An Index Developed for the Assessment of Occupational Health and Safety at Workplace: A Field Study in a Heavy Automotive Industry in the Northwest of Iran

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Abstract

Background: Most workers are exposed to a variety of hazards in their workplace. Devising a comprehensive checklist and developing an index for Occupational Safety and Health (OSH) assessment could be useful. This study was conducted in a heavy automotive company with the aim of developing and validating an OSH assessment index.

Methods: We used the experiences and comments of OSH experts to devise a checklist for OSH assessment. Weighting various harmful factors was done using Analytical Hierarchy Process (AHP) technique. Intra-class Correlation Coefficient (ICC) was applied to measure the reliability of the checklist (SPSS version 20). In the studied industry, 150 workstations were assessed using the developed comprehensive checklist. In order to validate the total index, we assessed its correlation with 4 groups of occupational statistics (i.e. accident frequency, severity rates, lost working time rate, and occupational disease incidence rate). A p value of < 0.05 was considered significant.

Results: Among 7 sub-indices, sub-indexes of occupational health and the workplace order (w=0.21) and housekeeping (w=0.04) had the highest and the lowest AHP weights, respectively. The mean of ICC was found to be 0.978. The total index ($OSHI_{Total}$) and the Accident Severity Rate (ASR) had a strong inverse significant correlation (r=-0.774, P=0.002).

Conclusion: The developed index covered important occupational hazards. The inter-evaluator reliability for this index was high.

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Introduction

Many techniques ranging from simple qualitative methods to advanced quantitative methods are available to help identify and analyze workplace hazards.[1] The use of multiple hazard analysis techniques is recommended because each has its own purpose, strengths, and weaknesses.[2] Successful occupational health and safety practices require the collaboration and participation of both employers and workers in health and safety program, and consider such issues as occupational medicine, industrial hygiene, toxicology, education, engineering safety, ergonomics, and psychology.[3]

In industrial environments in developing countries, workers are commonly exposed to diverse contaminants and harmful agents. This happens for different reasons such as inappropriate design, improper isolation of risk sources, inadequate establishment of occupational safety and health (OSH) systems, weakness of the OSH rules and regulations, and finally the employers' lack of awareness about the essentials of OSH.[4]

Studies and experiences of researchers show that most workers in industrial settings have complaints about exposure to a mixture of several harmful factors or hazards,[5] which might be tolerable on their own, or might not be acceptable in combination with other factors in long periods of time. Therefore, acceptable levels of occupational health require addressing all aspects of occupational hazards in the workplace. Moreover, many of the legal authorities in the field of OSH conditions emphasize the assessment of working conditions from various aspects. So far, there are few proper indices for comprehensive assessment of OSH conditions. One of the few studies on the development of an index for OSH assessment belonged to the Finnish Institute of Occupational Health which led to the development of the ELMERI index.[6] Despite its comprehensive viewpoint, this index has the following limitations and shortcomings:

1) Failure to assess the workload (mental and physical workload requirements, time pressure requirements, performance and efficiency, amount of effort and frustration) which, despite its considerable importance, hasn't been assessed in the ELMERI index.

2) In this index, there are no factors or ratios for indicating the amount or intensity of deviation from the standards; that is, a workstation with, for example, a sound pressure level of 86 dB is not different from a workstation with that of 95 dB and both are considered to be inconsistent with the standard (i.e. 85dB).[7] In the present study, in order to consider this shortcoming, we determined a ratio for the amount of deviation from the standards.

3) In the ELMERI index, the weights of all harmful factors are the same, while the adverse effects of harmful factors could be very different based on the target organ or intensity. In this study, using the Analytical Hierarchy Process (AHP) and the experiences and comments of experienced experts, the harmful factors were compared pair-wise and then using Expert Choice 11.1 (AHP) software, a ratio was determined for each sub-index as its weight from the total weight of the comprehensive index.

Considering the importance of a comprehensive index that can assess workplace hazards from various aspects and determine their combined effects on OSH conditions, we aimed to carry out a study with the objective of developing and validating the OSH assessment index. It is believed that this index might be of practical use for OSH experts and can fill the present gap in this field.

