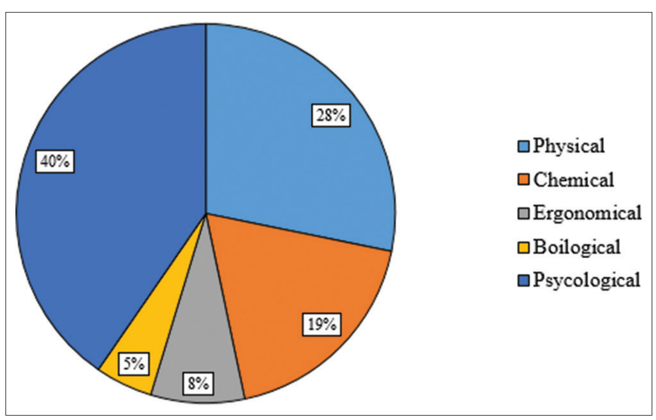

Figure 4: Importance of agents in oil and gas industry

The objective of this study was to construct a framework for evaluating importance and weight of KPIs in the oil and gas industry. Other studies confirm safety and health performance indicators have been developed based on a system such as health and safety management OHSAS18001 or ILO-OHS2001.[32] In this study, based on expert's opinion, KPIs for workplace psychological agents (23.5%) were the most important. Leka *et al*. in their study stated that psychosocial risks are among the harmful agents at the workplace.[33] Employees of the oil companies are suffering high workload and are working for long hours.[34] The remote site of national oil and gas installations requires a prolonged work pattern, as well as the prolonged work-hours, and shift-work patterns can have a significant effect on occurrence of psychosocial problems affiliated to work, events, diseases, and working performance.[35] Lack of social support, nonoccupational disease, and work-related stress can cause psychosocial problems and make them prominent compared to other harmful agents industry.[36-38] The results of the fourth report of labor situation in Europe in 2005 showed that 22% of workers in the EU 15 countries and 12% in the 10 new Europe members believed that their health due to work-related stress has been at risk.[39] Studies further suggested that these problems are one of the detrimental factors causing musculoskeletal disorders,[40] and their related psychological consequences (anxiety, tearfulness, and depression) in the workforce have revealed.[41] The results of the studies confirmed the importance of psychosocial performance indicators than other harmful agents. Occupational psychological factors are among those factors whose control is critical to promoting employee health, but the methods of controlling these factors are different from other occupational factors. Given the special importance of psychological factors as an occupational health risk, its control is very important. Many psychological problems are originated from working conditions, but also they depend on the personality traits and attitudes of the individual.[42,43] Therefore, holding training courses with the content of occupational psychology to increase workers' awareness of mental health issues is very useful to maintain and promote their mental health.

Table 3: Statistics of occupational health performance indicators

The type of indicators	Frequency (%)
Leading indicators	
Management	36 (56)
Occupational exposure	25 (40)
Lagging indicators	
Effects of occupational exposure	3 (4)
Total	64 (100)

Table 4: Mean scores of physical agents based on the criteria A and B

Physical groups	Average score of physical agents (total score=100)	Percent of score for each group (total=43.6)
Noise	32	13.8
Vibration	18	7.9
Heat	21	9.1
UV and IR	15	6.7
Lighting	14	6.1

IR=Infrared, UV=Ultraviolet

Next to the psychological agents, harmful chemicals (17.5%) and noise (13.8%) are in the second and third positions,

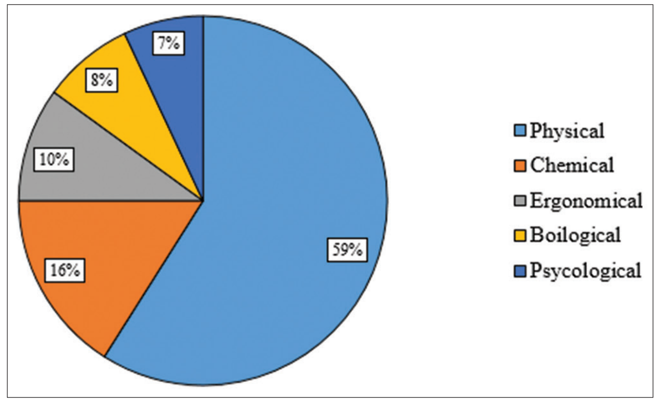

Figure 5: Score of indicators in terms of number of indicators in each group (the Criterion B)