Materials and Methods

In this cross-sectional study conducted from 2014 to 2015, 150 workstations were selected from 8 different workshops in a heavy automotive company in the northwest of Iran, using random sampling method. For a comprehensive assessment of the OSH conditions of the workshops, a comprehensive checklist of various harmful factors was devised using the original version of ELMER index as well as national occupational health and safety regulations. The checklist was sent to 10 OHS academic experts. They were asked to give their comments in a prepared form. The assessment checklist developed contained 7 sub-indices, including occupational health, safety behavior, machinery safety, workplace order and housekeeping, ergonomics, fire safety and first aids, and finally workload as described below:

The first sub-index: Occupational health with 7 items (including noise, lighting, IR and UV, magnetic fields, air quality (i.e. dust, fibers, fumes, gas, vapor and mist), workplace thermal condition, and chemicals in the workplace).[6-10]

The second sub-index: Safety behavior with one item (including the use of various kinds of personal protective equipment appropriate to the workplace hazards and avoiding unsafe practices).[6]

The third sub-index: Machinery safety with 4 items (including structural conditions and design, emergency stop and control equipment, machine safeguard, and electrical safety).[6, 10]

The fourth sub-index: Workplace order and housekeeping with 5 items (including desktops, shelves, machine surfaces and locks, waste and garbage containers, and floors and platforms).[6]

The fifth sub-index: Ergonomics in the workplace with 4 items for each workstation (including workstation design and posture assessment, manual load handling, motion repetitions, and various physical positions).[6,10-12]

The sixth sub-index: Fire safety and first aids with 3 items (including first aids kits, fire alarm and extinguishing system, and emergency exits).[6, 10]

The seventh sub-index: Workload with 6 items (including mental load requirements, physical load requirements, time pressure requirements, performance and efficiency, amount of effort and frustration).[13-17]

After preparing the checklist, based on a preplanned schedule, all assessments including measurements, observations and completion of the questionnaire were performed in 150 randomly selected workstations. All workstations were visited and the OSH checklist was completed for each of them. In each workstation, the checklist was completed using harmful agents measurement data existing in the OHS unit archive of the company through observation and also interviews with the workers. For quantitative and measurable harmful factors, we used the company documents available at the company's OSH unit. For workload assessment which was done using the NASA-TLX questionnaire, the workers were interviewed during their mid-day break. For qualitative items (e.g. safety issues, ergonomics and workplace order and housekeeping), the checklists were completed by the evaluators. Eventually, 150 workstations were assessed. Inter-evaluator reliability was used to validate the checklist. For this purpose, 20 workstations were reassessed by 7 occupational safety and health experts during a 30-day period. The Intra-class Correlation Coefficient (ICC) was used to examine the inter-evaluator reliability of the checklist.

The evaluators observed all items of the checklist at each workstation. Each item was assessed as either consistent with OSH standards or inconsistent with OSH standards. Then, the occupational safety and health index (OSHI) was calculated by the following formula:

$$OSHI=\left(\frac{\text{No. of consistent items}}{\text{No. of inconsistent items} + \text{No. of consistent items}}\right)$$

Assessment criteria for quantitative and measurable items were the national Occupational Exposure Limits (OEL);[7] also, for qualitative items the criteria were expertise based on observation and completion of the questionnaire.

In workload assessment by NASA-TLX, if the scores of the 1st, the 2nd, the 3rd, the 5th and the 6th stages were lower than 10 and higher than 10 in the 4thstage, the "consistent" option and otherwise the "inconsistent" option were selected.

As the OSHI was to reflect the workstations OSH conditions accurately, the weight of each sub-index had to be determined. For this purpose, we used the Analytical Hierarchy Process (AHP).[18] This process is widely used for group decision making in different contexts and fields.[19] Each sub-index was compared pair-wise with the other sub-indices (the other 6 ones) and scored. Ten experts, who were specialists in the field of OSH,[20] assessed and compared the two sub-indices from the viewpoint of risk in the company. Then, the weight of each sub-index (ranging from 0 to 1) was determined using Expert Choice 11.1 (AHP) software.

Total index ($OSHI_{Total}$) for each workshop was calculated by the following formula:

$$OSHI_{Total}=[(x_1 \times OSHI_1) + (x_2 \times OSHI_2) + (x_3 \times OSHI_3) + (x_4 \times OSHI_4) + (x_5 \times OSHI_5) + (x_6 \times OSHI_6) + (x_7 \times OSHI_7)]$$

In this formula:

$OSHI_{Total}$: Total occupational safety and health index

$OSHI_1$: Occupational health sub-index

X_1: Weight of occupational health sub-index

$OSHI_2$: Safety behavior sub-index

X_2: Weight of Safety behavior sub-index

$OSHI_3$: Machinery safety sub-index

X_3: Weight of machinery safety sub-index

$OSHI_4$: Workplace order and housekeeping sub-index

X_4: Weight of workplace order and housekeeping sub-index

$OSHI_5$: Ergonomics sub-index

X_5: Weight of ergonomics sub-index

$OSHI_6$: Fire safety and first aids sub-index

X_6: Weight of fire safety and first aids sub-index

$OSHI_7$: Workload sub-index

X_7: Weight of workload sub-index

One of the benefits of the Analytical Hierarchy Process (AHP) is monitoring the decision consistency. Using AHP, the decision consistency was calculated and its acceptability was assessed.[21] The less consistent a decision, the less consistent the matrix will be. The acceptable range of inconsistency in each system depends on the decision maker, but it has generally been suggested that if the ratio of inconsistency index exceeds 0.1, it is better that the decision maker reconsiders his assessment.[21]

In order to improve the assessment accuracy of the OSHI, the intensity of harmful factors should also be considered. For example, if the results of sound pressure levels field measurement were 86 dB for station 1 and 93 dB for station 2, although sound pressure levels are different, the "Inconsistent" option will be selected for both stations. To resolve this problem, sound pressure levels beyond the permissible limit were classified according to intensity. Based on a 3 dB increase in the sound pressure levels which decreases the exposure time by 50%,[7] harmful sound pressure levels were classified as follows:

85-88 dB sound pressure levels: Inconsistent,

88-91 dB sound pressure levels: Inconsistent +1,

91-94 dB sound pressure levels: Inconsistent +2,

Sound pressure levels beyond 94 dB: Inconsistent +3.

Lighting

If lighting levels are lower than the standard limit:

Inconsistent,

If lighting levels are 50% lower than the standard limit: Inconsistent +1,

If lighting levels are more than 50% lower than the standard limit: Inconsistent +2.

Air Qquality

If the measurement results for airborne hazards are higher than the relevant OEL: "Inconsistent",

If the results are 1.5 times higher than the relevant OEL: Inconsistent +1,

If the results are 2 times higher than the relevant OEL: Inconsistent +2,

If the results are 3 times higher than the relevant OEL: Inconsistent +3

Due to the variety of the studied harmful factors and having different qualitative and quantitative items with different permissible limits, determining the cut-off points was somewhat difficult. Also, because of lack of any specific and reliable standard, in this study we used the cut-off points related to quartiles,[22] which put the $OSHI_{Total}$ in one of the four categories shown in Table 1.

Table 1: Cut-off points and classifications of $OSHI_{Total}$

$OSHI_{Total} \leq 25\%$	Very Poor	VP
$26\% \leq OSHI_{Total} \leq 50\%$	Poor	P
$51\% \leq OSHI_{Total} \leq 75\%$	Moderate	M
$OSHI_{Total} \geq 76\%$	Good	G

In order to validate the total index, the correlations between $OSHI_{Total}$ with 4 groups of occupational statistics including accident frequency rate (AFR), accident severity rate (ASR), lost working time rate, and occupational disease incidence rate were examined using Pearson correlation coefficient. These four groups of occupational statistics were determined using accident statistics recorded in the company and medical records of the employees for the year 2014.

Results

The developed index contains 7 sub-indices, including Occupational health (7 items), Safety behavior (one item), Machinery and equipment safety (4 items), Workplace order and housekeeping (5 items), Ergonomics (4 items), Fire safety and first aids (3 items), and Workload (6 items) (Figure 1).

Figure 2 shows the pie chart of the harmful factors weights according to the experts' judgments. As shown in this Figure, each harmful factor holds a share of the $OSHI_{Total}$, and the sum weight of all shares equals to 1. According to experts, 'occupational health' received the highest weight with the ratio of 0.21, and after that 'machinery safety' with the weight of 0.17, 'safety behavior' and 'fire safety and first aids' with the equal weight of 0.16, 'ergonomics' and 'workload' with the equal weight of 0.13, and 'workplace order and housekeeping' with the weight of 0.04 held the next ranks.