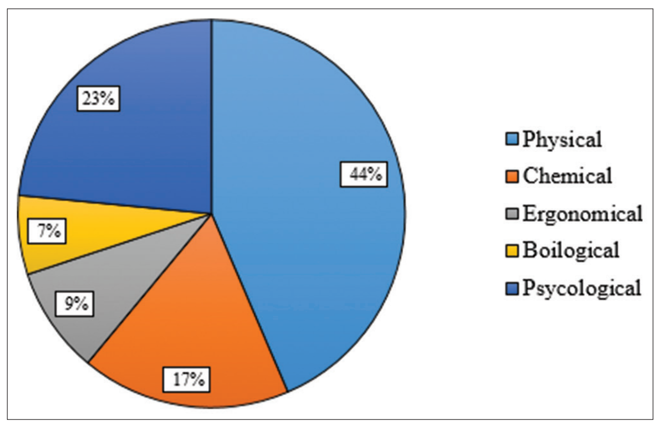

Figure 6: Score of each group based on Criteria A and B

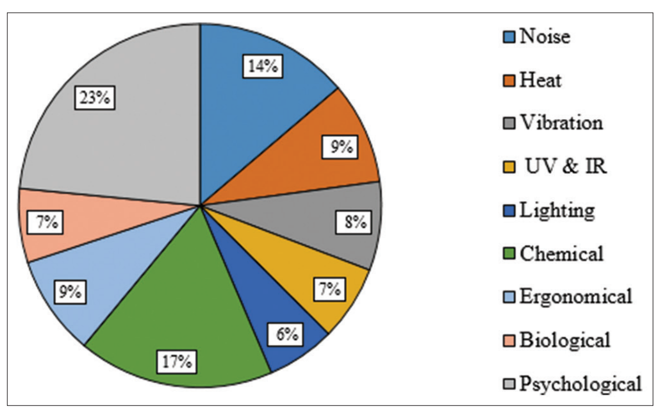

Figure 7: Overall ranking of the physical agent groups and other detrimental agents

Table 5: Indicators and their weights

Indicator category	Indicator type	Indicator group	Indicators title	Indicators weight
Management performance indicators	Leading indicators	Physical	Percent of workers exposed to noise pollution that have been trained about noise-induced risks and complications and their preventive methods	1.97
			Percent of high-risk workstations that their noise levels have fallen below the permissible limit	1.97
			Percent of workers exposed to vibration that have been trained about its risks and complications and their preventive methods	0.99
			Percent of high-risk workstations that their vibration levels have fallen below the permissible limit	0.99
			Percent of high-risk workstations using engineering and administrative methods, heat stress has fallen below the permissible limit	1.14
			Percent of employees exposed to heat stress that use personal protective equipment to cope with the heat	1.14
			Percent of employees exposed to IR and UV rays that use personal protective equipment to cope with them	0.96
			Percent of employees exposed to IR and UV rays that periodic medical examination has done for them	0.96
			Percent of workers that have been trained about low level of lighting-induced risks and complications	1.02
		Chemical	Percent of the occupations that produced chemicals in them have been identified	1.75
			Percent of the chemicals that their MSDS has been prepared	1.75
			Percent of workstations that required control measures has been done	1.75
		Ergonomic	Percent of the occupations that ergonomic risk factors that have been modified	1.48
			Percent of employees who received training about ergonomic risk factor-induced risks and complications	1.48
		Biological	Percent of kitchen employees who underwent the medical tests and health card is issued to them	1.32
			Percent of kitchen employees and food transportation and storage staff that have been biennial trained about the principles of food hygiene and public health	1.32
		Psychological	Percent of workers exposed to psychological risk factors that have been trained about its risks and preventive methods	5.87
			Percent of employees exposed to psychological risk factors that related periodic medical examination has done for them	5.87
Occupational exposure indicators	Leading indicators	Noise	Percent of workstations that noise measurement and analysis has been done on them	1.97
		Vibration	Percent of detected occupations that vibration measurement is taken in them	0.99
		Heat	Percent of points that their heat stress risks are higher than TLV, according to WBGT index	1.14
		Radiation	Percent of detected occupations that IR and UV rays measurement is taken in them	0.96
		Lighting	Percent of measured points that lighting is lower than the permissible level	1.02
		Chemical	Percent of occupations, the evaluation of employees' exposure to chemicals has been done for them	1.75
		Ergonomic	Percent of occupations, the evaluation of ergonomic risk factors has been done for them	1.48
		Psychological	Percent of employees, the evaluation of psychological risk factors has been done for them	5.87
Occupational outcome indicators	Lagging indicators		Occupational diseases attributable deaths during a year	N/A*
			Occupational diseases attributable working days lost during a year	N/A
			The rate of any occupational diseases during a year	N/A