Inconsistency index for pair-wise comparison was found to be 0.01735 among the 10 experts. Compared to baseline value suggested by Saaty (<0.1), inconsistency index was in an acceptable range.[21] The ICC for 7 evaluators was 0.978 (strong correlation) and internal consistency between evaluators was significant on the 0.001 level. The results indicated good validity of the $OSHI_{Total}$ index.

The results of the assessment of OSH conditions of the 8 different workshops in the heavy automotive company (totally, 150 workstation) are displayed in Table 2. As demonstrated in this Table, the safety behavior sub-index was poor in most of the studied workshops (87.5%). The ergonomics sub-index was in a better condition than the other sub-indices (50%).

Table 3 presents the results of calculation and assessment of $OSHI_{Total}$ in the 150 workstations studied in the whole company.

As can be seen in Table 3, the company OSH was in such conditions that 88% of its workstations were in the Poor and Very Poor categories and only 12%

Table 2: Mean scores of the best and worst sub-indices in different workshops studied

Workshop	Best sub-indices	Scores of sub-indices Mean±SD	Worst sub-indices	Scores of sub-indices(%) Mean±SD
Workshop No. 1	Workload	53±15.12	Safety behavior	25±43.85
Tooling	Ergonomics	63.50±15.51	Safety behavior	13.31±34.57
Casting	Fire safety & First aids	52±11.46	Safety behavior	-
Compressors & Boilers	Safety behavior	100±0	Occupational health	33.51±8.10
Pumps, clutch and dashboard	Ergonomics	59.75±10.42	Safety behavior	-
Machine manufacturing	Ergonomics	58±14.12	Safety behavior	20±41.04
Backhoe manufacturing	Ergonomics	63.40±13.71	Safety behavior	30±48.31
Warehouses	Order &housekeeping	54±16.63	Safety behavior	-

Items	Consistent	No. of consistent items	Inconsistent	No. of inconsistent items	N/A
1)Occupational health					
1-1) Sound					
1-2) Lighting					
1-3) IR, UV					
1-4) Magnetic fields					
1-5) Air quality					
1-6) Workplace thermal condition					
1-7) Chemicals					
2) Safety behavior					
2-1) Use of appropriate personal protective equipment					
3) Machinery safety					
3-1) Structural conditions & design					
3-2) Emergency stop & control equipment					
3-3) Machine safeguard					
3-4) Electrical safety					
4) Workplace order &housekeeping					
4-1) Desktops					
4-2) Shelves					
4-3) Machine surfaces & locks					
4-4) Waste & garbage containers					
4-5) Floors & platforms					
5) Ergonomics					
5-1) Workstation design & posture assessment					
5-2) Manual load handling					
5-3) Motion repetitions					
5-4) Various physical positions					
6) Fire safety & first aids					
6-1) First aids kits					
6-2) Fire alarm & extinguishing system					
6-3) Emergency exits					
7) Workload					
7-1) Mental load requirements					
7-2) Physical load requirements					
7-3) Time pressure requirements					
7-4) Performance & proficiency					
7-5) Amount of effort					
7-6) Frustration					

$OSHI_{Total} = [(x_1 \times OSHI_1) + (x_2 \times OSHI_2) + (x_3 \times OSHI_3) + (x_4 \times OSHI_4) + (x_5 \times OSHI_5) + (x_6 \times OSHI_6) + (x_7 \times OSHI_7)]$

Figure 1: The $OSHI_{Total}$ final checklist

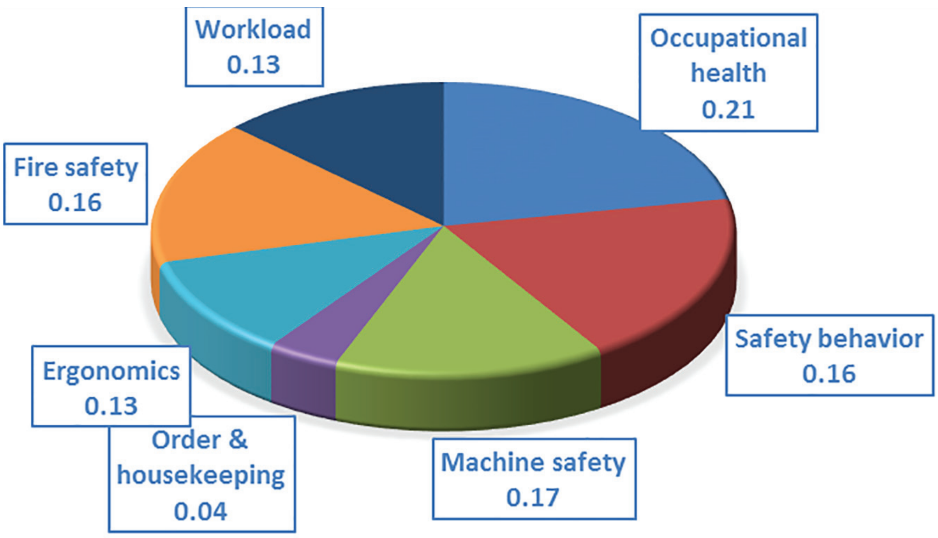

Figure 2: Weights of the harmful factors for development of $OSHI_{Total}$. (Expert Choice 11.1 software output)

Table 3: The results of calculation and assessment of $OSHI_{Total}$ in the whole company (n=150)

Workshop	No. of workstations	$OSHI_{Total}$ Min††	$OSHI_{Total}$ Max‡‡	$OSHI_{Total}$% Mean±SD	VP*	P**	M†	G‡ (%)
Workshop No. 1	40	13	57	34.47±14.37	40	45	15	0
Tooling	30	14	63	37.16±16.31	40	37	23	0
Casting	10	14.5	39	19.4±7.04	90	10	0	0
Compressors & Boilers	10	52	70	60.34±6.52	0	0	100	0
Pumps, clutch and dashboard	20	15.5	48	35.4±12.43	30	70	0	0
Machine manufacturing	20	14.5	58	34.17±15.36	40	45	15	0
Backhoe manufacturing	10	17	57	39.55±13.01	20	60	20	0
Warehouses	10	14.5	39	26.45±11.81	50	50	0	0
Whole company	150	13	70	35.62±15.71	39	49	12	0

*Very Poor; **Poor; †Moderate; ‡Good; ††Minimum $OSHI_{Total}$; ‡‡Maximum $OSHI_{Total}$

Table 4: Accident frequency and severity, lost working time rate and occupational disease incidence rate in different workshops during 2014 and 2015

Workshop	Number of workers	$OSHI_{Total}$% Mean±SD	Accident frequency rate	Accident severity rate	Lost working time rate*	Occupational disease incidence rate†
Workshop No 1	80	34.47±14.37	76.70	2818	0.022	0.29
Tooling	50	37.16±16.31	40	866	0.007	0.3
Casting	18	19.4±7.04	58.30	6119	0.047	0.78
Compressors & Boilers	35	60.34±6.52	28.70	373	0.003	0.37
Pumps, clutch and dashboard	50	35.4±12.43	40	714	0.006	0.18
Machine manufacturing	35	34.17±15.36	73.20	3164	0.025	0.23
Backhoe manufacturing	25	39.55±13.01	60.20	361	0.003	0.32
Warehouses	17	26.45±11.81	61.70	6173	0.047	0.29
Whole company	310	35.62±15.71	55.60	1730	0.016	0.31

*Lost time in each workshop divided by total working hours of all workers; †Number of recorded occupational disease in each workshop divided by number of all workers

were in the moderate category; no workstations was categorized as good.

After calculating the total index ($OSHI_{Total}$), mean and standard deviation of the total index were computed for each workstation individually (Table 3). The compressors and boilers unit with the total index mean of 60.34% had the best, and conversely, the casting unit with the total index mean of 19.4% had the worst OSH conditions.

Table 4 shows AFR, ASR, lost working time rate due to injury or occupational disease, and occupational disease incidence rate in different workshops of the company during 2014 and 2015.

Pearson's correlation coefficient was used to examine the correlation between $OSHI_{Total}$ and AFR, ASR, lost working time rate and occupational disease incidence rate. According to the existing references, correlation coefficient of 0–0.3 shows poor correlation, 0.3–0.7 moderate correlation, and 0.7–1 is indicative of strong correlation.[23] The results showed that:

The $OSHI_{Total}$ and AFR had moderate inverse correlation (r=-0.579), but it wasn't statistically significant (P=0.133).

The $OSHI_{Total}$ and the ASR had strong inverse correlation (r=-0.774), and it was statistically significant (P=0.024).