*Not applicable. IR=Infrared, UV=Ultraviolet, TLV=Threshold limit value, WBGT=Wet-bulb globe temperature, MSDS=Material Safety Data Sheet

respectively, which is consistent with Eyayo's study.[44] Gardner's study showed that leukemia is a prevalent occupational disease in oil and gas fields.[45] The results of Golara and Shokat Sadry's study and statistics of recorded occupational diseases by the Australian Institute of Petroleum showed that the chemical agents were the serious health risks in oil and gas industry.[46] Workplace heat stress and adverse ergonomic agents with 9.1% of the total placed fourth. Assessment of occupational heat stress management considered important due to hot and humid climate of geographical location of oil and gas industries. Ergonomic measurement indicators after heat stress were placed in the fifth position, namely 8.9%; according to England Health and Safety Executive, 40% of the lost work-days are due to work-related musculoskeletal disorders. Based on the Criterion A, weighted performance indicator of psychological health was 40.8% and of physical agents was 28.2%, but the total share of these two indicators based on both A and B Criteria was 23.5% and 43.6%, respectively. Detrimental physical agent consisted of five subgroups which make them as the main indicator, so its weight was much higher than the others. 125,600 registered occupational diseases in America showed that two-thirds of diseases related to skin damage and hearing loss and trauma such as contact pressure were caused by repetitive tasks and vibration.[45,47,48] This supported the key importance of detrimental indicators in this survey. However, the finding of the current study indicated that it is necessary to develop occupational health KPIs in accordance with amended conditions of physical, chemical, ergonomic, and psychosocial agents in the oil and gas industry.

Selected indicators in this survey were naturally quantitative and could be easily compared and measured, while indicators prepared by oil and gas producers were subjective and qualitative measures. Therefore, comparing occupational health status of the oil industries in this way has high importance. The main limitations of this study were expressed as follows: the first limitation concerns the lack of complete coverage of all oil and gas operations such as extraction, exploration, manufacturing, and construction, and the second limitation was the lack of indicators' validation. Therefore, further studies are necessary to improve occupational health leading indicators in the oil industry and designing an indicators' database software to improve the performance of OHS-MS. The innovation of this research is the application of the Swiss cheese model in providing an optimal approach to the development of leading indicators of the performance assessment of occupational health MS. This model helps that the extracted leading performance indicators be able to measure the status of all preventive control layers, such as management, engineering, and personal protection measures in the occupational health field. In this study, the application of the Swiss cheese model, in addition to the development of safety performance indicators, can also have a high potential for the development of occupational health performance indicators.

Conclusions

As well as, development and validation of leading occupational health performance indicators based on various conditions such as economics, knowledge, organization maturity, and workplace regulations is necessary. Comparing the results of various studies in the field of occupational medicine in the oil and gas industry and selected KPIs in the current study showed a high degree of compliance for selected indicators. Process of developing the indicators indicated that the major occupational health prevention measures in the oil and gas industry are focused on chemical, psychological, and physical agents in the order. Based on the results of this study, to prevent health risks caused by occupational factors, it is possible to educate the health risks caused by various factors based on their importance and in this way maintain or improve the workers' health status. Knowing the harmful factors of the job and determining their priorities allow us to be able to control these factors with a precise plan. Educating people about their mental health issues and holding training courses on the use of personal protective equipment and doing work safely are the key steps in reducing safety and health risks.

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Conflicts of interest

There are no conflicts of interest.

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