The $OSHI_{Total}$ and lost working time rate had moderate inverse correlation (r=-0.777), and it was statistically significant (P=0.023).

The $OSHI_{Total}$ and occupational diseases incidence rate had moderate inverse correlation (r=-0.381), but it was not statistically significant (P=0.351).

ASR and lost working time rate had strong direct correlation (r=1) and it was also statistically significant (P<0.001).

The results of examining the inter-observer reliability of the checklist by ICC showed that its value was 0.976 for the 7 evaluators (strong correlation), and internal consistency between evaluators was significant at the level of 0.001.

Discussion

The aim of this study was to develop and validate a comprehensive practical OSH assessment index for OSH experts to inspect workplaces from occupational health and safety perspective. According to the experts, the developed index and its sub-indices with their items can cover important and basic harmful agents of industrial workplaces. After receiving the experts' pair-wise comparison results, it was found that the results for some items were not consistent. For example, two experts' assessments of a specific comparison were different. At first glance, this problem appeared to be the consequence of the contradiction in the process of giving weights to harmful factors, but a deeper look into the problem revealed that the respondent experts had different areas of expertise in the field of OSH. Therefore, their assessments were oriented towards their area of expertise. Based on the output of the Expert Choice 11.1 (AHP) software and the experts' comments, the highest weight (0.21) belonged to the occupational health sub-index, which seemed reasonable considering the existing occupational diseases and industrial experiences. This sub-index was the most important one and had the highest weight. After that, the three sub-indices related to safety categories held the second to fourth positions (machinery safety with the weight of 0.17, safety behavior with the weight of 0.16, and fire safety and first aids with the weight of 0.16). This group of harmful factors was related to occupational accidents and totally they shared nearly 50% of the total indices weight. This clearly showed that this index considered safety issues and was not a mere health index.

The lowest weight among the 7 sub-indices was related to workplace order and housekeeping. This should not be misleading because many accidents which occur in industrial settings originate from poor housekeeping, and many of the internal and international standards have a special emphasis on workplace order and housekeeping.[24]

The results of workplace assessment in the studied company showed that the casting workshop with a total index of 19.4% had the worst OSH conditions and definitely had the highest priority for corrective and preventive measures. The results of surveying occupational diseases also showed that this unit had the highest rank in occupational disease incidence rate (0.78). This unit also held the second highest rank in ASR with a severity rate of 6119. In comparison, the compressors and boilers unit with a total index of 60.34 % had the best OSH conditions and the lowest priority for corrective measures.

The inter-evaluator correlation results showed that there was a strong correlation between the evaluators (0.978). One of the most important reasons for this strong correlation was that some parts of the checklist assessments were done based on measurement, some parts based on observations, and the other parts based on the questionnaire. This meant that there was no difference between the evaluators' assessments in items assessed based on field measurement and the questionnaire. The differences were related to the items which were assessed based on observation and expertise. These results indicated that the method developed in this study was not affected by the evaluators' errors, and had an acceptable reliability with a high ICC for OSH assessments in industries.

Inter-evaluator correlations in the ELMERI study was examined in five different periods. Five workstations were reassessed by 24 evaluators in each of the five periods; inter-evaluator error was estimated to be 14% in the first period, 10% in the second, 8% in the third, 15% in the fourth and 9% in the fifth period. Based on the results of this study, if inter-evaluator error was up to 10%, inter-evaluator correlation would be considered as good.[6]

This study had some limitations. First, OHSI shows the current condition of the inspected workplaces. Therefore, their correlation with the past accident frequency rate and severity rate might not completely accurate. Therefore, more follow up studies are required to assess the correlation between OHSI and accident and occupational diseases indices in the same year in future. Moreover, additive effects of multiple risk factors in the workplace were neglected. It is suggested that in future studies the additive effects of the harmful agents are considered in OSH conditions assessment of the workplace.

Conclusion

The developed index covers important and basic workplace hazards and assesses OSH conditions from various aspects. Harmful factors were given weights by OSH experts and each held a share of the total assessment weight. The results of validating the developed index indicated a strong correlation between evaluators. Therefore, it seems that the developed index is a suitable and reliable tool for assessing OSH conditions in industries. Moreover, in the heavy automotive industry studied, OSH conditions were unacceptable and corrective measures had to be implemented to improve working conditions

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